

Towards A Framework For ICT-Enabled Materials Management In Complex Projects

N. B. Kasim

narimah@uthm.edu.my

Universiti Tun Hussein Onn Malaysia

Abstract

This paper describes a research project, aimed at developing a system to integrate RFID-based materials management with resources modelling in project management to improve on-site materials tracking and inventory management processes. In order to develop the system, a comprehensive literature review and exploratory case studies were conducted to investigate current practices, problems, implementation of ICT and potential use of emerging technologies (such as RFID and wireless technologies) in overcoming the logistical difficulties associated with materials management. An initial assessment revealed that there is a potential to improve the tracking and management of materials using modern ICT, thus will enhance the operational efficiency of the project delivery process. Moreover, sophisticated technologies such as wireless systems and tagging are not generally used to overcome human error in materials identification and the space constraints inherent in many projects. This paper concludes the finding from case studies for developing a real-time materials tracking framework to support construction professional in handling materials more effectively.

Keywords: Construction Project, ICT, Materials Management, Materials Tracking, RFID.

INTRODUCTION

An important problem that adversely affects the performance of construction projects is the improper handling of materials during site activities. The inappropriate handling and management of materials on construction sites have the potential to severely hamper project performance (Ogunlana *et al.*, 1996). There are major issues which affect materials management activities such as constraints on storage areas, site logistics with regards to materials handling and distribution, and also ordering and delivery of materials to the construction site. Previous research has also highlighted materials management issues such as; improper storage (Canter, 1993), requirement for large storage capacity (Agapiou *et al.*, 1998), transportation difficulties and inappropriate materials delivery (Zakeri *et al.*, 1996). Other issues include; late delivery (Aibinu & Odeyinka, 2006), shortage of materials (Abdul-Rahman *et al.*, 2006), manual processes, and non-compliance with specifications (Dey, 2001).

There are currently a variety of approaches which are used to overcome materials management issues such as: proper planning of materials logistics, Just-In-Time (JIT) concepts to resolve the problems of space constraints, and the implementation of ICT such as bar-coding for tracking technologies of materials identification. However, there is a paucity of positive examples of where such tools have been used successfully. This can increase the scope for human errors (such as double handling) and the use of paper-based reports to exchange information related to the materials component within a supply chain which can be problematic, error-prone, and inefficient.

Generally, emerging technologies such as wireless technologies and Radio Frequency Identification (RFID) are not effectively employed in the tracking of materials. There is also insufficient support for the tracking and management of materials for operational efficiency in inventory management on site. Jaselskis *et al.* (1995) proposed the utilisation of RFID for controlling materials during a construction project by materials identification, in order to reduce the level of confusion regarding materials delivery from suppliers to the relevant locations at the jobsite. RFID has the potential to facilitate materials management processes for large scale projects, particularly with regard to the capability to store a large amount of data compared to bar-coding (Jaselskis and El-Misalami, 2003). It is expected that RFID can be beneficial in reducing paper-based requirements and can also be integrated with different applications such as project management systems (e.g. MS Project) to make tracking and management of materials easier and faster.

This paper explores the technologies for materials tracking on construction sites and the potential of emerging technology implementation. It then presents the case studies undertaken and discusses the findings by undertaking a cross-case analysis. This is followed by a description of the outline features of a proposed framework for real-time materials tracking.

TECHNOLOGIES FOR MATERIALS TRACKING

Bell and Stukhart (1986) stated that it is important for planning and controlling of materials management. The main aims are to ensure that the right quality and quantity of materials and installed equipment are appropriately specified in a timely manner, obtained at a reasonable cost, and are available when needed. Many construction projects apply manual methods, not only for the tracking of materials, but also for materials management as a whole, and this involves paper-based techniques which are problematic with many human errors. There are various advantages in the implementation of Information and Communication Technologies (ICT) in materials management, as ICT has the potential to significantly improve the management of materials on site. The use of ICT is increasing as new software is developed to support the effective management of construction activities. However, the most common use of ICT in materials management is in the cost estimating process. This involves the use of well known software such as Microsoft Excel and Lotus 1-2-3 (Sun and Howard, 2004).

Various opportunities for construction organizations to invest in advanced information technology and telecommunications systems are noted in Griffith *et al.*, (2000). An initial assessment of the tools and techniques currently in use in materials management suggests that most of them are under developed, with only a few being used on a commercial basis (BRE, 2005). The tracking of materials for identification during delivery times and at the storage area is commonly undertaken manually. Accordingly, there is scope for significant advantages if automated tracking technologies (such as bar-coding and RFID) are deployed to overcome problems in manual practices, which is labour intensive and error prone (Navon and Berkovich, 2006).

Many research projects have explored the potential of bar-coding. This includes the study of the use of bar-coding to provide instant and up-to date information of quantities of materials exchanges between the storage keeper and the group leaders in term of the measurement of materials wastage (Chen *et al.*, 2002). Cheng and Chen (2002) have developed an automated schedule monitoring system to assist the managers to control the erection process for precast building construction by integrating bar-code and Geographic Information System (GIS). In another study, Moselhi and El-Omari (2006) present a data collection methodology that utilizes both bar-coding and RFID technology to track project cost and schedule information. All the examples above show the successful research in implementation of bar-coding in undertaking materials management practices. However, the use of the bar-coding system could involve many constraints such as it can easily be damaged; cannot be read in direct sunlight; and cannot withstand harsh conditions (Jaselskis and El-Misalami, 2003). Thus, more sophisticated materials management technologies are expected to grow in usage and will incorporate technologies such as RFID, and wireless communications (Kasim *et al.*, 2005). These technologies have been successfully used in other industry sectors such as manufacturing, retail, and transportation in improving the logistics (BRE, 2005). There is a potential to apply the same concept to construction practices.

A considerable amount of literature has been published on the possibility of implementing RFID in the construction industry. Jaselskis and El-Misalami (2003) provided a procedure for helping construction industry owners and contractors, to enhance their operations using RFID technology. It provided a flowchart to assist contractors and owners in selecting the most appropriate RFID system. Peyret and Tasky (2002) performed an experiment to trace asphalt quality parameters using electronic tags and Global Positioning System (GPS). These test involved using RFID for storing the data into electronic tags, and GPS for positioning the material parameters with respect to the road-building project. The study of RFID utilisation on precast concrete components was carried out by Akinci *et al.* (2002), in developing the system to locate precast components in a storage area at the manufacturing plant. It also tracks the delivery of the components, and stores information from fabrication to post-construction for future use. Song *et al.* (2006) carried out a study on automating the task of tracking the delivery and receipt of fabricated pipe spools in industrial projects to determine RFID feasibility. Goodrum *et al.* (2006) through their research, developed a tool tracking and inventory system which is also capable of storing operation and maintenance (O&M) data using RFID tags and has significant potential to improve tool inventory and allocation on a construction jobsite. Torrent and Caldas (2006) integrated RFID and GPS with management tools to collect pre-fabricated pipe spools' location and identification data installed on handheld devices. Other automated data collection devices such as Personal Digital Assistants (PDAs), have been used in an automated model for collecting the data of purchasing, delivering, dispatching materials for installation by Navon and Berkovich (2006).

In general, from the literature, the current practices in tracking materials on construction projects are undertaken manually and are excessively paper-based. The studies undertaken above show the success of the implementation of automated tracking technologies (such as bar-coding) and growing use of emerging technologies (such as RFID, GPS, PDA) in improving tracking of materials in the construction site. It has been suggested that automated data collection technologies (such as bar-coding, RFID) can enhance the efficiency and accuracy of controlling materials in construction projects (Navon and Berkovich, 2006). Apparently, previous studies

have not shown positive examples of an effective integration of materials management with resource modelling in the work programme during construction projects. The next section, discuss the case studies undertaken on the construction project and present the findings.

CASE STUDIES

Method

This section presents the case studies undertaken to investigate current practices, problems and the potential for ICT implementation in materials management. There is the opportunity to identify the potential of using emerging technologies (such as RFID, wireless technologies) in overcoming the logistical difficulties associated with materials management on construction projects. The case studies span the materials management practices used on four complex construction projects. The data collected was based on semi-structured interviews with those responsible for materials management and site logistics. This was supplemented with the collection of documentary data on the nature of materials management processes on these projects. They were also used to acquire empirical data on the problems of storage space and materials tracking identified in the literature review.

A multiple-case research strategy was adopted for data collection. It was suggested that the data from the case study could be collected by questionnaires and interviews (Fellows and Liu, 1999). However, the interview is one of the most significant sources of information for the case study (Yin, 2003). Therefore, data collection on these case studies has primarily been by interviews. Interview questions were organised under broad headings including: (1) Key problems in materials management practices, (2) Approach to addressing problems, (3) ICT implementation, (4) Emerging technologies, and (5) Materials tracking systems. All the data was recorded and transcribed verbatim. Background information on four construction projects involved in the case studies are presented in Table 1.

Data analysis involved both single case and cross-case analyses. Single case analysis was conducted to produce individual case reports in order to gain the information of current practices, problems and ICT implementation in materials management practices. Amaratunga and Baldry (2001) specified that this allows the unique patterns of each case to emerge before pushing towards generalised patterns across cases. Cross-case analysis is used to make a comparison of the elements of analysis collected between the case studies (Yin, 2003).

Table 1: Construction Projects Involved in Case Studies

Case Study	Type of Project	Cost (£)
A	Hospital Building Project	333 m
B	Airport Terminals and Airfield Modification Project	450 m
C	New Airport Terminal Project	4.2 b
D	Residential Development Project	40 m

Case A: Hospital Building Project

Overview of Project, Key Problems and Approach to Address Problems

Project A involves the construction of a hospital building with a total cost of £333 million (RM1.7 billion). The main problems in materials management faced by this project are as follows:

- Inadequate site storage space;
- Tower crane distribution problems due to high demand of tower crane operations ;
- Logistics problems due to constraints of site space;
- Small loading area resulting in problems with materials delivery during loading and unloading operations;
- Site access problems due to one point site access and difficulties during traffic congestion.

Regular discussions and co-ordination meetings with all sub-contractors were used to resolve problems relating to materials logistics and distribution with a tower crane. Schedules are also used to record all tower crane activities within the construction site. In order to deal with the single access problem, a security guard was employed to organize the traffic flow into the construction site and also ensure safety of materials, equipment and other valuable things. Other approaches to dealing with the inadequate site storage space and small loading area involved the implementation of Just-In-Time (JIT) materials delivery to the construction site.

ICT Implementation, Emerging Technologies and Materials Tracking System

All basic ICT tools are fully utilised in managing materials in this project. These are as follows: (a) Fax system; (b) E-mail system; and (c) Microsoft Excel Spreadsheet. The use of the fax machine in this project is for purchasing activities, Microsoft Excel spreadsheet for gathering all materials information and as a recording system, and e-mail for communication purposes. The interviewees were aware of the potential to implement automatic tagging technologies to speed up materials ordering and tracking, reduce paper work, and facilitate the efficient control and checking of materials. Therefore, this project plans to implement bar-coding in their materials management.

Case B: Airport Terminals and Airfield Modification Project

Overview of Project, Key Problems and Approach to Address Problems

Project B is concerned with the modification of an airport terminal and airfield with a total cost of about £450 million (RM2.3 billion). The most significant challenges faced by this project are as follows:

- Inadequate site storage;
- Late delivery due to difficulty of materials delivery during aircraft operation;
- Regulation consideration due to time permission as set by the security;
- Inadequate loading area due to limited space for loading the materials at consolidation centre;
- Congestion due to many vehicles and materials at the loading area during loading and unloading operations.

There were several approaches adopted to deal with all the above problems. The implementations of a Consolidation Centre (CC) in this project helped to ensure that the correct materials were delivered efficiently to the correct construction site at the required time. In this way all the materials were transported to the CC before distribution to the construction site in order to avoid congestion of materials. The CC provides a solution to a number of issues such as:

reduces storage space problem, improves site security and safety, reduces congestion from construction traffic within the airport perimeter, improves delivery reliability, and improves workforce efficiency and reduces materials losses.

ICT Implementation, Emerging Technologies and Materials Tracking System

Generally, this project fully utilises basic ICT tools in purchasing activities and to facilitate the storage of all materials information. There were several ICT tools used in this project for managing materials: (a) Fax system; (b) Microsoft Excel Spreadsheet; (c) Bar-coding; and (d) An e-mail system. The e-mail system is used in this project for communication purposes only. Through this project the interviewee realized the importance of using automatic tagging technologies in helping to speed up materials ordering and tracking, reducing paper work, and facilitating the efficient control and checking of materials. In this project bar-coding was used in the CC operation for materials identification and delivery validation (such as location, time and date).

Case C: New Airport Terminal Project

Overview of Project, Key Problems and Approach to Address Problems

Project C involves the construction of a new airport terminal with a total construction cost of about £4.2 billion (RM21.3 billion). This project had the following main problems in materials management as follows:

- Site storage constraints;
- Supply chain challenge due to the variety and vast number of suppliers and materials;
- Supplier's and contractor's commitment to complete the jobs;
- Project size challenge due to problems with size of the project and physical access;
- Incorrect and late delivery of materials.

This project developed a Project Flow System to provide a transparent workflow management system to better coordinate the project team members, share resources and to improve performance. A Logistics Centre (LC) was set up to facilitate the huge number of materials that were employed in this project. The centre was responsible for materials logistics within the construction site and acted as a buffer before materials from vehicles can be supplied to the site. The project also applied the Just-In-Time (JIT) techniques to ensure the delivery of the right materials at the right time and at the right place. This arrangement reduces the congestion of vehicles and materials entering the construction site.

ICT Implementation, Emerging Technologies and Materials Tracking System

This project provided basic ICT tools together with automated tracking technologies to support materials management. These include: (a) Fax-system; (b) Microsoft Excel Spreadsheet; (c) Bar-coding; (d) RFID; (e) PDA; (f) E-mail system; and (h) Project Flow System. The basic ICT tools such as fax machine and Microsoft Excel Spreadsheet were utilised in this project to support managing materials in recording system and the e-mail system for communication purposes only. The implementation of bar-coding was used to facilitate tracking and control of the rebar, and RFID for tracking precast column. The Project Flow system was adopted to provide transparent workflow management and to better co-ordinate project team members, shared resources management and identify areas to improve performance.

Case D: Residential Development Project

Overview of Project, Key Problems and Approach to Address Problems

Project D involved the construction of residential buildings comprising of 316 apartments with a total cost of about £40 million (RM203 million). This project had several problems relating to materials management as follows:

- The surrounding project location with many public infrastructure (such as school, railways, local roads);
- Logistics problems due to associated constraints;
- Congestion at peak times due to delivery of materials;
- Site access permission for materials delivery;
- Consideration of local authority regulations.

The main contractor conducted everyday meetings to co-ordinate the subcontractor's daily activities. The biggest concern with respect to logistics was bringing in large materials and concrete onto a site which is surrounded by many public infrastructure/facilities such as schools and railways. This project used car park areas or empty buildings for storage purposes. However, valuable materials and small items had to be put into a lockable storage compound.

ICT Implementation, Emerging Technologies and Materials Tracking System

Generally, this project was supported by basic ICT tools in materials management practices. These included: (a) Fax system; (b) Microsoft Excel Spreadsheet; (c) E-mail system; and (d) Project Flow System. The fax machine was used for materials purchasing activities while the Microsoft Excel Spreadsheet was used to store all materials information. The e-mail system was used for communication purposes only. This project was not supported by automated tracking technologies with materials tracking undertaken manually. Project Flow system was implemented to integrate resource planning with the work programme.

DISCUSSION AND ANALYSIS

The result on cross case analysis within case studies is summarised in Table 3. Generally, the findings from case studies reveal that the major problems in term of materials management activities relate to constraints on storage areas, site logistics with regards to materials handling and distribution, and also with ordering and delivering of materials to the construction sites. The initial feedback identified the issue of space problems which had been experienced by all construction companies interviewed. The logistics problems are caused by single access to construction sites, surrounded by public infrastructure such as schools and railways, congestion of materials' vehicles during peak time, and regulation considerations. The implementation of JIT techniques and the CC approach provided in overcoming logistics and storage problems for materials management processes. The implementation of CC as a temporary storage outside the construction boundary for the construction materials before delivery to site, can also overcome the problem of congestion of materials transportation into the site during peak time.

Excellent collaboration is needed between contractors and suppliers in order to achieve better management of materials delivery to the construction sites. Problems with late and incorrect delivery can be solved by keeping suppliers informed if any unexpected events occur. Tremendous monitoring and handling are required throughout the materials management processes by a project representative who could facilitate tracking of materials delivery and materials that do not comply with the standard requirements. However, the current practices in handling and monitoring of materials which are done manually has the potential for human error

in tracking the availability of materials at the storage area, and the verification of quantities and damage during materials delivery.

Basic ICT tools (such as fax machine and spreadsheets) are used to support purchasing activities in many construction projects. However, there is inadequate use of modern ICT tools such as RFID to assist with automatic identification and tracking of materials. There is also a lack of robust ICT tools which can integrate materials, labour and plant into one system. In order to improve efficiency and effectiveness of handling materials, it is important to change from manual practices to automatic practices and also provide real-time information. As a result, this research will develop a system to integrate RFID-based materials management with resources modelling in project management systems to improve on-site materials tracking and inventory management on construction projects. The next section presents the outline features of a framework for a real-time materials tracking system.

Table 3: Cross-Case Analysis

Element of Analysis	Case A	Case B	Case C	Case D
Materials Management Problems	(1) Inadequate site storage (2) Tower crane distribution problems (3) Logistics problems (4) Small loading area (5) Site access problems	(1) Inadequate site storage (2) Late delivery (3) Regulation consideration (4) Inadequate loading area (5) Congestion time	(1) Site storage constraints (2) Supply chain challenge (3) Supplier's and contractor's commitment (4) Project size (5) Incorrect and late delivery	(1) Project location (2) Logistics problems (3) Congestion time (4) Site access constraints (5) Regulation consideration
Approaches to addressing problems	(1) Regular discussion and meeting (2) Provide enough storage and monthly stock checking (3) Record scheduling (4) Just-In-Time	(1) Consolidation Centre (CC) (2) Undertake airport security requirements	(1) Project Flow System (2) Logistics Centre (LC) (3) Just-In-Time	(1) Everyday meeting (2) Regulation comply (3) Project Flow System
ICT implementation	(1) Fax System (2) Microsoft Excel Spreadsheet (3) E-mail System	(1) Fax System (2) Microsoft Excel Spreadsheet (3) E-mail System (4) Bar-coding	(1) Fax System (2) Microsoft Excel Spreadsheet (3) E-mail System (4) Project Flow System (5) Bar-coding	(1) Fax System (2) Microsoft Excel Spreadsheet (3) E-mail System (4) Project Flow System (5) Bar-coding
Use of emerging technologies (RFID, wireless)	No	No	Yes (RFID, PDA)	No
Materials tracking system	Manual	Bar-coding Manual	Bar-coding RFID PDA Manual	Manual

TOWARDS A FRAMEWORK FOR REAL-TIME MATERIALS TRACKING

In order to overcome the problems, with current manual practices, of tracking materials which is affected by many human error and excessive paperwork there is potential to implement emerging technologies (such as RFID, wireless technologies) to support an automatic materials tracking. The integration RFID-base materials with resource modelling in the work programme are important to provide the real-time materials tracking in materials management. The development of a framework for a real-time materials tracking system is intended to improve the overall process of materials management on construction projects. The framework for a real-time materials tracking system consists of the following:

- *Materials Delivery:* Delivery of purchased materials with RFID tags detected by RFID reader at the main entrance of the construction site. The RFID reader with antenna attached with PDA for Site Manager/Subcontractors checked required information of materials delivery within the database.
- *Materials Storage:* At the storage area, Site Manager/Subcontractor periodically check the availability of materials at the storage area and required for installation by using RFID reader attached with PDA. This is required integration with the database and work programme.
- *Materials Use:* Site Manager/Subcontractors check required information of materials to be used for installation (integration with the database and work programme) by using PDA attached with RFID reader at the construction site.
- *On-Site Control Centre:* The site office was established as and on-site control centre. All data collection gathered into the database for materials ordering, delivery status, storage information and use status.
- *Report Transmission:* All the information of real-time materials tracking send to the main office via e-mail through internet connection. The real-time materials tracking framework can be illustrated as Figure 1 below.

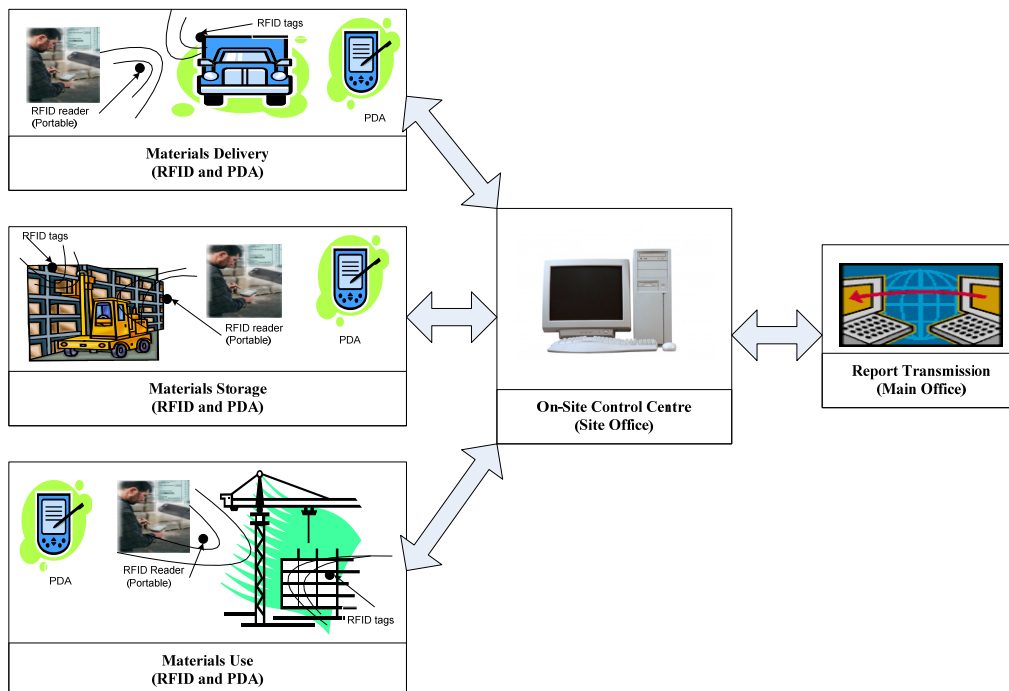


Figure 1: Framework for a Real-Time Materials Tracking System

CONCLUSIONS

A total of four case studies had been undertaken in order to achieve the objectives of this study. That is to investigate the current issues and problems in materials management, and also the implementation of ICT and the potential of emerging technologies in overcoming the logistical difficulties on construction projects. Findings from the analysis show that many of the case study projects have similar problems with constraints of storage area. Handling and monitoring activities at site such as tracking of materials, is still facilitated by manual operations in most of the case studies, with a potential for many human errors and excessive paperwork. The use of sophisticated technologies (such as bar-coding, RFID and wireless) as recommended from the case studies to facilitate an automated materials tracking on construction projects can be implemented. However, more integrated solutions are essential as the case studies presented in this paper demonstrate. Therefore, the framework of real-time materials tracking system as illustrated above has been developed to integrate RFID-based materials management with resources modelling in project management systems to improve on-site materials tracking and inventory management on construction projects. The development of the appropriate mechanism for data capture from RFID tags by RFID reader can store the information into the database and integrate with the work programme.

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