Abstract
Due to the complex and dynamic nature of the construction industry, construction materials management (CMM) faces many unique challenges from material planning, ordering, receiving and storing, handling and distribution, site usage and monitoring. Poor materials management has been identified as a major source of low construction productivity, cost overrun and delays. Lack of active, accurate and integrated information flow of CMM is a major contributor to such problems. However, it is difficult to obtain such accurate information actively due to the nature of the industry. This paper presents a Radio Frequency Identification system (RFID) facilitated CMM system where RFID technology is used to facilitate the CMM material information including dynamic material planning, ordering and monitoring. This paper particularly focuses on the evaluation of the application of the system in a water-supply project.

Keywords: construction, material management, information flow, radio frequency identification

1 Introduction
The Radio Frequency Identification (RFID) technology 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 identification 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, and high level of data security (Mital 2003).

Given its unique advantages, several research initiatives have been developed to adopt RFID in the construction industry such as material tracking system (Song et al. 2006), tools and equipment tracking system (Goodrum et al. 2006), security, service and maintenance (Ko 2009), supply chain management (Wang et al. 2007), health and safety (Buckingham 2008), and quality control (Wang 2008). RFID has been proven as a promising technology for enhancing construction operations (Patel 2006). However, many of the applications in construction over-exaggerate the strength of the technology while ignoring the nature and specific problems of the industry (Deloitte 2004). There is a lack of integration between the technology and the management systems (Ren et al. 2007).

Construction Materials Management (CMM) includes the process of planning, inventory control, receiving and storing, material handling, physical distribution, and relevant information from the point of origin to point of consumption. It has been estimated that a 2% saving in materials costs could increase profits by 14.6% (Chadwick 1982). On the other hand, inappropriate CMM is a main cause
of low productivity, cost overruns, and delays (Olomolaiye et al. 1998). In the UK, at least 10% of all raw materials delivered to most sites are wasted through damage, loss, and over-ordering (Guthrie et al. 1998). The difficulties of CMM lay at the large amount of materials used, complex internal and external issues, dynamic process, multiple parties involved, and the broken information flow linking different phases, which is more severe in large, concurrent, poorly designed, or material intensive projects (Sha 2006). There is a lack of integrated material information flow facilitated by the active material planning and monitoring system.

This research aims to tackle the dynamic nature of CMM by integrating the information flow among designers, planning team, procurement department, warehouse, site and control staff. This is achieved with the support of RFID which help to collect and monitor the material plan, storage, usage, and change in an active and accurate way. Unlike other research, this study focuses on the integration and improvement of the materials management information flow of the CMM lifecycle. The developed RFID-facilitated Construction Materials Management (RFID-CMM) system has been applied in a water supply project. This paper particularly focuses on the assessment of the system in the project.

2 RFID facilitated construction materials management system

Figure 1 illustrates the conceptual model of the RFID-CMM system. Started by obtaining material from the design or Bill of Quantities (BOQ), the system considers and manages the process of material planning and the alignment between material planning and scheduling, inquiries and purchase orders for materials, expediting, recording and control material deliveries, inventory/stock control management, material tracking and monitoring on site, and material changes and re-planning or ordering. The key stages of the RFID-CMM system include:

1) **Material planning**: Project planners identify all the key construction materials from the project drawings, Bill of Quantities and specifications. This work is started while preparing the bid and further refined in the project buyout stage. All these key materials are coded with unique IDs. These IDs, names, technical features, specifications, usages, design drawing numbers, manufacturers, together with the scheduled site and data are input into the material database.

2) **Dynamic material database**: The dynamic material database is the core of the system which is accessible by all the relevant project parties (with different authorities and focuses). This online database is created in the stage of material planning process, and can be updated by all the related parties based on their in-time information. The relevant parties, especially project planners, will be notified immediately regarding any severe material problems (e.g. shortage or mistake).

3) **Material inventory**: After the key materials are delivered to the store, they have RFID tags attached. Relevant coding information about the materials are input into the RFID tags and the dynamic material database. Meanwhile, when materials are delivered from the store to the site, the readers installed at the main gate will report the information to the database.

4) **Material monitoring and control on site**: Portable reader and other supporting facilities on site allow site engineers to track the material delivery, on site storage, installation, progress and changes. This information is sent to the dynamic material database in a live or nearly live manner, and the other project teams will be able to obtain the material information in a real time manner.

5) **Re-planning and scheduling**: Key project management staff can compare the live information received with the material plan, schedule and design to identify and predict problems, and to take corrective actions. For example, the project manager may decide to make another order of materials if s/he finds there is a shortage of key materials; the project planner may change the initial material plan to allow one site to use the materials which was initially booked for another site, or change the schedule based on the material status.
3 Test bed

The system was implemented and tested in a water supply project located in country S. The project includes 110km DI pumping main (diameters varying from D250mm to D1200mm) and 480km PVC branches (diameters varying from D75mm to D200mm), which covers an area of more than 80km² with a high population and narrow roads. Some of the materials problems of this project are:

- Due to the complex environment, the initial design is only used as a tender guide. Fittings (e.g. bends, couplings, adapters, tees, valves) could only be finalized on site. Therefore, the actual quantities of the pipes and fittings used on site are very different from the numbers provided in the BOQ and drawings. Hundreds of shop drawings were issued for such detailed joints.
- 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.
- 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 were delayed for 8 and 11 months respectively due to the shortage of materials.
- When the system was introduced, the project had already started for nearly 18 months, with 4 months delay. Each site team was paid according to the length of the pipe laid and the number of fittings used. Site teams did not care whether a fitting was ordered for their work. They often forced storekeepers to release the fittings without any concern about the needs of other teams.

The RFID-CMM system was introduced in such a situation. The system included RFID readers, active and passive tags, PDAs and laptops. People involved in the system included the construction manager, design group, procurement manager, storekeepers, site engineers and technical officers on each site and a co-ordinator. The major procedures included:
- The collaborator worked with the design group to identify the key fittings; altogether 19 fittings were tracked (mainly 111/4, 221/2 DI bends of different diameters, strengthened couplings and...
adapters, gate valves and air valves). 24 attributes of each fitting was tracked such as: product id, name, material, diameter, nominal length, weight, quantity, batch no., type, drawing no., specification, manufacturer, instore_date, site_in_charge, store, etc. The information on control fittings was input into a separate database which was sharable among the related project staff.

- RFID tags were attached to the identified fittings in the store with key information input. Active tags were attached to those fittings which could suffer from the highest risk of shortage, being misused or design changes. These fittings were particularly pointed out by construction managers. For example, appropriate personnel were able to update the information in the tags while the sites of the bends were changed with the revision of drawings.

- Readers were installed at the entrances of the main store and the four site stores. Each site engineer was issued a PDA. Through the RFID readers installed around site, the PDA recorded the fittings taken, installed, or stored on each site. Site engineers were also required to fill a spreadsheet form in the PDA each day to report and forecast the possible changes of fittings on their site. The PDA was returned to the storekeeper each day, who would then collate the information.

- The information from storekeepers was sent to the design and planning team daily. They monitored and analyzed the usage of the fittings and changes. Based on this information and compared with the baseline material plan and schedule, they forecasted the possible increase in number of fittings. Also, variations of design were made accordingly. This reduced the chances of mistakes and the lag of information transferring between the site and design team which on this project normally took about 10-15 days.

4 Evaluation

After the system was implemented and tested on the water supply project, a workshop was held on site to assess the overall system and the prototype developed. Twenty four staff from this project attended the workshop which include the project manager, construction manager, design engineer, planning engineer, quality control manager, site managers, site engineers, technical officers, and store keepers. They had knowledge about the system and have been involved in the operation directly or indirectly. Four major aspects of the system were regarded as important for material management, and thus were assessed.

- **Effectiveness:** The criteria to assess the effectiveness of the system are time and cost saving or reduction of the rework. The initial outcome showed that there was an overall cost saving of $26,400 within the 28 week period of applying the system. This figure was obtained by comparing the overall expenses (both direct and indirect) related to the major tracking fittings with the previous 16 months when the RFID-CMM system was not installed. The calculation of cost saving was conducted by comparing the time used to order, deliver and use the same types of pipe fittings within these two periods. The biggest savings were from the in-time order of three types of pipe fittings from the UK and South Africa. The time savings and reduction of rework were then translated into cost savings based on the human and machinery rate. To avoid exaggerating the cost savings, the expenses over the first 16 weeks were also compared with another water supply project at the same scale.

In addition, the effectiveness was also evaluated by the project participants based on six criteria, which reflect the impacts to the delivery and use of material on site (e.g. accuracy, time saving, reduction of rework) and the management process (e.g. communication, information sharing, risk avoidance and reduction, and collaboration). Table 2 shows the result of project participants’ assessment to each criterion. The figure represents the percentage which the evaluators think that the RFID-CMM brings to the project.

- **Utility/Usefulness:** All participants saw the system was well-targeted. 89% of them agreed that there was a potential for the RFID technology to be used to solve the existing problems in materials management. Some of the important statements which the participants agreed with are: a) The attributes show that the major features of the system are well defined and targeted to the most
important problems of CMM- the dynamic nature and lack of integrated information flow. b) The system is novel in terms of the technology it adopts to tackle the problems and the infrastructure of the system. c) The key for the successful of the system lies in the seamless integration of the technology with the construction material management system. d) As all the major fittings are identified automatically in store and on site, it reduces the potential for errors.

Table 2 The result of the evaluation of effectiveness

<table>
<thead>
<tr>
<th>Accuracy</th>
<th>Quality</th>
<th>Quantity</th>
<th>Time</th>
<th>Cost</th>
<th>Availability</th>
<th>Communication</th>
<th>Inform. sharing</th>
<th>Collaboration</th>
<th>Risk avg./red</th>
</tr>
</thead>
<tbody>
<tr>
<td>77%</td>
<td>61%</td>
<td>78%</td>
<td>80%</td>
<td>81%</td>
<td>78%</td>
<td>71%</td>
<td>92%</td>
<td>72%</td>
<td>89%</td>
</tr>
</tbody>
</table>

- **Fitness**: A simple ratio of available features to desired features in the prototype was used to evaluate the fitness of the overall RFID-MMC system. The list contained a total of 63 features, which were classified into three main categories: novel features, supporting features and deployment features. The evaluation based on a simple feature count provided a very useful way of measuring the completeness of the prototype and its fitness to test novel features. The evaluation result showed that most of the desired features have been implemented in the prototype (Table 3).

Table 3  The result of the evaluation of fitness

<table>
<thead>
<tr>
<th>Feature</th>
<th>Novel feature</th>
<th>Supporting feature</th>
<th>Deployment feature</th>
<th>Overall fitness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>71%</td>
<td>83%</td>
<td>61%</td>
<td>72%</td>
</tr>
</tbody>
</table>

- **Usability**: The evaluation was carried out to test the usability of the prototype, which includes two parts: a) whether the prototype developed can be used by project staff; b) whether the RFID-CMM system could fit the existing project management system. 82% of project participants agreed that the system could be used by intuitive users with little instruction. Since several departmental teams were involved in the application (e.g. design, planning, store, procurement, site management and construction), their understanding about the usability are different which is highly related to the existing system of each department (e.g. database software, project planning software, and management system) and each individual participant’s position.

Apart from the benefits, the participants also raised the following issues/problems.

a) Since this test case was initiated by senior managers, the cost and resources involved were not a major issue, but it could be a major concern in other projects. Also, some of the project participants were not convinced that the system would bring a significant improvement to the CMM due to the low awareness of the technology and the extra work on tagging the pipes and fittings. Rather they preferred to adhere to the traditional CMM with all the responsibilities on site management. On the other hand, the system was embraced by site engineers/management, construction manager, and storekeepers as it reduced their workload and responsibility.

b) The system was not stable during the implementation process due to the limited maturity of the system. It was reported that the devices and the overall system did not perform properly around 10-15% of time. About a quarter of tags were lost/stolen on site. This caused data loss in the first place. Technically, a major limitation of the system is the immature technology. Apart from the limited reading range between a reader and tags, another problem is the disturbance to the signal when pipe fittings were moved into deep excavated trenches or pump stations supported with sheet piles, irregular corners or with several tags working close by within the pump stations.

c) With the implementation of such a system, the workload and requirements to project staff who are involved in the material management are higher, especially for the site engineers, technical officers and store keepers. Also, the full assistance and cooperation of project staff was also essential for the success of the system. Only when the RFID-CMM system fits well with the existing management systems, can it achieve its expected strength.
5 Conclusions

Unlike other RFID-facilitated material management systems in the industry, this research focuses more on how the technology could be integrated with the existing construction material management system seamlessly, rather than the technology itself. Here the RFID technology is used as a lever to integrate the discrete material management information on a project. With the help of the technology, the RFID-CMM system tackles the two most important problems of construction material management: the dynamic process, and the discrete material information.

The importance of the RFID-CMM system lies not only in the material monitoring through the RFID readers and tags, but also on the material information flow integrated by the technology. The CMM system is improved when it is integrated with all the relevant teams such as design, procurement, plan, inventory, and site management. Some of the specific advantages of the RFID-CMM system include: a) Being seamlessly integrated with the existing construction material management system; b) Maintaining a key-materials-list with a full audit trail of all changes; c) Efficiently generating material inquiries, purchase orders, and manage changes; d) Recording deliveries to site; e) Analyzing material availability to identify shortages early, therefore reducing the risk of late or wrong materials ordered or delivered to site; and f) Tracking material issues and stock to ensure material quantities are updated at each location.

Two levels of improvements to system have been suggested: a) From the technical perspective, it is expected that long range tags and reader (with affordable cost) will be adopted. Also, the resistance to disturbance within complex working environments should be improved; b) From the material management system perspective, a wide user requirement specification should be defined in order to deal with different construction project (e.g. building, infrastructure). The material coding for different projects is important for the success of the system. The RFID-CMM system could be improved based on such refined user specifications.

6 References


MITAL, T., 2003. The Emergence of RFID Technology, University of Houston, Houston.


