RFID FACILITATED CONSTRUCTION MATERIAL MANAGEMENT - A CASE STUDY OF WATER SUPPLY PROJECT

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ABSTRACT: Due to the complex and dynamic nature of the construction industry, construction material management faces many unique challenges from material planning, ordering, receiving and storing, handling and distribution, site usage and monitoring (Johnston and Brennan 1996). Poor material management has been identified as a major source for low construction productivity, cost overrun and delay (Fearon 1973, Olomolaiye et al. 1998). Although many factors contribute to the problems of material management, the lack of active, accurate and integrated information flow from material planning, inventory to site use and monitoring is the major contributor. However, it is difficult to obtain such accurate information actively due to the nature of the industry, particularly for large or material intensive projects such as oil or water pipe-laying projects. A Radio Frequency Identification system (RFID) facilitated construction material management system has been developed to tackle this problem. This latest technology helps the project team to collect material storage and usage in an active and accurate way, and further to facilitate the information flow through the construction material management process with focus on the dynamic material planning, ordering and monitoring. The developed system is being implemented in a water-supply project.

KEYWORDS: RFID, construction, dynamic, material planning, monitoring.

1 INTRODUCTION

In recent years, automatic identifications have become popular in services, purchasing and distribution logistics, manufacturing and material flow systems (Finkenzeller 2003). Automatic identifications provide information about people, animals, goods and products in transit. The traditional barcode labels are being found to be inadequate in many cases (e.g. low storage capacity and cannot be reprogrammed). The technically optimal solution would be the storage of data in a silicon chip (e.g. the smart card based upon a contact field). However, the mechanical contact used in the smart card is often impractical. A contactless transfer of data between the data-carrying device and its reader is far more flexible. The Radio Frequency Identification (RFID) technology provides solution to such problems.

RFID offers wireless communication between the tags and readers with non line-of-sight readability, which eliminates manual data collection and introduces the potential for automated identity process. The technology offers some unique advantages over the traditional barcode or smart card such as the flexible contactless identification range, multiple products identification, expressive read reliability and durability, massive data storage, high level of data security (Mital, 2003, Finkenzeller 2003). RFID technology is becoming popular in the areas of transportation, human identification, security, purchasing and distribution logistics, manufacturing and material flow systems.

Given its particular advantages, several research initiatives have been developed to adopt RFID in the construction industry such as material tracking system (Furlani et al. 2000), tools and equipment tracking system (Lewis 2000), security, service and maintenance (Goodrum et al. 2003). RFID has been proven as a promising technology for enhancing construction operations (Patel 2006, Thompson 2006). On the other hand, most of the applications in construction over-exaggerate the strength of the technology whilst ignoring the nature and specific problems of the industry (Deloitte 2004).

Material management includes the process of planning, inventory control, receiving and storing, material handling, physical distribution, and related information from the point of origin to point of consumption for the purpose of conforming to customer requirements. It has been estimated that a 2% saving in materials costs could increase profits by 14.6% (Chadwick 1982). On the other hand, inappropriate material management and the consequent problems (e.g. shortage of important materials, inaccessibility of items or excessive time) are a main cause of low productivity, cost overruns and delay in construction (Barker 1989, Kaming et al. 1998, Arnold 1998, Olomolaiye et al. 1998). A major difficulty of construction material management is the complex and dynamic process of material planning, ordering to the site monitoring and re-planning. There is a lack of integrated material information flow facilitated by the active material planning and monitoring system.

This paper presents the research work conducted for the improvement of the construction material management. It tackles the dynamic process of material planning, ordering and monitoring by adopting the RFID technology to actively monitoring the planning the material usage and the relevant information flow. The developed RFID facilitated material management system is being tested in a water supply project which used to suffer from poor material management due to the complex operation environment.

2 RFID TECHNOLOGY

According to RFID journal (www.rfidjournal.com), RFID generally is a generic term for technologies that use radio waves to automatically identify a person, object, or other information. There are three major components of RFID, the reader, the tag and the antenna. The antenna enables the chip to transmit the identification information to a reader. The reader generates or listens to and converts the radio waves reflected back from the tag into digital information that can then be passed on to computers that can make use of it. Depends on whether the tags are internally powered, the RFID is classified as active and passive tags. Active tags are powered by an internal battery and are typically read/write. Passive RFID tags operate without a separate external power source and obtain operating power generated from the reader. They are consequently much lighter than active tags, less expensive, and offer a virtually unlimited operational lifetime. However they have shorter read ranges than active tags and require a higher-powered reader.

RFID is a fast and reliable means of automatically identifying and logging just about anything, including retail items, vehicles, documents, people, components, library books and works of art (Farragher 2004). As it makes use of radio waves, there is no need for “line of sight” reading of information, which is one of the limitations associated with barcode systems. It means RFID tags can be embedded in packaging or, in some cases, in the goods themselves. In addition, RFID tags are reusable, and can withstand harsh environments. Over the past five years the IT industry has seen a surge towards the development of an affordable RFID tag. Such developments have lead to larger reading ranges, greater memory capacity, and faster processing of radio frequency operating systems. The RFID market is one of the fastest growing sectors in IT areas. RFID is getting popular in much wide areas such as public transport (Swedberg 2004), ticketing (Finkenzeller 2003), security (Schneider 2003), and children caring (Ohkubo et al 2004).

During the past few years, several research projects have been conducted to explore the possibility to adopt RFID technology to tackle the construction problems. For example,

1. Material tracking system: Identification and tracking technologies have the potential to enable the construction industry to seamlessly integrate work processes at the job-sites (Furlani et al 2000). Knowledge of this information in a quick and accurate fashion, would dramatically improve productivity and reliability. Individual objects scheduled for arrival on the construction site are tagged at the fabricators using RFID transponders. The encoded information is scanned wirelessly relayed to a remote project database. A database query returns graphical representations, or virtual reality mark-up language models of scanned objects and additional information as appropriate. These models, coupled with user-friendly web browsing software, guide field workers through the acquisition of key fiducially points using scanning devices integrated with GPS technology to determine an object's position and orientation.
2. Tools and Equipments: The construction tool industry has been using embedded systems such as RFID technology to track tool usage and to prevent tool mishandling and wrongful installation (Lewis 2000). Although the construction industry is generally not as high tech as the manufacturing industry, tools and equipment cost can be critical to complete projects within estimated budgets. Interest in tool-tracking technologies is on the upswing because it holds the potential for reduced expenditures and tighter job costing (Marshutz 2002).
3. Security, service and maintenance: Workers, operators, and equipment tagged with RFID can record and make certain proper usage and handling of equipment, materials, and documents. These systems will ensure that only qualified operators can access to the restricted equipment, reducing the likelihood of misuse and accidents (Goodrum et al. 2003). Besides tracking objects and people within the jobsite, it would also secure the site from unauthorized people and vehicles. RFID can be a helpful record-keeping tool for high-value assets and equipment service logs. Applications would allow mechanics in the service bay to read and write to the tags, reducing the amount of paperwork related to warranties and time-consuming maintenance logs.
4. Document control for material management: The construction industry is an industry that is very dependent upon paper for transmittals of shop drawings, plans and specifications, change orders and billing, and requests for information. Although the Internet has allowed the use of e-mailing documentation there is still a mailed copy sent to other players involved (contractors, architects, engineers, owners, etc.). When the costs of RFID technology is more reasonable, applications that embed tags into construction documents, files, or file folders would significantly reduce the amount of time and money spent managing files, and until the industry is paperless there will always be a way to more efficiently manage documents.

3 CONSTRUCTION MATERIAL MANAGEMENT

Material management is a wide spectrum of activities and is totally committed to providing a smooth flow from suppliers to production to project inventory to reach the possible maximum productivity (Colton et al. 1985). Figure 1 illustrates the construction material management process, which is characterised as complex, integrated, and dynamic. Involved with almost all the major project participants, material management starts at the tendering stage till the project close up.

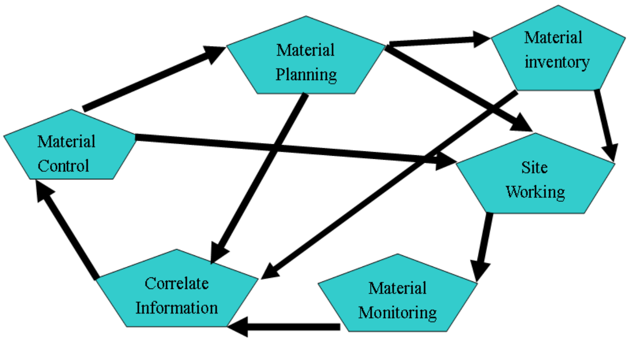

Figure 1. The construction material management lifecycle.

- *Material planning*: The management planning is probably the most important part of the overall material management process (O'Brien et al 1991). Typical material plans are developed from detailed project design, bill of quantities and integrated into project schedule. However, it is normally difficult to have all the materials identified at the project buyout/planning stage due to the limited information. Even if it is very well planned, materials will still be short during the construction stage. This is particular severe for large or concurrent projects. Therefore, Mawdesley et al. (1997) emphasise that the material planning process is not a static process; rather it is dynamic and should be integrated with the monitoring and control process.
- *Site working and material monitoring*: The site work should be done in a way which keeps all the materials achieve the preparation checklists set in the planning phase. Various preparation checklists may have been set and the details will depend on the level at which the material planning is being exercised. Material monitoring should track the status of material usage with all the key information and report promptly any material change. Only when this has been done can the next phase, correlation of information, be carried out.
- *Correlate information*: The information here is the progress information (collected in the monitoring phase) which is to be correlated with the planning information. In this phase the achievement is compared with the targets. Several technologies are available to help with this and most texts on 'control' concentrate almost exclusively on the phases up to and including the correlation phase. However the difficulty is the inaccurate or delayed progress of information.
- *Control*: Control action should be based on the results of the correlation of information and may be of the traditional reactive type in which action is taken to affect the work output based on recent information and past experience. For material management, control usually means avoiding the shortage and waste. In order to achieve these two aims, detecting and realising the problem in time are necessary, which require the good corporation of each role of the project, from project manager to worker.

Successful material management is vital for project management, but it is difficult to achieve due to the complex internal and external issues, dynamic process, and multi-parties involved. Researchers (e.g. Guthrie et al. 1998, Good 1986, Ala-Risku et al. 2004) summarised some of the typical problems in the four major phases of construction material management (Table 1). Moreover, many more problems are created due to the lack of an effective material management approach which could seamlessly integrates the information flow between different material management phases in order to tackle the dynamic nature of construction material management (Figure 2). The information flow linking different phases is often broken which is more severe in large, concurrent, poor designed or material intensive projects (Sha 2006).

Table 1. Typical construction material management problems.

Phases	Problems
Ordering	• over-ordering, • ordering the wrong type, quality, size, etc., • ordering standard lengths rather than the lengths required, • ordering for delivery at the wrong time.
Delivery	• damage during unloading, • delivery to inappropriate areas of site, • accepting incorrect deliveries, specification or quantity.
Storage	• exceed shelf lives, • damage or contamination from incorrect storage, Loss, theft and vandalism
Handling	• damage or spillage through incorrect or repetitive handling, • delivering the wrong materials to the workplace.

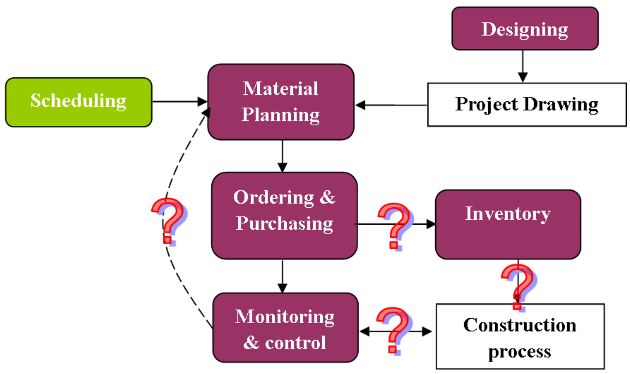

Figure 2. Problems in traditional material management system.

4 RFID FACILITATED MATERIAL MONITORING SYSTEM

The proposed RFID-facilitated material management system aims to tackle the dynamic nature of construction material management by integrating the information flow among design and material planning team, warehouse, site office, construction site and material monitoring staffs. The integration is achieved with the support of RFID technologies which help to collect and monitor the material storage, usage, change in a more active and accurate way. Unlike the application of traditional bar code in facilitating material inventory, the system focuses on the improvement of the material management information flow and actively data collection and monitoring. It targets on the seamless integration of the application of new technology with classic construction material management theories and practices. There are four components of the system: RFID planning aid, RFID inventory support, RFID monitoring assistant, and RFID maintenance support (Figure 3).

Started by obtaining material from the design or Bill of Quantities (BOQ), the system considers and manages the process of (Sha 2006):

1. Material planning and the alignment between material planning and scheduling.
2. Inquiries and purchase orders for materials.
3. Expediting, recording and control material deliveries.
4. Inventory/Stock control management.
5. Material tracking and monitoring on site.
6. Material changes and re-planning or ordering.

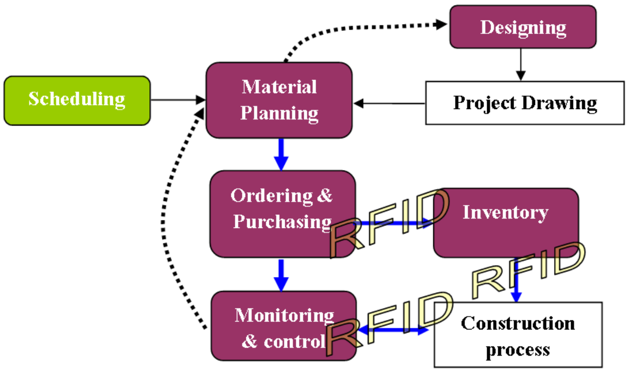

Figure 3. The elements of RFID material monitoring system.

Due to the space limitation, this paper only focuses on the interactions between the RFID facilitated material planning, inventory and monitoring systems (Figure 4).

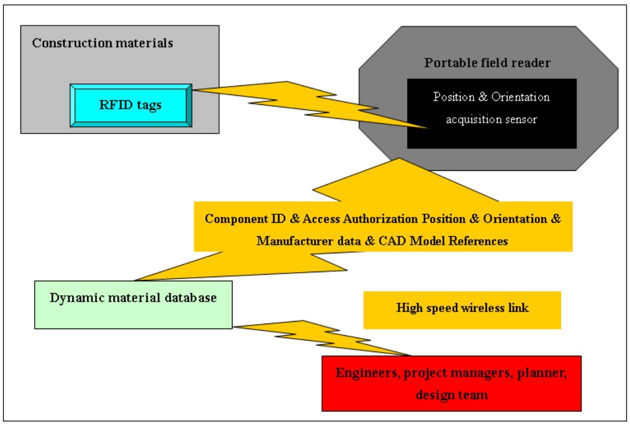

Figure 4. RFID facilitated material planning, monitoring and control.

1. Material planning: Project staffs identify all the key materials or long-delivery materials out of the project design. This is conducted in the early stage of project buyout stage. All these key materials are numbered and given unique IDs; these IDs, names, usage, design drawing number, manufacturer, together with the scheduled site and data are input into a key material database or highlighted in the general material database.
2. Material store: After the materials are delivered to the store, they are labelled and attached with RFID tags. Relevant information (e.g. ID, manufacturer, drawing no. date into store, scheduled date to install, site to be installed, person in charge, etc.) about the key material are contained into the RFID tags and the store database.
3. Material monitoring and control: The RFID tags, readers and other supporting facilities provide an effective approach to track the material delivery, storage on site, and installation. Related project staff will be able to obtain the material information in a live or nearly live approach. Since the key materials have already been identified in drawing, planning and schedule, the project staff can make a quick comparison and analysis to decide whether to make another order of materials or to change the initial material plan.

5 SCENARIO

The test case is a water supply project located in country S. The project includes 110KM DI (Ductile Iron) pumping main (diameters varying from D250mm to D800mm) and 480KM PVC branches (diameters varying from D75mm to D200mm), which covers an area of more than $80KM^2$ with high population and narrow road (Figure 5). Some of the materials problems of this project are described below:

Figure 5. Construction work on site.

1. Due to the complex environment, the initial design is only used as tender guide. Most of the fittings (e.g. bends, couplings, adapters, etc.) could only be finalised based on site situation. Therefore, the actual amount of the pipes and fittings used on site are very different from the numbers provided in the BOQ and drawings. For example, if an additional culvert crossing is added, it would need 4 extra bends, 8 couplings and relevant flange spigot pipes. Hundreds of shop drawings were issued for such detailed joints. Although much effort has been made during the tendering and early stages of the project, there is still a very

high uncertainty regarding the ordering and usage of the pipes and fittings.

2. Although the PUC pipes are manufactured locally, the DI pipes and all the fittings for DI pumping main and PVC branches have to be imported from the UK. It takes at least 6-8 months to order, manufacture and deliver the pipes and fittings to the site. The progress of the project is mainly controlled by the materials. On the other hand, since the fittings are rather expensive, the contractor could only make 5-10% extra order each time.
3. Based on the experience from the other two completed projects in the same package, it took at least 4 or 5 orders to get all the necessary pipes and fittings for a project. Those two projects have been delayed for 8 and 11 months respectively due to the shortage of materials. Although the contractor was granted a time extension, no additional cost was paid by the client.
4. When the RFID system was introduced, the project has already been started for nearly 18 months, the first order of materials has already been used; the second order has been made. The project progress is 4 months behind the baseline. To crash the project, there were 4 direct teams who laid DI pipes and 6 subcontractors who were responsible for PVC pipe laying. Each team's payment is linked to the length of the pipe they laid and the numbers of fittings they used. Construction teams do not care whether a fitting is order for their part. They often force the storekeeper to release the fittings they need without concerning other teams. As a result, it is often very difficult for the construction manger to know what have been used and what needs to be ordered.

The RFID facilitated material management system was introduced in such a situation. The system included a serial of RFID readers, active and passive tags, PDAs and laptops. People involved in the system include the construction manager, design group, procurement manager, storekeepers, site engineers on each site and a co-ordinator who is particular responsible for the overall system (in this case, the researcher). The major procedures include:

1. The collaborator worked with the design group to identify the key fittings (mainly 111/4, 221/2 DI bends of different diameters, strengthened couplings and adapters, gate valves and air valves). All the information of control fittings is highlighted and input into a separate database which is sharable among the construction manager, site engineers, store keepers and contractor's design group.
2. RFID tags are then labelled on any of the identified fittings in the store with information including ID, manufacturers, drawing map, designed location, person in charge, etc. To save cost, both active and passive tags were used. Active tags are used for those fittings which suffer from the highest risk of shortage or being misused.
3. Readers were installed at the entrances of the main store and the four site stores. In the mean time, each site engineer was issued a PDA. Through the RFID readers installed around site, the PDA records the fittings taken, installed, or stored on each site. Site engineers are also required to fill a spreadsheet form in the PDA each day to report and forecast the possible changes of fittings on his/her site (Figure 6). The PDA is returned to the storekeeper each day, who will then collect the information.
4. The information from storekeepers is sent to the design team everyday through the Internet, who monitors and analyses (in this case, it is done by the researcher but supervised by the design engineer) the usage of the fittings and changes on site. Based on this information and compared with the baseline material plan and schedule, they forecast the possible increase of fittings. Also, variations of design are made accordingly. Unlike the traditional management system, a direct information flow is built between the site and the design engineers. This reduces the chances of mistakes and the lag of information transferring between the site and design team which in this project normally takes about 10-15 days.

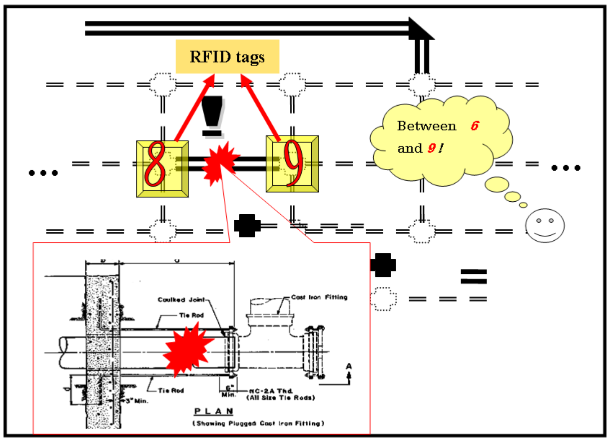

Figure 6. Site operation.

Currently, this system has just been set up for three months. With the help of the active material monitoring system, the third order of fittings will be placed soon.

6 EVALUATIONS AND CONCLUSIONS

Although the concept and model have been developed for a while, the testbed has just been set up. The overall evaluation of the system will be conducted when the project is completed. Below are some of the initial comments from peer review and project participants (Sha 2006):

1. The major features of the system are well defined and targeted to the most important problem - the dynamic nature of construction material management and the lack of the integrated information flow of construction material management. The system is novel in terms of the technology it adopts to tackle the problems and the infrastructure of the system. As all the major fittings are identified automatically in store and on site, it reduces the chances of errors. Below are some of the specific advantages of the system:
   a) Maintain a key-materials-list with full audit trail of all changes,
   b) Efficiently generate material inquires and purchase orders and manage changes.
   c) Maintain all expediting events with full history.

d) Record deliveries to site.
e) Analyze material availability to identify shortages early.
f) Track material issues and stock to ensure updating material quantities at each location.

2. Since the system is at the early stages of development, there are quite a few challenges for the uptake of the system, particularly in terms of its application. For example,

a) Since this test case was initiated by senior managers, the cost is not a major concern (whilst it could be a major consideration in other cases). Nevertheless, most of the middle project management staffs (e.g. construction manager, quantity surveyors) are still not convinced that the system would bring a significant improvement to the material management due to the low awareness of the technology and the extra work on labelling the fittings. Rather they prefer to adhere to the traditional material management with clear responsibilities to site engineers. On the other hand, the system is braced by site engineers and storekeepers as it reduces their workload and responsibility.
b) Although the system has been studied and proposed for a long time, there are still some broken links in the material information flow when it is implemented. For example, the devices (e.g. the tags, the readers and PDAs) do not always perform well. This might cause data loss in the first place.
c) No matter how effective and convenient the system is, the design and implementation of the system still need the full assistant of the project staff. Only when the system could be integrated with the existing management systems (e.g. design, site monitoring, project buyout, incentive mechanisms), it could achieve its strength. Also, basic training is necessary. Readers and tags have been found damaged or being stolen on site.

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