Improving materials management on construction projects

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IMPROVING MATERIALS MANAGEMENT ON CONSTRUCTION PROJECTS

NARIMAH BINTI KASIM

A thesis submitted in partial fulfilment of the requirements of Loughborough University for the degree of Doctor of Philosophy

January 2008
ABSTRACT

An essential factor adversely affecting the performance of construction projects is the improper handling of materials during site activities. Materials management is made problematic by materials shortages, delays in supply, price fluctuations, damage and wastage, and lack of storage space. In addition, paper-based reports are mostly used to record and exchange information related to the materials component within a supply chain which is problematic, error-prone, and inefficient. Generally, modern technologies are not being adequately used to overcome human error and are not well integrated with project management systems to make the tracking and management of materials easier and faster. Thus, this research focuses on the development of a mechanism to improve materials management on construction projects through the integration of materials tracking and resource modelling systems.

A multi-faceted research approach was adopted. Initially, a literature review on materials management process in the construction project was conducted. This was followed by case studies involving six construction projects in order to investigate current practice in materials management to establish key problem areas and elements of good practice. The case studies also explored the requirements for integrating materials management and resource modelling in project management systems. The case study findings underpinned by literature results were used to develop a real-time framework for integrating RFID-based materials tracking and resource modelling.

The framework was encapsulated in a computer-based prototype system based on Microsoft Visual Basic.NET. The prototype system was developed by amalgamation of all the software and hardware chosen such as MS Access (database system), MS Project (resource modelling) and RFID (automated materials tracking) to provide the mechanisms for integrating materials management and resource modelling in the construction industry. Evaluation of the prototype system was carried out by a series of interviews with industry practitioners to assess its appropriateness and functionality. It also established the skills and other requirements for the effective use of the real-time materials tracking system. The evaluation established that the
prototype system demonstrated many benefits and is suitable for use in materials tracking and inventory management processes.

It is concluded that the prototype system developed can improve materials management on construction projects, particularly with regard to materials tracking and integrating materials utilisation with the resource modelling subsystem in project management applications. Adoption of the approaches suggested in the thesis will enable the construction industry to improve the real-time management of materials on sites, and hence improve project performance.
DEDICATION

I dedicate this thesis to

Almighty ALLAH,
My late beloved father (Kasim Radzuan), My mother (Sayanah Jaffar)
and
My husband (Amran Mahmud) who give me encouragement and love.
ACKNOWLEDGEMENTS

First and foremost, I would like to express my gratitude to my supervisors, Professor Chimay J. Anumba and Professor Andrew R. J. Dainty, for providing me with invaluable guidance, inspiration and support for my research. My special thanks to Professor Chimay J. Anumba for being instrumental in helping me to realise my research project, and for being a mentor and supporter with his constant inspiration and encouragement.

I will also like to thank my Director of Research Dr David J. Edward; the Research Administrator, Ms Helen Newbold; all the academic, support and technical staff of the Department of Civil and Building Engineering; and the colleagues with whom I had constructive interactions and shared valuable moments together. I would also like to express my gratitude to my sponsor (Ministry of Higher Education, Malaysia), my employer (Universiti Tun Hussein Onn Malaysia, UTHM) for the study fellowship and financial support. I am also grateful to the organisations which participated in the research during the case studies and evaluation of the prototype system.

Finally, I would like to thank my husband, mother, brothers and sisters for all the love, understanding encouragement throughout the research period.
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<td>Auto-ID</td>
<td>Automatic Identification</td>
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<tr>
<td>CC</td>
<td>Consolidation Centre</td>
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<td>CMPS</td>
<td>Construction Materials Planning System</td>
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<tr>
<td>COME</td>
<td>Construction Materials Exchange</td>
</tr>
<tr>
<td>DS</td>
<td>Delivery Status</td>
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<tr>
<td>EAN</td>
<td>European Article Numbering</td>
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<tr>
<td>E-mail</td>
<td>Electronic mail</td>
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<td>EPC</td>
<td>Electronic Product Code</td>
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<td>ERP</td>
<td>Electronic Road Pricing</td>
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<td>ESCAP</td>
<td>Expert System Advisor for Concrete Placing</td>
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<tr>
<td>FM</td>
<td>Facilities Management</td>
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<td>GIS</td>
<td>Geographic Information System</td>
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<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
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<tr>
<td>IC</td>
<td>Integrated Circuit</td>
</tr>
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<td>ICT</td>
<td>Information and Communication Technologies</td>
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<td>IDE</td>
<td>Integrated Development</td>
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<td>IEPC</td>
<td>Internet-based Electronic Product Catalogue</td>
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<td>ITC</td>
<td>Information Technology in Construction</td>
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<tr>
<td>JIT</td>
<td>Just-In-Time</td>
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<td>LC</td>
<td>Logistic Centre</td>
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<td>LED</td>
<td>Light-emitting diode</td>
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<td>MHESA</td>
<td>Material Handling Equipment Selection Advisor</td>
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<td>MO</td>
<td>Materials Order</td>
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<td>O&amp;M</td>
<td>Operation and Maintenance</td>
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<td>OAN</td>
<td>Japanese Article Numbering</td>
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<tr>
<td>OCR</td>
<td>Optical Character Recognition</td>
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<td>PC</td>
<td>Personal Computer</td>
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<td>PDA</td>
<td>Personal Digital Assistant</td>
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<td>Radio Frequency Identification</td>
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<td>RTM</td>
<td>Real Track Materials</td>
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<td>Description</td>
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<td>SDK</td>
<td>Software Development Kit (SDK)</td>
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<td>Universal Product Code</td>
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<td>Virtual Construction Material Router</td>
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CHAPTER 1
INTRODUCTION

This chapter presents the context for this research. It starts with a brief background to the research, and then justifies the need for the research. It also states the aim and objectives of the research and the methodology adopted. Lastly, it describes the structure of the thesis.

1.1. Background

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 has 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; manual processes, and non-compliance with specifications (Dey, 2001), late delivery (Aibinu and Odeyinka, 2006), shortage of materials (Abdul-Rahman et al., 2006).

There are several varieties of approaches, which are used to address materials management issues. These include: proper planning of materials logistics, Just-In-Time (JIT) concepts to resolve the problems of space constraints, and the implementation of Information and Communication Technologies (ICT) such as bar-coding for automatic tracking of materials. However, there is a paucity of positive examples of where such tools have been successfully used. An initial assessment of
the tools and techniques currently in use in materials management suggests that most of them are under development, with only a few being used on a commercial basis (BRE, 2005). The tracking of materials during delivery times and at the storage area is commonly undertaken manually. 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 can be problematic, error-prone and inefficient.

Generally, tracking technologies such as wireless, bar-coding and radio frequency identification (RFID) are not adequately employed in developing materials tracking practices on construction projects (Kasim et al., 2005b). There is also insufficient support for the tracking and management of materials for operational efficiency in inventory management on site. Accordingly, there is scope for significant advantages if automated tracking technologies are deployed to overcome problems in manual practices, which is labour intensive and error prone (Navon and Berkovich, 2006). 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. Therefore, this research focuses on the deployment of RFID to improve on-site materials tracking, inventory management processes, and resource management.

1.2. Justification for the Research

Materials management is an important function for improving productivity in construction projects. The management of materials should be considered at all the phases of the construction process and throughout the construction and production periods. This is because poor materials management can often affect the overall construction time, quality and budget. Bell and Stukhart (1986) stated that it is important for planning and controlling of materials 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. The scope of the research will focus on space constraints due to the logistics in construction sites and particularly in large and complex projects. 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 and is problematic with many human errors.

There are various advantages in the implementation of ICT in materials management, as ICT has the potential to significantly improve the management of materials on site. A range of opportunities for construction organisations to invest in advanced information technology and telecommunications systems are noted by Griffith et al., (2000). In other areas of business, such as publications, advertisement and manufacturing the growth of ICT has been very rapid. According to a Building Research Establishment report (BRE, 2005), ICT applications in the construction industry are now commonplace for facilitating procurement, collaboration and knowledge management. For example, product procurement has such features as direct and indirect purchasing, electronic payment, and material aggregation which can be supported by ICT. This can eliminate paper work, lower product and operational costs, and reduce cycle times. ICT is used in materials management for cost estimating through involving a well known software such as Microsoft Excel (Sun and Howard, 2004). However, there is not much use of modern ICT tools (e.g. wireless communications, bar-coding and RFID) to facilitate materials management processes in tracking materials quickly, accurately, and easily.

In general, the current practices in tracking materials on construction projects are undertaken manually and are excessively paper-based. Previous research projects have demonstrated the successful use of automated tracking technologies such as bar-coding in helping improving materials tracking in the construction site. This includes the study of the use of bar-coding to provide instant and up-to-date information on 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-coding and Geographic Information System (GIS). In another study, Moselhi and El-Omari (2006) present a data collection methodology that utilises both bar-coding and RFID technology to collect data (such as working hours and materials quantities) on construction sites and store the data in a central database for tracking project cost and schedule information.

All the above examples have shown the successful implementation of bar-coding in materials tracking processes. However, the use of the bar-coding system could involve many constraints such as it can easily be damaged, it cannot be read in direct sunlight, and it cannot withstand harsh conditions (Jaselskis and El-Misalami, 2003). Thus, incorporate technologies such as RFID and wireless communications are expected to grow in usage to support materials management practices (Kasim et al., 2005a). These technologies have been successfully used in other industry sectors such as manufacturing, retail, and transportation in improving logistics. There is potential to apply these in construction practices (BRE, 2005).

Several papers have discussed the possibility of implementing RFID in the construction industry. Jaselskis and El-Misalami (2003) presented 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). This involved RFID for storing the data into electronic tags, and GPS for positioning the material parameters to trace asphalt quality with respect to the road-building project. The study of RFID utilisation on precast concrete components was carried out by Akinci et al. (2002) who developed a system to locate precast components in a storage area at the manufacturing plant. It also tracks the delivery of the components, and stores information on them from fabrication to post-construction.

Song et al. (2005) carried out a study on automatically tracking the delivery and receipt of fabricated pipe spools in industrial projects to determine RFID feasibility. Goodrum et al. (2006) 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 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 (Navon and Berkovich, 2006).

From the above, it is evident that there is growing use of RFID in the construction industry, and many application areas have emerged. However, there is inadequate integration of RFID-based materials tracking with resource modelling (Kasim et al., 2005a). This has the potential to facilitate the timely delivery, monitoring, utilisation and inventory management of materials on construction projects. In large-scale projects, where there is a high volume of materials usage (some of which are high value components and sub-assemblies), there is the potential for huge savings. Therefore, this research will develop a system to integrate RFID-based materials management with resources modelling in project management systems. The specific research is concerned with the potential implementation of RFID technology in the resolution of the specific problem related to materials management on large and small construction projects.

1.3. Aim and Objectives

The aim of this research project is to develop mechanism to improve materials management on construction projects through the integration of materials tracking and resource modelling system. The specific objectives of the research include:

1. To review existing literature on materials management processes in construction projects;

2. To review current industrial practice in materials management and to establish key problem areas and elements of good practice;
3. To establish the requirements for integrating materials management and resource modelling in project management systems (i.e. real-time materials tracking);

4. To develop and evaluate a prototype system for integrating materials management and resource modelling; and

5. To investigate requirements necessary for effective use of the system, such as skills and knowledge requirements.

1.4. Research Methodology

To achieve the research objectives, a combination of research methods was adopted. The research methods adopted included literature review, case studies, rapid prototyping, and evaluation. Figure 1.1 shows the relationship between selected research methods and the output of the related activities. The following sections briefly summarise the research methods used, and in Chapter 2 provides full details of the research methods adopted, including a justification for their use.

(a) Literature Review

The literature review process started with searching the existing literature on materials management on construction projects. It also reviewed the implementation of ICT and emerging technologies to support materials management practices in construction projects. The literature review was based on a variety of sources including books, refereed journals, the Internet, company reports, workshops and seminar proceedings, doctoral dissertations, and conference proceedings. The aim of the literature review was to identify problems and aspects of materials management practices that can be improved, and to examine the implementation of ICT and potential emerging technologies. The process was an ongoing process, carried out concurrently with all stages in the research project.
Chapter 1: Introduction

Research Method Activities Output

- Review existing literature in materials management processes and ICT implementation on construction projects

- Review existing literature in materials management processes and ICT implementation on construction projects

- Identify the key problems in materials management practices and ICT implementation on construction projects

- Identify potential use of RFID to support on-site materials tracking and requirements for the integration with resource modelling in project management system

- Design and develop the prototype system for real-time materials tracking

- Evaluate the real-time materials tracking framework and prototype system

- Identify requirements necessary to facilitate materials tracking using RFID and other associate technology

- Research context in materials management and ICT implementation

- Current issues in materials management and ICT implementation

- Potential use of RFID for materials tracking and integration requirements

- Prototype system

- Refine and improve the prototype system

- Requirements necessary (such as skills and knowledge)

Figure 1.1: Overview of the Research Method, Activities and Output
Case studies were undertaken to review current industrial practice in materials management to establish key problem areas and elements of good practices. They were also essential to identify how ICT is being used to facilitate materials management processes, and how these could be improved to address the real-time tracking (identification, update, safety) problems in inventory management on site. Six construction projects were used for the case studies. An analysis of the data obtained from the case studies was used as a foundation for developing a real-time materials tracking process for integrating materials tracking and resource modelling systems. The case studies undertaken followed the process below.

- **Identification of organisations**
  The identification of construction organisations focuses on large and small projects, which attempted to implement new technologies (such as RFID) for real-time materials tracking. The selection of case study organisations was based on the willingness of individuals within the organisations to participate and share their experience.

- **Data collection**
  Data collection involved semi-structured interviews, recorded on tape and transcribed verbatim. This was used to identify current materials management problems, the causes, how to address problems, and how ICT is used to facilitate materials management practices. The 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.

- **Data analysis**
  Data analysis was concerned with gathering information on the problems on current practices of materials management, current approaches to address problems, ICT implementation, the use of emerging technologies, and current materials tracking systems. Results from the analysis were used to support the development of a real-time materials tracking system.
(c) *Rapid Prototyping*

Prototyping is a process of building an experimental system quickly and inexpensively for demonstration and evaluation, so that users can better determine information requirements (Laudon and Laudon, 2002). The development of a prototype was made on a personal computer (PC) and Personal Digital Assistants (PDAs), and the working environment was Microsoft Visual Basic.NET. The prototype system also utilised RFID technology to facilitate materials tracking on the construction sites. There were a few steps in developing the prototype as below:

- **Identify the users’ requirements**
  The results from literature review and case study findings were used to create the basic requirements for improving materials management practices.

- **Develop an initial prototype**
  An operational prototype was developed using Microsoft Visual Basic.NET programming language. There was also the amalgamation of all the selected software such as MS Access (for database system), and MS Project for resource modelling. The hardware used for developing prototype system was used RFID technology (such as RFID reader and tags) for automated materials tracking.

- **Use the prototype**
  The demonstration of the prototype system was made with construction professionals (e.g. site managers, project managers) to evaluate the its performance and to ensure accuracy and efficiency.

- **Revise and enhance the prototype**
  The refinement of the prototype was based on the feedback obtained from the construction professionals involved in the evaluation.
(d) **Formative and Summative Evaluation**

The evaluation session consisted of three main elements: presentation on the background to the prototype system, prototype demonstration, completion of an evaluation questionnaire and discussion of the key issues relating to the system. The relevant feedback gained from the evaluation was used to refine and improve the prototype system. Construction professionals from five construction organisations participated in the evaluation of the prototype system.

1.5. **Structure of the Thesis**

This thesis is structured into eight chapters. The content of the chapters is briefed as follows.

*Chapter 1* introduces the context of the research and briefly discusses the background. It explains the need for the research, the aim and objectives, and research methodology.

*Chapter 2* reviews the research methodology, the methodological consideration for this study, and justification for the adoption of the specific research method.

In *Chapter 3*, the focus is on materials management practices in the construction industry. It also discusses the current problems that occur in materials management practices, followed by a discussion of the implementation of current technologies and the potential use of emerging technologies for automatic materials tracking.

*Chapter 4* presents the findings from six case studies. The findings were used to reveal the materials management problems, approaches to addressing problems, ICT implementation, use of emerging technologies and materials tracking system. The chapter concludes with suggestions on conceptual framework for real-time materials tracking framework.
Chapter 5 discusses the real-time materials tracking process by describing five main components such as materials delivery, materials storage, materials use, on-site control centre, and report transmission. It is also presents the real-time materials tracking process by highlighting the key features.

Chapter 6 describes the choice of a development environment and system architecture for the prototype system. The development of real-time materials tracking system and is followed by the operation and testing of the prototype system.

Chapter 7 presents the system evaluation process. It starts with an introduction to the evaluation aim and objectives. This is followed by the evaluation process and the outcomes. It also discusses the skills requirements for effective use of real-time materials tracking, and the benefits and the limitations of the prototype system.

Chapter 8 presents the summary and conclusions of the thesis. It discusses the findings, the conclusions of the research, and the limitations, and provides recommendations for future work.

1.6. Summary

This chapter has presented the issues of materials management and a justification for the need for the research provided. There are many issues in materials management, but the focus of this research will be on space constraints due to logistics problems on construction sites. There are also problems with many human errors and excessive paperwork. The potential use of emerging technologies (such as RFID, wireless system) could facilitate materials tracking is also acknowledged. This chapter has also presented the aim and objectives of the research, followed by the outline of research methodology, and the structure of the thesis. The next chapter focuses on the research methodology applied in this study.
CHAPTER 2
RESEARCH DESIGN AND METHODOLOGY

2.1 Introduction

This chapter describes the research methodology adopted throughout the research project. It starts with an introduction to research, research approaches and then justifies the selection of the research methodology. Finally, it explains the methods adopted for this research.

2.2 Introduction to Research

The Concise Oxford English Dictionary (COED, 2004) defines research as ‘the systematic investigation into and study of materials and sources in order to establish facts and reach new conclusions’. Greenfield (1996) asserts that research is an art aided by skills of inquiry, experimental design, data collection, measurement and analysis, interpretation, and presentation. Many researchers have described research as a systematic and organised effort to investigate a problem that needs a solution (Neuman, 2006; Walker, 1997; Sekaran, 1984).

Research methodology can be defined as “the principles and procedures of the logical thought process which are applied to a specific investigation” (Fellows and Liu, 1999). Klien and Myers (1999) consider it “the principles and procedures of the logical thought process which are applied to a specific investigation”. According to Peters and Howard (2001), whatever the method chosen, good research must be rigorous, systematic, integrated and focussed. Remenyi et al. (1998) stated that, the primary drivers for choosing an appropriate research methodology includes:

- the topic to be researched;
- the specific research questions; and
the resources available.

A "nested research methodology" introduced by Kagioglou et al. (2000) can be divided into three main interrelated themes: *research philosophy*, *research approaches* and *research techniques*, as shown in Figure 2.1. The research philosophy created the outer box guides and energises the inner research approaches and research techniques. The research approaches incorporate qualitative and quantitative methods. Research techniques consist of data collection tools such as literature review, interviews, questionnaires surveys, experiments, observation, workshops etc.

![Figure 2.1: A Nested Research Methodology](source: Kagioglou et al., 2000)

According to Bryman (2004), there are two main philosophical schools of thought in social research: *ontological* and *epistemological*. The ontological philosophy involves the logical investigation of the different ways in which the different types of things are thought to exist, and the nature of the various kinds of existences. It can be divided into realist and relativist approaches. An epistemological consideration deals with question of knowledge acceptability in a discipline, and the methods through which knowledge is acquired. The epistemological philosophy can be divided into...
interpretivist and positivist approaches. Table 2.1 shows the summary of philosophical considerations.

Table 2.1: Summary of Philosophical Considerations
(adapted from Bryman, 2004; Fitzgerald and Howcroft, 1998)

<table>
<thead>
<tr>
<th>Ontological considerations</th>
<th>Relativist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Realist</td>
<td>Relativist</td>
</tr>
<tr>
<td>• External world comprises pre-existing hard and tangible structures</td>
<td>• Existence of multiple realities as subjective construction of the mind</td>
</tr>
<tr>
<td>• Structures exist independent of individual’s ability to acquire knowledge</td>
<td>• Socially-transmitting terms vary across different languages and cultures</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Epistemological considerations</th>
<th>Interpretivist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positivist</td>
<td>Interpretivist</td>
</tr>
<tr>
<td>• Application of natural science methods to the study of social reality and beyond</td>
<td>• Absence of universal truth and emphasis on realism of context</td>
</tr>
<tr>
<td>• World conforms to the laws of causation and complex issues can be reduced through reductionism</td>
<td>• Understanding and interpretation come from researcher’s own frame of reference</td>
</tr>
</tbody>
</table>

The interpretivist approach is related to knowledge development and theory built through developing ideas inducted from the observed and interpreted social constructions (qualitative approach) (Love et al., 2002), and the positivist associated with knowledge development by investigating the social reality through observing objective facts (quantitative approach) (Blumberg et al., 2005). Easterby-Smith et al. (2002) suggests that there are three key importance issues to understanding the philosophical research:

- it can help to clarify research designs;
- knowledge of philosophy can help the researcher to recognise which design will work and which will not; and
- knowledge of philosophy can help the researcher identify and even to create designs that may be outside the researcher’s experience.

The details about the research approaches are described in the following section.
2.3 Research Approaches

A research approach is a way of unfolding a specific style and employment of different methods in doing research. It has been referred to as a research strategy by Naoum (2002) and as a research method by Yin (2003). According to Yin (2003), the selection of a suitable research approach should be governed by the basis of:

- the nature of the enquiry and the type of questions being posed;
- the extent of the investigator's control over the actual behavioural events; and
- the degree of focus on contemporary events.

The research approach is concerned with the types of evidence to be collected and the sources of such evidence, as well as the process of interpretation used to obtain satisfactory answers being posed (Easterby-Smith et al., 2002). There are three types of research methodology; quantitative, qualitative and a combination of both methods called triangulation or mixed method (Neuman, 2006; Fellows and Liu, 1999) which will be described in the following section.

2.3.1 Quantitative Research

Fellows and Liu (1999) defined quantitative research as "seeks to gather factual data and to study relationships between facts and how such facts and relationships accord with theories and the findings of any research executed previously (literature)". Quantitative research is used to answer questions about the relationship between the measured variables with the purpose of explaining, predicting and controlling phenomena (Leedy and Ormrod, 2001). This approach employs the use of mathematical and statistical techniques to identify facts and casual relationships, and samples can be larger and more representative (Fitzgerald and Howcroft, 1998). Bryman (2004) outlined the main steps in quantitative research as presented in Figure 2.2, and emphasised that they represent an ideal account of how research should progress.
The samples collected from quantitative research are often large and representative, and the results can be generalised to the larger population within acceptable error limits (Bryman, 2004). Patton (2002) stated that, the validity of results depends on the careful choice of measuring instrument and how accurately it measures targets. The analysis of quantitative data can be categorised into two types: Statistical Analysis and Content Analysis. Statistical analysis involves analysis of collected quantitative data with the aid of either descriptive statistics (e.g. histograms, pie charts, etc.) or inferential statistics (e.g. correlation, regression, etc.). Content analysis seeks to classify communication acts into categories that have common features, and can provide the researcher with a qualitative picture of the respondents' concerns, ideas, attitudes and feelings (Emmit and Gorse, 2003).

The quantitative research approach has also received some criticisms from the research community and can be outlined as follows (Bryman and Bell, 2003):

- Quantitative researchers fail to distinguish people and social institutions from 'the world of nature';
• The measurement process possesses an artificial and spurious sense of precision and accuracy;
• The reliance on instruments and procedures hinders the connection between research and everyday life; and
• The analysis of relationships between variables creates a static view of social life that is independent of people's lives.

The following are the two most commonly used quantitative research approaches.

2.3.1.1 Experimental Research

There are two types of data collection techniques for experimental research: laboratory and field experiments. According to Fellows and Liu (1999), laboratory experiments are augmented to test the relationship between identified variables, and field experiments are not conducted in specially built laboratories but in a dynamic social, industrial, economic and political arena. In general, experimental data collection methods tend to be easier to replicate, less expensive and less time consuming than the other techniques (Neuman, 2006; Blumberg et al., 2005). However, the key disadvantage of this method is that it is extremely difficult in a study involving human individuals (Alasuutari, 1999). Neuman (2006) also stated that, the limitation of the experimental research is that some questions cannot be addressed using experimental methods because control and experimental manipulation are impossible. Another limitation is that experiments usually test one or a few hypotheses at a time.

2.3.1.2 Surveys

According to Neuman (2006), survey research is a process of asking many people the same questions and examining their answers. This method produces observations that are constructed in a specific manner. In survey research, the types of data collection method includes: questionnaires (mail and self-administered), interviews (face-to-face and telephone interviews) and web survey. The selection of data collection
method is important because it affects the quality and cost of the data and avoids interviewer bias, but the researcher cannot control the conditions under which a questionnaire is completed. In general, the interview survey is more capable of obtaining quality data compared to a questionnaire survey. In terms of cost, the questionnaire survey is cheaper. However, in terms of time, web-based surveys over the Internet or by e-mail are very fast and inexpensive and they allow a flexibility of design that can also use visual images, and even audio or video in some Internet versions.

2.3.2 Qualitative Research

Qualitative research is research that produces descriptive data such as an individual’s own written words or observable behaviour (or concerns groups of people). In social science, the qualitative research approaches were originally developed to enable researchers to study social and cultural phenomena. Creswell (1998) defined qualitative research as “an inquiry process of understanding based on distinct methodological traditions of inquiry that explores a social or human experience”. The characteristics of the qualitative methodology are as following below (Dainty, 2004):

- Inductive (concepts are developed from data);
- Subjects and settings are viewed holistically;
- Researchers are aware of their effect on the people that they study;
- Gains an understanding from the informant’s perspective;
- Methods are humanistic - they look beyond the specific aspect being examined;
- The data collected is rich, and difficult to analyse;
- It demands that the researcher gets close to the data and to the phenomena which are being examined; and
- It emphasises validity.

The outline of qualitative research process can be depicted in Figure 2.3 below.
The main steps involved in qualitative research are non-linear and the research questions are often driven by theoretical issues, which in turn drive the data collection and analysis (Bryman, 2004; Neuman, 2006), and operate under the assumption that reality is not easily divisible into discrete, measurable variables (Creswell, 1998). Bryman (2004) also argued that the qualitative research approach may be adopted where the situation is as follows:

- No existing research data on the topic and the most appropriate unit of measurement is not certain; and
- The concepts to be researched are assessed on a nominal scale, with no clear demarcation and involve exploring behaviour or attitudes.

Qualitative research also makes considerable use of inductive reasoning (Neuman, 2006; Bryman and Bell, 2003). They are related to the theory and emphasise words rather than quantification in the collection and analysis of data (Bryman and Bell, 2003), and making many specific observations and then inferences about larger and more general phenomena (Neuman, 2006). However, there are criticisms from the...
research community about the limitations of a qualitative research strategy identified by Bryman and Bell (2003) as follows:

- **Problems of generalisation.** The sample sizes and sampling methods used qualitative research reduce the capability to generalise the research results.
- **Qualitative research is too subjective.** The strength of deeper understanding provided by a qualitative strategy is in itself a weakness as it limits confidence in the results.
- **Difficult to replicate.** Another weakness of qualitative strategy is the limitation in terms of replication by other researchers. For example, what one researcher might focus on, might not be the focus of another researcher.
- **Lack of transparency.** The process of collecting and analysing qualitative data is something difficult to establish and can lack clarity.

Amaratunga *et al.* (2002) state that, qualitative data, with its emphasis on peoples' 'lived experience', are fundamentally well suited for locating the meanings people place on the events, processes and structure of their lives: their 'perceptions, assumptions, prejudgements, presuppositions'. Data analysis is involved with understanding and interpretation of the data collected in a systematic and logical manner to afford authentic conclusions. According to Emmit and Gorse (2003) there are three main categories of qualitative research methods of analysis include: *conversation analysis, discourse analysis,* and *semiological analysis.* Conversation analysis concerned with the contextual sensitivity of language with a focus on interaction and social action. Transcripts or audio recordings of interaction are required to provide the detailed data necessary for conversation analysis. The analysis attempts to understand the relationship between different events. Discourse analysis slightly broader term than conversation analysis, and involves the scrutiny of transcripts of discussions and statements. The content and the linguistic context are considered when establishing meaning and intention of the interaction. Semiological analysis assumes a relationship between the appearance and structure of the text, and interaction and the meanings that it produces within a specific culture or context.
Chapter 2: Research Design and Methodology

The discussions of the various types of the qualitative approaches are discussed follows.

2.3.2.1 Case Studies

The technical definition of a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used (Yin, 2003). Case study refers to the examination of a single entity (the case) or multiple cases by using a variety of data collection methods (such as documentation, archival records, interviews, direct observations, participant-observations, and physical artefacts) during a sustained period of time. A good and effective case study research should have the following elements (Johnston et al., 1999):

- The case study must begin with theory and the development of research hypothesis;
- A systematic research design must be followed; and
- An evaluation criteria must be implemented to independently assess potential biases and to ensure the methodological rigour of the case studies.

Yin (2003) asserts that case studies are the preferred strategy when 'how' and 'why' questions are being posed, when the investigator has little control over events, and when it is on a contemporary phenomenon within some real-life context. The key feature of the case study approach is not method or data but the emphasis on understanding processes as they occur in their context (Amaratunga et al., 2002). According to Leedy and Ormrod (2001), the key strength of case study research is because it suitable for learning more about a little known or poorly understood situation. It may also be useful for investigating how an individual changes over time, perhaps as the of certain circumstances or interventions.

In many instance, the researcher may spend an extended period of time on-site and interact regularly with people who are being studied to gain an insight into behaviour.
and attempts to discover unique features and common traits shared by all persons in a
given classification. Meredith (1998) point out that some difficulties of doing case
study research includes: the requirements of direct observation in the actual
contemporary situations (cost, time, access hurdles); the need for multiple methods,
tools, and entities for triangulation, the lack of controls; and the complications of
context and temporal dynamics. However, case studies have become theory-based,
rigorous and more objective, if the case study design considers three important
elements of case studies: it must define the unit of analysis; select the appropriate
cases to study, and decide on what data to collect and how to collect it (Johnston et
al., 1999).

According to Naoum (1998) the case study designs can be divided into three types as
follows:

- The descriptive case study, which is similar to the concept of the descriptive
  survey (i.e. counting), except it is applied to a detailed cases;
- The analytical case study, which is similar to the concept of the analytical
  survey (i.e. counting, association and relationship), except it is applied to a
detailed cases; and
- The explanatory case study, which is the theoretical approach to the problem.
  It explains causality and tries to show linkages among the objects of the
  study. It also asks why things happen the way they do. In other words, the
  researcher collects facts and studies the relationship between them.

2.3.2.2 Action Research

Action research is an amalgamation of both action (change, improvement) and
research (understanding, knowledge). Furthermore, action research intends not only
to help determine some of the practical concerns of the people, or clients, who are
trying to deal with a problematic situation but also to contribute to existing
knowledge. The main aim to do the action research is to contribute both to the
practical concerns of people in immediate problematic situations and to the goals of
social science by joint collaboration within a mutually acceptable ethical framework.
Blumberg et al. (2005) comments that there are four main characteristics of action research:

- Address real-life problems and is bounded by the context
- Collaborative venture of researchers, participants and practitioners;
- Continuing reflecting process of research and action; and
- The credibility and validity of action research are measured on whether the actions solve the problems and realise the desired change.

The key advantages of using action research include: it provides an experience for researchers who want to work closely with the practitioner community; it can be used in many research modes, both to generate a new theory and to reinforce or contradict an existing theory; and it can be combined with other research methods in order to diversify a research project (Abdullah, 2003). Blumberg et al. (2005) stated that, the key weakness of this method is that it cares less about general principles, although these can be the outcome of the project.

### 2.3.2.3 Grounded Theory

According to Leedy and Ormrod (2001), a grounded theory is a research method that attempts to construct a theoretical model by using multiple stages of data collection and the refinement of information. The main data collection methods for grounded theory are: interviews, observations, documents, historical records, videotape, and anything else of potential relevance to the research question. McKenzie et al. (1998) asserts that, grounded theory has become popular in social research, because it enables processes to be explored systematically and does not require large sample sizes. It is also considered appropriate when there is no existing theory or where existing theory is too remote or abstract to give guidance (MacPherson et al., 1993). Strauss and Corbin (1998), stated that, through this method, the researcher develops theories to explain his/her own observations, which are grounded in the data collected, also under the method, data collection, analysis and theory stand in reciprocal relationship with each other.
2.3.2.4 Ethnographic Research

An ethnographic research is "a description and interpretation of a cultural or social group or system" (Creswell, 1998). According to Alasuutari (1998), ethnographic research is a study of an intact cultural group over a prolonged period of time by collecting primarily observational data. Leedy and Ormrod (2001) asserts that the ethnographic research focuses on the investigation of the everyday behaviours (e.g. interactions, language, rituals) of the people in the group, with an intent to identify cultural norms, belief, social structures, and other cultural patterns. In ethnographic research, the process of data collection involves a group of people through participant observation or through one-to-one interviews with members of the group and is based on site-based fieldwork. The researcher studies the meanings of behaviour, language, and interactions of the culture-sharing group for a lengthy period of time.

2.3.2.5 Phenomenological Study

Leedy and Ormrod (2001) defined phenomenological study "is a study that attempts to understand people’s perceptions, perspectives, and understandings of a particular situation". According to Creswell (1998), phenomenological study is a research method in which human experiences are examined by doing detailed descriptions of the people being studied. An investigation of a particular phenomenon is the main focus of this method as it is typically lived and perceived by human beings. The goal of a phenomenological study is to better understand the essential, invariant structure (or essence) of the experience, recognising that a single unifying meaning of the experience exists (Creswell, 1998). Unstructured interviews are almost exclusively used for the purpose of the data collection method and typical sampling is from 5 to 25 individuals (Leedy and Ormrod, 2001).
2.3.3 Triangulation

Triangulation is the combination of approaches in the study of the identical phenomenon (Amaratunga et al., 2002). Furthermore, triangulation is a means of representation based on the logic in moving closer to obtaining a truer picture by making multiple measurements, using multiple methods, or at multiple levels of analysis (Love et al., 2002). Typically, the triangulation process involves corroborating evidence from different sources to shed light on a theme or perspectives (Creswell, 1998). Fellows and Liu (1999) asserts as triangulated studies employ two or more research techniques, qualitative and quantitative approaches may be employed to reduce or eliminate disadvantages of each individual approach whilst gaining the advantages of each, and of the combination as illustrated in Figure 2.4. Quantitative data can help with the qualitative side of a study during design by finding a representative sample and locating deviant samples, while qualitative data can help the quantitative side of the study during design by aiding with conceptual development and instrumentation (Amaratunga et al., 2002).

According to Esterby-Smith et al. (2002), there are four distinct categories of triangulation involving the theoretical, data, investigator and methodology triangulation as follows:

- **Theoretical triangulation** involves borrowing models from one discipline and using them to explain situations in another discipline;
- **Data triangulation** refers to research where data is collected over different time frames or from different sources;
- **Investigator triangulation** is where different people collect data on the same situation, and the results are then compared; and
- **Methodological triangulation** using both quantitative as well as qualitative methods of data collection such as questionnaires, interviews, telephone survey, and field study.

There are two main advantages of combining qualitative and quantitative research approaches highlighted by (Love et al., 2002) includes: (1) it increases the capability
to transmit the knowledge in a tangible form; and (2) convergent findings can provide greater researcher confidence in the reliability and/or validity of results, whereas divergence can lead to greater definition and theoretical elaboration as the researcher attempt to put together the many pieces of a complex puzzle into a coherent picture. Moreover, Abdullah (2003) suggests that triangulation methods may lead to a better understanding of the phenomena under investigation, when additional information may be revealed that would otherwise remain undiscovered via a single methodological approach. For example, using a qualitative methods such as semi-structured interviews and/or case studies provide a better understanding of the same study and combining it with quantitative method such as questionnaire survey can provide a broader idea on the subject studied.

![Figure 2.4: Triangulation of Quantitative and Qualitative Data (source: Fellow and Liu, 1999)](source: Fellow and Liu, 1999)

However, there may be problems in implementing triangulation methods in any research (Yin, 2003). First, the collection of data from multiple sources can be more expensive than if data were collected from only a single source. Second, each investigator needs to know how to carry out the full variety of data collection techniques. If any research technique is used improperly, the opportunity to address a broader array of issues or to establish converging lines of inquiry may be lost. The
distinguish characteristics of quantitative and qualitative research methods including their main strengths and weakness can be summarised in Table 2.2.

Table 2.2: Distinguishing Characteristics of Quantitative and Qualitative Research Methods (adapted from Leedy and Ormrod, 2001; Amaratunga et al., 2002; Abdullah, 2003; Neuman, 2006)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Qualitative Research</th>
<th>Quantitative Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>• To describe and explain</td>
<td>• To explain and predict</td>
</tr>
<tr>
<td></td>
<td>• To explore and interpret</td>
<td>• To confirm and validate</td>
</tr>
<tr>
<td></td>
<td>• To build theory</td>
<td>• To test theory</td>
</tr>
<tr>
<td>Objective</td>
<td>• Study issues in-depth and detail and seeks to gain insight and understand people’s perceptions</td>
<td>• Gather factual data and study relationships between facts and relationships in accordance with theory</td>
</tr>
<tr>
<td>Theory</td>
<td>• Theory can be causal or non-causal and is often inductive-concerned with development of theory from specific instances</td>
<td>• Theory is largely causal and is deductive-associated with verification of theory and hypothesis testing</td>
</tr>
<tr>
<td>Process</td>
<td>• Holistic</td>
<td>• Focused</td>
</tr>
<tr>
<td></td>
<td>• Unknown variables</td>
<td>• Known variables</td>
</tr>
<tr>
<td></td>
<td>• Flexible guidelines</td>
<td>• Established guidelines</td>
</tr>
<tr>
<td></td>
<td>• Emergent design</td>
<td>• Statistic design</td>
</tr>
<tr>
<td></td>
<td>• Context-bound</td>
<td>• Context free</td>
</tr>
<tr>
<td></td>
<td>• Personal view</td>
<td>• Detached view</td>
</tr>
<tr>
<td>Research Procedures</td>
<td>• Research procedures are particular, and replication is very rare</td>
<td>• Procedures are standard, and replication is frequent</td>
</tr>
<tr>
<td>Data Collection</td>
<td>• Informative, small sample</td>
<td>• Representative, large sample</td>
</tr>
<tr>
<td></td>
<td>• Observations, interviews, documents</td>
<td>• Standardized instruments – questionnaires, laboratory experiments, etc.</td>
</tr>
<tr>
<td>Data Characteristics</td>
<td>• Soft data, descriptive, less structures, analysed using non-statistical methods</td>
<td>• Hard data, structured, large sample size, analysed using statistical methods</td>
</tr>
<tr>
<td>Data Analysis</td>
<td>• Analysis proceeds by extracting themes or generalisations from evidence and organising data to present a coherent, consistent picture.</td>
<td>• Analysis proceed by using statistics, tables or charts and discussing how they show relates to hypothesis</td>
</tr>
<tr>
<td>Reporting Findings</td>
<td>• Words</td>
<td>• Numbers</td>
</tr>
<tr>
<td></td>
<td>• Narrative, individual quotes</td>
<td>• Statistics, aggregated data</td>
</tr>
<tr>
<td></td>
<td>• Personal voices, literary style</td>
<td>• Formal voice, scientific style</td>
</tr>
<tr>
<td>Outcome</td>
<td>• Exploratory and/or investigate and findings are contextual</td>
<td>• Conclusive findings used to recommend a course of action</td>
</tr>
<tr>
<td>Strengths</td>
<td>• Data gathering methods seen as natural than artificial</td>
<td>• Provide wide coverage of the range of situations</td>
</tr>
<tr>
<td></td>
<td>• Ability to look at change process over time</td>
<td>• Fast and economical</td>
</tr>
<tr>
<td></td>
<td>• Ability to understand people’s meaning</td>
<td>• Where statistics are generated from large samples, they may be considerable relevance to policy decisions</td>
</tr>
<tr>
<td></td>
<td>• Contribute to theory generation</td>
<td>• Data collection can be tedious and require more resources</td>
</tr>
<tr>
<td>Weaknesses</td>
<td>• Data collection can be tedious and require more resources</td>
<td>• Tend to be rather inflexible and artificial</td>
</tr>
<tr>
<td></td>
<td>• Analysis and interpretation of data may be more difficult</td>
<td>• Not very effective in understanding process</td>
</tr>
<tr>
<td></td>
<td>• Harder to control the pace, progress and end-points of research process</td>
<td>• Not very helpful in generating theories</td>
</tr>
</tbody>
</table>
2.4 Research Strategy Decision

A decision on a suitable research strategy to be adopted for a certain research project is essential to produce good quality research products. However, many researchers struggle with the difficult question of how to choose an appropriate methodology for the research problem they are attempting to investigate (Walker, 1997). According to Yin (2003), research strategy should be chosen as a function of the research situation. It is dependant on three conditions: the type of research question; the control that the investigator has over actual behavioural events; and the focus on contemporary as opposed to historical phenomena. Table 2.3 shows these three conditions and show how each is related to the five most common research strategies.

Table 2.3: Relevant Situation for Different Research Strategies (source: Yin, 2003)

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Form of Research Question</th>
<th>Requires Control of Behavioural Events</th>
<th>Focuses on Contemporary Events?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment</td>
<td>How, Why?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Archival analysis</td>
<td>Who, What, Where, How Many, How Much?</td>
<td>No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>History</td>
<td>How, Why?</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Case study</td>
<td>How, Why?</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The choice of research strategy is affected by consideration of the scope and depth required (Fellows and Liu, 1999). Figure 2.5, show the choice between a broad, but shallow study at one extreme and a narrow and deep study at the other, or an intermediate position.

![Figure 2.5: Breadth and Depth in 'Question-based' Studies](source: Fellow and Liu, 2003)
Leedy and Ormrod (2001) assert that, in planning the research strategy, it is extremely important for the researcher not only to choose a viable research approach, but also to consider the kinds of data an investigation of the problem will require and feasible means of collecting this data. The guide for developing any research methodology is that it must completely address the research questions (Creswell, 1994). To meet these objectives, a research study should have a detailed research design for collecting observations and data that are connected to the research objectives.

2.4.1 Selection of Research Methodology

The aim of this research project is to develop mechanism to improve materials management on construction projects through the integration of materials tracking and resource modelling system. For the purpose of this research, the selection of the research methodology adopted as depicted in Figure 2.6.

![Figure 2.6: Selection of Research Methodology](image)

The position of the research paradigm for this research is epistemological philosophy and this study favours more towards interpretivism (qualitative approach). This approach is used to gain an insight into people's perception and understanding of materials management issues in detail. The nature of this study intends to explore the explanation of the perceptions of the construction industry in the materials management processes and the implementation of ICT into their practices of
managing materials on site. A case study approach is adopted in this research because it afforded an opportunity to investigate and to achieve deeper insights into the areas examined. According to Johnston et al., (1999), the case study approach consists of a detailed investigation that attempts to provide an analysis of the context and processes involved in the phenomenon under study.

Laboratory and field experiments are excluded from this research, as the detailed information required will mainly be based on personal experience, which can be obtained by case studies without setting up laboratory for experiments. The research techniques used for data collections are involved literature review, interviews and questionnaire. The interview was mainly used for collecting data for the case study approach, and the questionnaires have been used to gain the information of the functionality and appropriateness for the evaluation of the prototype system developed.

2.4.2 Selection of Multiple Case Studies and Interview Techniques

The selection of the multiple case studies and interview techniques adopted for this research are discussed in the following section.

2.4.2.1 Multiple Case Studies

Blumberg et al., (2005) classified case study research in to two main types: single and multiple case studies. According to Yin (2003), there are four types of case study: single-case (holistic) designs (Type 1), single-case (embedded) designs (Type 2), multiple-case (holistic) designs (Type 3), and multiple-case (embedded) designs (Type 4). Type 4 – the multiple-case (embedded) approach has been chosen for this research in order to make a comparison of the materials management practices between case studies. The multiple case studies involved six construction projects as the unit of the analysis with five embedded unit of analysis for each of the six construction projects (refer section 2.5.2). According to Perry (1998), the ideal number of multiple-case studies is between four and ten cases. The basic types of the case study designs as depicted in Figure 2.7
Yin (2003) also developed a three stage process to help guide case study research, in order to conduct a systematic case study approach as shown in Figure 2.8. These processes include a define and design stage; a prepare, collect and an analysis stage; and an analysis and conclusion stage. The stages involved with the theory development then shows the case selection (under define and design stage), conducted every case study and produced individual case report (under prepare, collect and analysis stage), and provided a cross-case report for analysis and the conclusion stage.

Figure 2.8: Case Study Method (source: Yin, 2003)
An essential factor to undertake the case study research is a case study protocol. The case study protocol is important to increase the reliability of case study research and give the investigator some guidelines in carrying out the case study. This is because, one of the problems with case study research is its inherent “looseness”. According to Yin (2003), one way to combat this looseness is to establish a protocol that outlines the procedures and general rules that will be used during data collection. The procedures provide the steps such as: an overview of the project, definitive data collection procedures, and the instruments that will be used for data collection. Johnston et al., (1999) stated that, when developing a case study protocol, there are four important considerations:

- **Defining the unit of analysis**: One of the major problems in designing a case study is defining the units of analysis to be used during the research. Choosing the unit of analysis pushes the researcher to articulate the conceptual frame of reference and encourages proposition development. McClintock et al. (1997) write; "Although the units of analysis are typically defined as individuals, groups, or organisation, they could almost be any activity, process, feature, or dimension of organisational behaviour."

- **Case selection**: Whilst a single-case study needs only to focus on one case, in multiple-case studies, cases should be selected so that they are replicating each other; either direct replications or predictably systematic replications. Using single-case design, the investigator should be prepared to make an extremely strong argument in justifying the choice for the case. In contrast, analytical conclusions independently arising from multiple-case study will be more powerful than those coming from a single case alone.

- **Data collection**: A systematic plan must be developed that stipulates what information is to be sought to fully investigate the research hypotheses and how this is to be obtained. Yin (2003) asserts the use of a ‘study protocol’ which systematically documents all decisions pertaining the research design, and includes the set of substantive questions reflecting the actual inquiry.

- **Data analysis**: The analysis of each case study research represents assessing whether or not the evidence within each case is internally valid, supportive
of the pre-specified hypotheses across the multiple cases, and conclusive. The study preferred strategy, which have shaped the data collection.

2.4.2.2 Interview Techniques

An interview technique was used for data collection for this research. The interview involves the interaction between two people in order to discover opinions and specific information, and can be divided into two approaches: face-to-face interviews and telephone interviews. A face-to-face interview approach is a two-way conversation initiated by an interviewer to obtain information from a participant. According to Blumberg et al., (2005), the main strength of this approach is that the interviewer can pre-screen respondents to ensure he/she fits the population profile; and the weakness of this approach is that it is too costly (both in time and money). A telephone interview approach is helpful in arranging personal interviews and screening large populations for unusual types of participants (Blumberg et al., 2005). The main advantages of this approach are that it is less time consuming and less expensive. The key weakness is that the response rate is lower than for comparable face-to-face interviews.

There are three categories of interviews: structured interviews, semi-structured interviews and unstructured interviews (Neuman, 2006; Fellow and Liu, 1999). In a structured interview, the interviewer administers a questionnaire by asking questions and recording the responses, and asking supplementary questions to obtain more details and to pursue new and interesting aspects with only little scope for probing those responses. The research may follow the standard questions with one or more individually tailored questions to get clarification or to probe a person reasoning, under semi-structured interviews category. In unstructured interviews, the interviewer introduces the topic briefly and records all the respondent’s responses (Leedy and Ormrod, 1999). Table 2.4 summarises the main differences between, structured, semi-structured and un-structured interviews.
Table 2.4: Comparison of Interview Techniques (source: Wright and Ayton, 1987)

<table>
<thead>
<tr>
<th>Category</th>
<th>Process</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structured Interview</td>
<td>• Questions are set in advance</td>
<td>• Quick and easy to answer</td>
<td>• Inflexible</td>
</tr>
<tr>
<td></td>
<td>• Each interview is conducted in exactly the same way</td>
<td>• Answers are easy to code and analyse</td>
<td>• Participants may be forced into giving responses which do not reflect their true feelings about an issue</td>
</tr>
<tr>
<td></td>
<td>• The question and their order are the same for all respondents</td>
<td>• The direction of the inquire is clear</td>
<td>• Gathers a limited amount of information: lack the richness obtained by more open-ended interviews</td>
</tr>
<tr>
<td></td>
<td>• The range of possible responses is determined by the researcher</td>
<td>• High degree of reliability – straightforward ‘factual’ information</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Products ‘comparable’ data</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Reduced possibility of interviewer bias</td>
<td></td>
</tr>
<tr>
<td>Semi-structured Interview</td>
<td>• Very much like questionnaire</td>
<td>• Less intrusive to those being interviewed as the semi-structured interview encourages two-way communication</td>
<td>• Requires interviewing skill</td>
</tr>
<tr>
<td></td>
<td>• Open-ended questions</td>
<td>• Confirms what is already known but also provides the opportunity to learning</td>
<td>• Need to meet sufficient people in order to make general comparisons</td>
</tr>
<tr>
<td></td>
<td>• Permissible to stray from the subject area and ask supplementary questions</td>
<td>• Gives the freedom to explore general views or opinions in more details</td>
<td>• Time consuming and resource intensive</td>
</tr>
<tr>
<td></td>
<td>• They can be used both to give and receive information</td>
<td></td>
<td>• Preparation must be carefully planned so as not to make the questions prescriptive or leading</td>
</tr>
<tr>
<td>Unstructured Interview</td>
<td>• Exploratory approach</td>
<td>• Allows flexibility</td>
<td>• Requires interviewing skill</td>
</tr>
<tr>
<td></td>
<td>• No prepared list of questions</td>
<td>• Respondents can answer in their own word</td>
<td>lack of standardisation</td>
</tr>
<tr>
<td></td>
<td>• Open-ended questions</td>
<td>• The nature of the response is not limited</td>
<td>• The answers are difficult to analyses</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The result of this more open-ended approach is a richness of data</td>
<td>• Depends on the ability respondents to express themselves</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• More complex and sensitive questions possible</td>
<td>• Time consuming</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Largest potential for interviewer bias</td>
</tr>
</tbody>
</table>

The following section discusses the methodologies adopted in detail for the research in order to achieve the aim and specific research objectives.
2.5 The Methods Adopted for this Research

The research process was designed to pursue the aim of this research, which is to develop a mechanism to improve materials management on construction projects through the integration of materials tracking and resource modelling. In achieving this aim, five research objectives as stated in Chapter 1 in section 1.3 were formulated. In order to achieve the aim and objectives of this research, the overall research process was developed as illustrated in Figure 2.9. Firstly, a literature search was made to review materials management practices and ICT implementation on construction projects. The multiple case studies approach was used to review current practices on materials management and ICT implementation. The integration requirements for materials management and resource modelling were also investigated. The next stage of the research process by developing rapid prototyping with first develop a framework for real-time materials tracking and encapsulated the framework into a prototype system. The formative and summative evaluation was used to determine the appropriateness and functionality of the developed prototype system with conducted interviews with project manager or site manager.

Figure 2.9: Overall Research Process
Brief descriptions of the research methodology used in this research were presented in Chapter 1, Section 1.4, and the following section provides further details of these methods.

2.5.1 Literature Review

Neuman (2006) stated that the systematic literature search has five main processes, including: define and refine the search; design a search; locate research reports; evaluating research articles, and taking notes. The review of the current literature is a crucial part of every research project (Blumberg et al., 2005). Sekaran (1984) asserts that, the purpose to undertake a literature review is to ensure that no important variables are ignored that has in the past been found repeatedly to have anon the problems. Therefore, the literature should not simply be found and reviewed, but it is important that the body of relevant literature from previous research should also be reviewed critically (Fellows and Liu, 1999).

For this research, the literature review was conducted for searching the existing literature on materials management on construction projects. It also reviewed the implementation of ICT and emerging technologies to support materials management practices in construction projects especially for complex projects. This is to fulfil the first research objective as proposed by this research that was explained in Chapter 1, section 1.3. Full-text publications of theoretical and empirical studies for representing the original works, can be classified as primary sources. On the other hand, secondary sources are compilations of information, either in printed or digital form.

The search for relevant literature was carried out through the Loughborough University Library (to search books, refereed journals, and doctoral dissertation), Loughborough University Metalib (an integrated search engine that facilitates search across different databases and electronic journals), Internet search engines such as Google Scholar, conference proceedings and company reports. After the related literature was found, the next step was to undertake the literature review (either previous or current issues).
To achieve the first objective of the research, two main topics were selected for review as illustrated in Figure 2.9:

- To identify problems and which aspects of the materials management practices could be improved;
- To consider the implementation of ICT and emerging technologies in supporting materials management practices, focussing on establishing the most viable emerging technologies (such as RFID) for use in materials management practices on construction projects.

The literature review is a continuous process, and will be carried out simultaneously with the case study, prototype development and evaluation stages to capture new issues and gaps in the existing literature. Other topics relating to the research, such as the research methodology and the prototype system development process were also reviewed.

2.5.2 Case Studies

The case study approach was adopted for carrying out the second and third research objectives in this study. Case studies were undertaken to review the current industrial practice in materials management to establish key problem areas and elements of good practice. They were also essential in identifying how ICT is being used to facilitate materials management processes, and how these could improve problems in inventory management on site. This is to fulfil the second and third research objectives identified by this research. This involved investigating the current practices of materials management and ICT implementation, and also to establish the integration requirement of materials tracking and resource modelling systems.

Through this study, the multiple-case studies approach has been used in order to investigate a contemporary phenomenon within six construction projects. This involved the comparison between six construction projects of materials management practices, to establish key problem areas and elements of good practices and to identify how ICT is being used to facilitate materials management processes, and
how these could improve problems in the inventory management on site. There were also used to investigate the requirements for integrating materials management and resource modelling for developing a real-time materials tracking system. The main advantage of case studies compared to other approaches is that they allow the combination of different sources.

The description of the case study protocols used in this research is as follows:

- **Defining the unit of analysis:** The selection of the 'unit of analysis' is geared towards achieving the study objective, which is to investigate the potential for improving materials management practices through the integration of materials tracking and resource modelling system. Through this study, the unit of analysis is base on each of the construction project. The “embedded unit of analysis” adopted are as follows:
  
  o **Materials management problems:** This explores the most significant problems that occurs with materials management practices;
  
  o **Approaches to addressing problems:** This aims to identify strategies used by site managers to solve materials management problems on the construction site;
  
  o **ICT implementation:** This aims to identify the use of ICT in managing materials on the construction site;
  
  o **Use of emerging technologies:** This investigates the potential of the emerging technologies to facilitate materials management practices; and
  
  o **Materials tracking systems:** This seeks to identify current methods used by site managers to facilitate materials tracking on the construction site.

- **Case selection:** According to Creswell (1994), a “case” is defined by the setting of the project, the people who manage the project, the events that occur, and the processes that develop over the project. This research focused on the integration of materials tracking and resource modelling systems, therefore, the selected “case” was small and large construction project used for the case study. The identification of construction organisations focuses on large and small projects, which attempted to implement new technologies (such as RFID) for real-time
Chapter 2: Research Design and Methodology

The six construction projects were selected based on the following criteria:

- Complexity of the materials management (e.g. logistics) on small and large projects; and
- Adequate access to explore the relevant materials management issues to be investigated.

There is also the willingness of organisation’s individuals to participate and share their experience in managing materials on the construction site.

- **Data collection**: Semi-structured interviews have been used for data collection to interview with project manager or site manager in each of the projects. A set of questions were designed as a tool for semi-structured interviews conducted to gain opinions and responses from project managers or site managers about current problems and which aspects needed to be improved in materials management on construction projects. The questions were organised under broad headings including: key problems in materials management practices; approach to addressing problems; ICT implementation, emerging technologies; and materials tracking systems. Interviews lasted from two to four hours, which included an interview session, site visit and demonstration of current management system on materials management. Data collected from interviews were recorded on tape and were transcribed verbatim.

- **Data analysis**: This was concerned with gathering information and analysing data on the problems on current practices of materials management, current approaches to addressing problems, ICT implementation, the use of emerging technologies, and current materials tracking systems. The results can be used to support the development of real-time materials tracking framework through the integration of materials tracking and resource modelling systems. The findings from each interview will be described in detail in Chapter 4.

The data collected was primarily from semi-structured interviews with the project managers or site managers of the construction organisations. The semi-structured interviews consisted of a set of questions designed to facilitate opinions and responses from project managers or site managers regarding current problems, and
aspects of materials management practices that required improvement. Current implementation of ICT in materials management practices on construction projects was also investigated. The interviews included an interview session of two to four hours, a site visit and a demonstration of the current materials management system used. Selecting the semi-structured interviews allowed the interviewer freedom to explore the expert's views or opinions while maintaining a level of comparability between interviewees.

The semi-structured interviews contained of three parts. Part 1 aimed to capture general information about the site managers such as role of site managers, type of project and experience involved in construction project management. Part 2 aimed to look at current problems and ICT implementation of materials management practices and Part 3 aimed to investigate the integration requirement for materials management and resource modelling. Key findings from the case studies were essentially used in order to make a judgement of the problems, improve aspects of materials management practices and to identify the approach in solving the problems. Moreover, from the finding, this study attempts to identify the potential use of RFID for materials tracking and the integration requirement with resource modelling in the project management system. Chapter 4 describes the findings from each interview in detail.

2.5.3 Rapid Prototyping

Developing a prototype system for integrating materials management and resource modelling is to fulfil the fourth objective of the research. Initially, the development of framework for integrating RFID-based materials management with resource modelling in project management systems was undertaken. The integration framework achieved through case study findings and supported by extensive literature review on materials management processes and ICT implementation to facilitate materials management on construction projects. The case studies have helped to identify aspects of ICT implementation in materials management practices. The organisations have a variety of mechanisms for managing materials on the construction projects. Nonetheless, the site managers have difficulties with regards to
resolving materials management problems on the current practices. The key findings from case studies are as follows:

- Inadequate techniques to overcome human error such as double handling and paper-based report of materials tracking on construction projects; and
- Inadequate use of modern ICT tools such as RFID to assist with an automatic identification of materials tracking.

The integrated framework consists of five components:

- **Materials Delivery**: Automatic identification of materials tracking using RFID technologies and integrating with resource modelling in project management system during materials delivery to the construction site;
- **Materials Storage**: RFID-based materials tracking for automatic identification of materials and integrating with resource modelling in project management system at the storage area;
- **Materials Use**: Automatic identification of materials during installation at the construction site and integration with resource modelling in project management system;
- **On-site Control Centre**: Gathering and analysing real-time materials tracking data (materials delivery, materials storage and materials use) in the database at site office; and
- **Report Transmission**: Sending the real-time materials tracking reports from the site office to the main office.

The framework provides a structured approach to managing real-time materials tracking process in the construction site. The integrated include the integration of RFID technologies to provide real-time materials tracking and resource modelling in project management system. Chapter 5 provides detail discussion of the real-time materials tracking framework for this research.

The automation and implementation of the framework was the next stage in the development of the prototype system. Specifically, the intention was to encapsulate
the developed real-time materials tracking framework into a prototype system. Prototyping is a process of building an experimental system quickly and inexpensively for demonstration and evaluation so that the users can better determine information requirements (Laudon and Laudon, 2002). The aim of developing prototype in this research is to integrate of RFID-based materials management and resource modelling in project management systems (such as MS Project). A rapid prototyping methodology was used in the developing of the prototype system. According to Turban and Aronson (1998), the key strength of the prototyping include: short development time; short user reaction time (feedback from user); improved user understanding of the system, its information needs, and its capabilities, and low cost. Several iterations to refine and enhance the prototype can be done before completing with the final operation, because the prototype can be developed quickly and inexpensively. Nevertheless, prototyping can gloss over essential steps in systems development (Laudon and Laudon, 2002). If the completed prototype works reasonably well, management may not believe there is a need for reprogramming, redesign, or full documentation and testing to build a polished production system. The process of rapid prototyping is shown in Figure 2.10.

![Figure 2.10: Rapid Prototyping Process (source: Turban and Aronson, 1998)](image)

The process in developing the prototype system started with the selection of the software for integrating materials management and resource modelling for creating the development environment, designing the system architecture, and identifying the
software and hardware integration requirements. Next, several tests were carried out in order to examine all the functions that the developed prototype system could be operated appropriately based on the program code and detecting with RFID tags. Afterwards, the project managers or site managers were invited to participate in the evaluation session to gain professionals’ feedback regarding the effectiveness of the software. The refinement of the prototype system was based on the analysed feedback obtained from the professionals involved in the evaluation. The discussion of the overall development of the system’s operational framework is described in Chapter 5, and Chapter 6 described the development process of the prototype system.

2.5.4 Formative and Summative Evaluation

There are two types of evaluation research identified by Neuman (2006), there being formative and summative. Formative evaluation is built-in monitoring or continuous feedback on a program used for program management and capture during development of the systems. While, summative evaluation looks at final program outcomes and takes place after development of the system. Both are usually necessary to decide how well a program is working or reaching its aims and objectives. Table 2.5 shows the comparison between summative evaluation and formative evaluation.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Summative Evaluation</th>
<th>Formative Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>Determine effectiveness of human interventions and action</td>
<td>Improve an intervention</td>
</tr>
<tr>
<td>Focus</td>
<td>Goal of the interventions</td>
<td>Strength and weakness of the specific program</td>
</tr>
<tr>
<td>Desired Results</td>
<td>Judgements and generalisations about effectiveness types of interventions and the conditions under which those efforts are effective</td>
<td>Recommendations for improvements</td>
</tr>
<tr>
<td>Level of Generalisation</td>
<td>All interventions with similar goals</td>
<td>Limited to specific setting studies</td>
</tr>
</tbody>
</table>
An evaluation session was conducted to determine the appropriateness and functionality of the developed prototype system in improving materials management practices on the construction site. Five of the construction organisations who were willing to participate in the evaluation session undertook the evaluation sessions. The evaluation session consisted of three main elements. First, there was a short presentation on the background to the system's operational framework and prototype system. Then, a demonstration of the prototype system was carried out. Next, the participants were asked to complete a questionnaire, followed by open discussions to get further feedback and suggestions from the participants.

The prototype system was evaluated using questionnaire survey techniques: closed questions and open-ended questions. Closed questions limit the respondent's answer to the survey and allowed them only to choose either a pre-existing set of answers (i.e. yes/no, true/false), or rating scale response action (i.e. 1-strongly agree, 2-agree, 3-neutral, 4-disagree, 5-strongly disagree, or multiple choice with an option for 'other'. Neuman (2006) stated that, the main limitation of the close ended questionnaire technique is that the researcher cannot visually observe respondents' reactions to questions, physical characteristics, or the setting. Closed ended and open-ended questions give freedom to the respondents and encourage them to explain their answers and reactions to the question with a sentence, a paragraph, or even a page or more, depending on the survey. According to Fellows and Liu (1999), open-ended questions enable respondents to answer to whatever extent the respondent wishes. The designed survey questions were divided into three parts: Part A, Part B and Part C. Part A intended to obtain the information of the participants involved in the evaluations. Part B was aimed to assess the appropriateness and obtain comments for improving the prototype system. Part C of the questions is intended to assess the views of the respondents about the relevance requirements for the effective use of the prototype system. The discussion of the evaluation process of the prototype system is explained in Chapter 7.

The research methods adopted to achieve the research objectives are summarised in Table 2.6.
Table 2.6: Summary of Research Methods Used

<table>
<thead>
<tr>
<th>Research Objectives</th>
<th>Research Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Literature Review</td>
</tr>
<tr>
<td>(1) To review existing literature on materials management processes in construction projects.</td>
<td>X</td>
</tr>
<tr>
<td>(2) To review current industrial practice in materials management to establish key problem areas and elements of good practice.</td>
<td>X  X</td>
</tr>
<tr>
<td>(3) To establish the requirements for integrating materials management and resource modelling in project management systems (i.e. real-time materials tracking).</td>
<td>X  X</td>
</tr>
<tr>
<td>(4) To develop and evaluate a prototype system for integrating materials management and resource modelling.</td>
<td>X  X</td>
</tr>
<tr>
<td>(5) To investigate requirements necessary for effective use of the system, such as skills and knowledge requirements.</td>
<td></td>
</tr>
</tbody>
</table>

2.6 Summary

This chapter has discussed the research methods adopted and used in this study. It presented a nested approach to research design that highlighted the three key themes of research philosophy, research approaches and research techniques. Qualitative and quantitative research and combination of both approaches (triangulation) were discussed. The selection of research methodology adopted several approaches and is presented through four main sections: literature review; case studies; development of the prototype system; and evaluation of the prototype system. The next chapter focuses on materials management process and technologies implementation. It discusses current problems that often occur, the implementation of existing technologies, and the potential use of emerging technologies for automatic materials tracking.
CHAPTER 3
MATERIALS MANAGEMENT – PROCESSES AND TECHNOLOGIES

3.1 Introduction

This chapter reviews materials management practices on construction projects. Firstly, it describes the definition of materials management, managing construction materials and the process of materials management. Secondly, it discusses the current problems that often occur with materials management practices and the approaches to address these problems, followed by a discussion of the implementation of current technologies, advantages and the limitations. Finally, this chapter presents the implementation of RFID technologies into materials management, and also reviews the potential use of RFID into construction and others business applications. More emphasis is placed on the technology aspects, as these offer the greatest potential for improving materials management.

3.2 Materials Management

This section defines materials management and reviews materials management on construction projects.

3.2.1 Definition of Materials Management

Materials management is an important function in order to improve productivity in construction projects. According to Bell and Stukhart (1986) materials management functions include “material requirement planning and material take off, vendor evaluation and selection, purchasing, expenditure, shipping, material receiving,
warehousing and inventory, and material distribution”. This is concerned with the planning and controlling process to ensure that the right quality and quantity of materials and installed equipment are appropriately specified in a timely manner, obtained at reasonable cost and are available when needed.

Materials management involves the logistics of the materials components of a supply chain which involves the process of planning, implementing and controlling of the movement and storage of raw materials, work-in-process inventory, and finished goods from point-of-origin to point-of consumption. The management of materials should be considered from the phases of the construction process and throughout the construction period. Generally, construction materials are bulky, expensive and are supplied in large amounts to construction sites. Therefore, there is a need for an excellent management system for handling materials.

3.2.2 Materials Management on Construction Projects

The construction industry is the most significant industry in the economy and the successful measure with completion within time, budget, accordance with specification and satisfaction of stakeholders (Nguyen et al., 2004). Construction is the process of physically erecting the project and putting construction equipment, materials, supplies, supervision, and management necessary to accomplish the work (Clough et al., 2000). Construction projects are complex, with many organisations involved such as clients or owners, architects, engineers, contractors, suppliers and vendors. This includes the heterogeneous and often complex process of producing unique, large and immovable products with a supply of the resources (money, equipment, material, and labour).

The management of materials in construction projects is an important function that significantly contributes to the success of a project. As projects grow in scale and complexity, materials management becomes more difficult, often requiring the use of appropriate tools and techniques to ensure, amongst other things, that materials are delivered on time, stock levels are well managed, the construction schedule is not compromised, and that wastage is minimised. Materials management is especially
problematic for large and complex projects, where sophisticated tools and techniques are necessary. The management of materials in complex construction projects needs adequate consideration due to the various elements involved and the importance of the project. Furthermore, the implementation of appropriate Information and Communication Technologies (ICT) could facilitate new management processes for complex projects. For example, the potential of emerging technologies such as wireless technologies and tagging technologies could have a strong impact on materials management processes in the future.

The improper handling and management of materials on construction sites has the potential to severely hamper project performance (Ogunlana et al., 1996). The result of improper handling and managing materials on site during construction process will influence the total project cost, time and the quality (Che Wan Putra et al., 1999). The costs of materials management may range from 30-80% of the total construction costs depending on the type of construction (Muehlhausen, 1991). However, Kini (1999), accounted 50-60% of the total cost of construction projects is for construction materials and equipment. According to Stukhart (1995) materials are a major component on any project with value 50-60%. Therefore, there is a need for efficient materials management in construction projects. This is because poor materials management will affect the overall construction time, quality and budget. Therefore, an effective materials management system is required in order to avoid problems, such as delays in a construction project.

Delays in materials supply have been found to be a major cause of time overrun (Dey, 2000). Many factors accelerate the delay of project duration, however poor materials management can have a major effect on site activities. Ogunlana et al. (1996) suggested that the main reasons for project delays on housing projects in Thailand were incomplete drawings, material management problems, organisation deficiencies, shortage of construction materials, and inefficiencies in site workers. Dey (2000) also suggested that delays in materials supply was a major cause of time overrun. Thus, it would seem that materials delays are a major cause of delays in construction projects. There is also a need for an integrated material handling process from the design stage to the usage of materials. This could happen, with a good management system with the implementation of ICT in managing materials. Hence, a
good materials management environment enables proper materials handling on construction sites.

3.3 Materials Management Processes

Materials management processes involve the planning, procurement, handling, stock and waste control, and logistics surrounding materials on construction projects. A good materials management environment enables proper materials handling on construction sites. In order to better understand materials management the following processes are discussed: planning, procurement, logistics, handling, stock and waste control.

3.3.1 Planning

The process of planning construction methods has been defined as "understanding what has to be built, then establishing the right method, in the most economical way to meet the client's requirements" (Illingworth, 1993). This is a detailed scheme for achieving an objective for certain work tasks. In the case of materials, there is a need for an appropriate planning, which must be done concurrently with engineering, construction, and other project plans (Stukhart, 1995). Stukhart (1995) also mentioned material planning will provide guides for all the subsequent activities and can have a great impact on the project plan. The materials planning process covers setting up and maintaining the records of each part used in each plant to determine target inventory levels, and delivery frequency (Payne et al., 1996). As a result, an excellent management of the materials record will help the flow of materials at the site in order to avoid several problems such as materials out of stock and materials that have not been delivered.

Stukhart (1995) mentioned that material planning would provide guides to all the subsequent activities and that this could have a great impact on the project plan. The materials planning process covers the set up and maintenance of records and
determines the target inventory levels, and delivery frequency (Payne *et al.*, 1996). Planning of access and routing of materials within a construction site has an important implication for the development of an effective materials management strategy (Faniran *et al.*, 1998; Olusegun *et al.*, 1998) particularly in terms of increasing productivity and profit, and facilitating the timely completion of construction projects (Wong and Norman, 1997). The requirement for efficient materials planning is, to increase productivity and profit of the company, and facilitate the completion of construction projects (Wong and Norman, 1997). Thus, better planning of raw materials on site can help to eliminate project delays and reduces activity times, resulting in better service.

3.3.2 Procurement

The term procurement encompasses a wide range of activities that includes purchasing of equipment, materials, labour and services required for construction and implementation of a project (Barrie and Paulson, 1992). The objective of procurement in materials management is to provide quality materials at the right time and place, and at an agreed budget. Payne *et al.* (1996) stated that procurement is about organising the purchasing of materials and issuing delivery schedules to suppliers and following-up, to make sure that suppliers deliver on time. A failure in the purchasing process or in overseeing and organising the buying functions as listed by Canter (1993) could result in:

- Over-ordering of materials (wastage problems);
- Over-payments for materials (inadequate administration procedures);
- Loss of benefits (lack of skilled negotiating procedures); and
- Lack of knowledge (when and where the best service/source might be available at any particular time).

In order to avoid failure, it is important to know how the typical purchasing procedure takes place, and this is illustrated in Figure 3.1. Procurement of materials begins with defining the requirements of the project, followed by the selection of
suppliers or subcontractors, and ends with the delivery of materials at the destination (Kent, 1991). Purchasing materials from the best source, at the right price and with timely delivery are challenges of many construction companies. Therefore, a control strategy is needed during materials procurement to achieve the targeted objectives. All requests for quotations and purchases must be initiated through a properly authorised requisitioning procedure normally controlled by the Project Manager. The Project Manager must ensure that the purchasing of materials follows the standard requirement, time and quality.

![Tender Stage Diagram](source: Canter, 1993)

Figure 3.1: Typical Purchasing Procedure (source: Canter, 1993)
3.3.3 Logistics

Logistics is a concept that emphasises movement and it encompasses planning, implementing, and controlling the flow and storage of all goods from raw materials to the finished product to meet customer requirements (Stukhart, 1995). Raw materials for construction are usually varied, bulky and heavy and required proper handling in the supplying process. Consequently, the construction industry requires active movement of materials from the suppliers to the production area in both the factory and the worksite (Pheng and Chuan, 2001).

The primary focus of the logistics concept in construction projects is to improve coordination and communication between project participations during the design and construction phases, particularly in the materials flow control process (Agapiou et al., 1998). They also mentioned that problems arise in the materials flow control process which includes delays of materials supply, due to some materials purchased just before they are required and waste of materials during storage, handling and transporting when procured in large quantities without complying with the production needs on site. The previous research suggested that, the routing of materials is one of the main causes which affect cost and time during construction projects (Varghese and O'Connor, 1995). Hence, the factors that should be taken into consideration during the logistics process for effective materials management include:

- optimum forecasting of materials movement (Mahdjoubi and Yang, 2001);

and

- planning of access and routing of material within a construction site (Olusegun et al., 1998).
3.3.4 Handling

Tompkins and White (1984) define effective material handling as using the right method in providing the right amount of the right material, at the right place, time, sequence, position, condition, and cost. This involves handling, storing, and controlling of the construction materials. Therefore, materials handling provides movement to ensure that materials are located and that a systematic approach is required in designing the system. Handling of materials is the flow component that provides for their movement and placement. The importance of appropriate handling of materials is highlighted by the fact that they are expensive and engage critical decisions. Due to the frequency of handling materials there are quality considerations when designing a materials handling system. The selection of the material handling equipment is an important function as it can enhance the production process, provide effective utilisation of manpower, increase production and improve system flexibility (Chan, 2002).

The importance of appropriate handling of materials is highlighted by the fact that there are expensive and engages critical decisions. Estimated costs for materials handling may range from 30-80% (Proverbs et al., 1999) and 10-80% depending on the type of facility (Tompkins and White, 1984) from total construction costs. Because of the percentage amounts, there are certain quality considerations in designing materials handling systems. The materials handling equipment selection is an important function in the design of a material handling system in order to enhance the production process, provide effective utilisation of manpower, increase production, and improve system flexibility (Chan, 2002). In addition, materials scheduling is also an essential part of handling material on site, which has several benefits (Che Wan Putra et al., 1999) such as:

- showing the quantities involved in each particular operation;
- providing a key to the distribution of materials on site; and
- demonstrating useful way of checking quantities required by sub-contractor, etc.
Materials must be delivered to site undamaged and without any wastage. Most common problems associated with materials supply is inadequate unloading and handling facilities, which attribute a high proportion of wastage (Canter, 1993). Therefore, handling with safety during movement of materials at site, which reduce the percentage of materials wastage and finally foster significant improvement can often the total system productivity.

3.3.5 Stock and Waste Control

The European Construction Institute’s Total Productivity Management report (ECI, 1994) states that “materials delivery to site is a critical, productivity-related aspect which demands the introduction of a carefully developed system of monitoring and control as early as possible”. Delivery of the bulk of the construction materials requires proper management of the stock control. Stock control is a technique to ensure all items such as raw materials, processed materials, components for assembly, consumable stores, general stores, maintenance materials and spares, work in progress and finished products are available when required (Prabu and Baker, 1986).

Construction activity can generate an enormous amount of waste (Teo and Loosemore, 2001) and materials waste has been recognised as a major problem in the construction industry (Formoso et al., 2002). There are also mentioned that construction materials waste, in the USA contributes approximately 29%. In the UK it contributes more than 50% and in Australia it contributes 20-30%. This is evidence to control constructions materials in a good way during the construction process. The cause of waste in construction projects indicates that waste can arise at any stage of the construction process from inception, right through the design, construction and operation of the built facility (Faniran and Caban, 1998). Therefore, waste can be reduced through the careful consideration of the need for minimisation and better reuse of materials in both the design and construction phases (Dainty and Brooke, 2004).
Material storage on site requires close attention in order to avoid waste, loss and any damage of materials which would affect the operations on the construction project. Problems often arise during materials supply because of improper storage and protection facilities (Canter, 1993). Previous studies have identified that building materials often require a large storage capacity which is rarely available on site (Agapiou et al., 1998). However, Stukhart (1995) suggested that there are a few considerations to be taken into account in the planning of the storage space such as timing of the initial buy, and historical information and experience. Materials management on site should seek to reduce loss of profit due to theft, damage and wastage, as well as running out of stock. Therefore, the requirements of storing space should be taken into consideration from the initial stage of the construction process.

3.4 Materials Management Problems

There are many issues which contribute to poor materials management in construction projects. Zakeri et al. (1996) suggested that waste, transport difficulties, improper handling on site, misuse of the specification, lack of a proper work plan, inappropriate materials delivery and excessive paperwork all adversely affect materials management. Shortage of materials contributes to the cause of delay in managing materials in the construction site (Mansfield et al., 1994; Ogunlana et al., 1996; Abdul-Rahman et al.; 2006; Aibinu and Odeyinka, 2006). Late delivery of ordered materials is also problematic in materials management. Furthermore, Dey (2001) noted that the common issues relating to materials management are as follows:

- Receiving materials before they are required, causing more inventory cost and chances of deterioration in quality;
- Not receiving materials at the time of requirement, causing loss of productivity;
- Incorrect materials take-off from drawings and design documents;
- Subsequent design changes;
- Damage/loss of items;
• Selection of type of contract for specific materials procurement;
• Vendor evaluation criteria;
• Piling up of inventory and controlling of the same; and
• Management of surplus materials.

The traditional construction methods apply paper-based work during the construction process. This can produce excessive paperwork and contributes poor materials management in construction projects (Zakeri et al., 1996). There is also give problematic, error-prone and inefficient in the recording and exchanging information of materials component within a supply chain. The implementation of ICT can help the management of construction activities to become more effective and faster. The emergence of ICT systems could transform conventional methods and improve materials management. The use of ICT has also increased with new software related to the construction industry and can support the effective management of materials practices. Therefore, the ICT-enabled solution could help in order to overcome the problems. For example, improving materials supply management through an intelligent system to facilitate bidding, requisition and ordering of materials.

3.5 Technologies in Materials Management

The development of ICT in the construction industry can transfer information much faster globally than traditional methods. According to Björk (1997) that ICT as electronic machines and programs including computers and the software, other devices like the telephone, the photocopying machine and the telefax for processing, storage, transfer and presentation of information. Information delivery has traditionally been dominated by paper documents such as drawings and specifications.

The growth of ICT has been very rapid in other areas of business (such as publications, advertisement and manufacturing) to expand their business operations globally. In the construction industry, the development of ICT has improved through emerging technologies that can support any type of construction activities. Griffith et


al., (2000) stated that, there are great opportunities if construction organisations can spend their money on technology advancement in information and telecommunication. There are could also expand in ICT usage by powerful computer and better connectivity provided into construction industry (Sun and Howard, 2004). New information technologies could also improve materials management are develop and varies in construction industry.

3.5.1 Current Technologies

The implementation of ICT in materials management could facilitate the effective and efficient control of materials on site. Common use of ICT in materials management is in the cost estimating process by using software such as Microsoft Excel and Lotus 1-2-3 (Sun and Howard, 2004). The Internet is widely used for electronic mail (e-mail) and electronic commerce including electronic invoicing, payments and receipt of materials process (Harris and McCaffer, 2001). In order to improve productivity in ordering and quotation activities, contractors and suppliers could change their activities from conventional to more sophisticated or innovative tools and techniques. Accordingly, there is scope to make more use of computer-based systems to improve materials management on construction sites (Faniran et al., 1998). For example, applications developed for this purpose by many researchers include the following:

- **Expert System Advisor for Concrete Placing (ESCAP)** – for assist in planning and controlling concrete-placing operations without much experienced personnel incharge (Alkass et al., 1993);
- **Pen-Based Computer** – to automate construction field-data collection (McCulloch and Gunn, 1993);
- **Construction Materials Planning System (CMPS)** - for planning the use of construction materials to achieve the right materials in terms of quantities, time and meet the work programs (Wong and Norman, 1997);
• **Construction Materials Exchange (COME) (E-Commerce system)** – to improve efficiency and effectiveness of materials procurement process in construction (Kong and Li, 2001);

• **Internet-based Electronic Product Catalogue (IEPC)** – provide product information such as product category and other information related to the product by browsing or searching online (Kong et al., 2001);

• **Virtual Construction Material Router (VCMR)** – to provides the decision-support system for materials movement for assisting site managers and planner in complex construction site (Mahjoubi and Yang, 2001);

• **Material Handling Equipment Selection Advisor (MHESA)** - for material handling equipment selection (Chan, 2002);

• **Bar-code system** - for material storage management (Chen et al., 2002); and

• **Geographical Information System (GIS) and E-Commerce** – for construction materials trading (Li et al., 2003).

Lately, there is a need to make use of more computer-based systems to improve material management in construction sites (Olusegun et al., 1998). One example of the tools to manage construction materials is the construction materials planning system (CMPS). CMPS is a computer-aided planning system that integrates the scheduling and management of construction materials in providing the right materials with the right quantities at the right time to meet the demand for scheduled construction activities (Wong and Norman, 1997). Another development is an intelligent material handling equipment selection system called MHESA (Material Handling Equipment Selection Advisor) (Chan, 2002). These types of tools are needed, rather than checklists to assist engineers in the selection of appropriate, cost effective material handling equipment due to complex and tedious tasks.

Many computer software and Information Technology in Construction (ITC) tools have been developed recently and are widely used in construction to help the process of the activities. For example, like bar codes for managing materials on site to maintain inventory records purposes and wide use of the internet for electronic mail (e-mail) and electronic commerce (like electronic invoicing, payments and receipts of materials processes) (Harris and MacCaffer, 2001). Other examples are the cost
estimating process for materials, the wide and successful use of spreadsheets like Microsoft Excel and Lotus 1-2-3, provide contractors and project managers with a powerful and a convenient analytical and presentation tool (Sun and Howard, 2004).

The use of ICT has increased as new software relating to the construction industry that supports the effective management of construction activities have been developed. Various opportunities for construction organisations to invest in advanced information technology and telecommunications systems are noted in Griffith et al., (2000). Despite advances in the construction ICT development, an initial assessment of the tools and techniques currently in use in materials management suggests that most of them are under development with a few being used on a commercial basis. Therefore, more sophisticated solutions are expected to be used in the future such as wireless communication, bar-coding and radio frequency identification (RFID) for tagging technologies. These technologies have been successfully used in other industry sectors for example manufacturing, retail, and transportation and logistics. There is potential to apply the same concept to construction practices (BRE, 2005). By using RFID technology, there is predicted that in the future the construction site manager will walk around the construction site where all the items will be tagged (Wing, 2006). For example, an RFID reader can check whether all the materials delivered by a lorry are at the correct construction site and if any components are missing. The use of electronic tags with combination cyber agents at the gates of the construction site in order to check the deliveries of different materials has been suggested by (Wing and Atkin, 2002).

3.5.2 Advantages of Current Technologies

Implementation of ICT in materials management could help create an effective and efficient controlling process of materials activities on site. Construction materials come in various sizes and types that require proper handling and management in order to achieve productivity. The traditional practices in managing on-site activities by paper documents are not practical in today’s construction business. The contractor should implement more computer-based and electronic business (e-business) through the Internet in their activities in handling materials at site. In order to improve
productivity in ordering and quotation activities, contractors and suppliers could change their activities from conventional to more sophisticated or innovated tools and techniques. Conventional communications between the main contractors and suppliers through paper document changed to electronic trading in their business activities (HMSO, 1995).

According to Construction Software (2005), much software can support construction activities on site including materials management as listed follows:

- **Construction Materials Management System** – link engineering, construction, accounting, vendors and other critical functions to manage the procurement, warehousing, delivery and reporting;
- **Material Management System QMS** – system for managing all phases of the material management process;
- **BARRICADE software** – saves time, manages inventory, generates invoices, and improves cash flow;
- **Best Estimate** – a fast, simple, pure estimator for renovators & remodelors general contractors;
- **BidWorx** – whether you need benchmarking, bid summary, detailed time and materials;
- **Builders Software** – general contracting business software the people, money, time and materials;
- **COMMANDconcrete** – batching system integration and financial management;
- **Estimate Builder** – for quick and accurate materials and labour estimates! Estimate Builder was created;
- **GoTakeoff** – complete material list for standard construction in a matter of minutes;
- **Power! Electrical Material Data Base** – Comprehensive electrical parts list; and etc.

Materials management is required to be efficient and effective, and is more complicated for large scale projects due to the vast amount and variety of
construction materials needed. An application of the bar-code system for reducing construction waste can provide instant and up-to-date information of quantities of materials exchanged between the storage keeper and the group leader (Chen et al., 2002). RFID has the potential to facilitate materials management processes for complex projects, particularly with regard to the capability to store a large amount of data compared to bar codes (Jaselskis and El-Misalami, 2003). For example, it is possible to use RFID in materials identification on construction projects in order to reduce the level of confusion regarding materials delivery from suppliers, and the relevant locations at the jobsite (Jaselskis et al., 1995).

Several research projects have been undertaken on the potential implementation of RFID in materials management processes. The conceptual design of a RFID system has been presented by Jaselskis et al. (1995) to track material delivery vehicles, materials handling equipment, the material itself, and also to track concrete delivery vehicles. The concept of tracking delivery vehicles using RFID technology for quality control has been applied by Peyret and Tasky (2002) for plant mixed asphalt. RFID technology has also been proposed for use in tracking precast concrete pieces and storing information through the supply chain (Akinci et al., 2002 and Ergen et al., 2003).

3.5.3 Current Technological Challenges

In other areas of business such as publications, advertisements, manufacturing and many more, the ICT growth has been rapid (BRE, 2005). ICT has developed new software relating to the need of the construction industry in order to support construction activities and manage the effectively. Various opportunities for construction organisations to invest in technological advances in information systems and also advancements in telecommunications have been noted (Griffith et al., 2000). Therefore there are advantages for further development on what has already been developed to create a sophisticated, more reliable and affordable software. On the other hands, ‘more powerful computers and better connectivity will provide a strong ‘technology push’ for wider use of IT in construction’ (Sun and Howard, 2004).
According to a Building Research Establishment report (BRE, 2005), current implementation of ICT in materials management processes are under development and not many has been commercialised. IT applications in the construction industry are now commonplace for facilitating procurement, collaboration and knowledge management. For example, product procurement has such features as direct and indirect purchasing, electronic payment, and material aggregation. This can eliminate paper work, lower product and operational costs, and reduce cycle times. However, more sophisticated solutions to effective materials management in the future are expected to use wireless communications and tagging technologies such as RFID (Kasim et al., 2005a). Consequently, this can give the construction industry opportunities in order to choose the appropriate technology to improve their materials management practices.

3.5.4 Automatic Identification Technologies

Automatic identification technologies have tremendous potential in materials management and are reviewed here.

3.5.4.1 Introduction

Automatic identification (Auto-ID) embodies a broad type of technologies that are used to help machines identify objects, humans, or animals (Wyld, 2006). These are referred to as automatic data capture for identifying items and gathering data without human intervention or data entry. According to the RFID Journal, the auto-ID technologies have been employed to reduce the amount of time and labour needed to input data manually and to improve data accuracy (RFID Journal, 2007a). Finkenzeller (2003) asserts that Auto-ID technologies provides facilities in many service industries, purchasing and distribution logistics, industry, manufacturing companies and materials flow systems. There are numerous techniques of auto-ID including: Barcode Systems, Passive RFID, Active RFID, Biometric Systems (Fingerprint Procedures, Voice Identification), Smart Cards, Optical Character
Recognition (OCR). Figure 3.2 shows a schematic diagram of the most important automatic identification systems.

Several auto-ID technologies, such as bar-coding systems often require a person to scan manually a label or tag to capture the data. RFID, unlike bar-coding is designed to enable readers to capture data on tags and transmit it to a computer system without needing a person to be involved. Table 3.1 shows the comparison of auto-ID technologies, but bar-coding and RFID technologies will be discussed further in the next section.

Table 3.1: Comparison of Different Auto-ID Systems Showing Their Advantages and Disadvantages (source: Finkenzeller, 2003)

<table>
<thead>
<tr>
<th>System parameters</th>
<th>Barcode</th>
<th>OCR</th>
<th>Voice recog.</th>
<th>Biometry</th>
<th>Smart card</th>
<th>RFID systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical data quantity (bytes)</td>
<td>1-100</td>
<td>1-100</td>
<td>-</td>
<td>-</td>
<td>16 – 64k</td>
<td>16-64k</td>
</tr>
<tr>
<td>Data density</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Very high</td>
<td>Very high</td>
</tr>
<tr>
<td>Machine readability</td>
<td>Good</td>
<td>Good</td>
<td>Expensive</td>
<td>Expensive</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Readability by people</td>
<td>Limited</td>
<td>Simple</td>
<td>Simple</td>
<td>Difficult</td>
<td>Impossible</td>
<td>Impossible</td>
</tr>
<tr>
<td>Influence of dirt/damp</td>
<td>Very high</td>
<td>Very</td>
<td>-</td>
<td>-</td>
<td>Possible (contacts)</td>
<td>No influence</td>
</tr>
<tr>
<td>Influence of (opt.) covering</td>
<td>Total failure</td>
<td>Total failure</td>
<td>-</td>
<td>Possible</td>
<td>-</td>
<td>No influence</td>
</tr>
</tbody>
</table>
3.5.4.2 Bar-coding

The bar-coding technologies are well established and widely employed for identifying and tracking products across most industries and around the world than any of the other auto-ID technologies. In the construction industry, the application of bar-coding has been introduced since 1987 for materials management, plant and tool control (Chen et al., 2002). By the implementation of the bar-coding technologies, the management of construction materials can be facilitated effectively. The bar-coding provides an instantaneous and up-to-date information of quantities of materials exchanged between the storage keeper and the group leaders. In particular, the bar-coding technologies can provide the following functions:

- Automatically track real-time data of construction materials on the site;
- Automatically record historical data of construction materials consumed in the project;
- Automatically monitor materials consumption of working groups; and
- Automatically transfer real-time data of materials to head office via Intranet and/or Internet.
According to Finkenzeller (2003), the bar-coding system is a binary code comprising a field of bars (wide and narrow) and gaps arranged in parallel configuration and can be interpreted numerically and alphanumerically (as shown in Figure 3.3). They are normally displayed on paper products or hard metals and are vulnerable to harsh environments and rough handling (Wood and Alvarez, 2005). The bar-coding system comprises the components such as bar-coding labels, laser scanner and printer. The bar-coding labels are printed on paper and coded using the Universal Product Code (UPC). The UPC is generally used in a product coding system for the grocery industry and has become the most widely used standard for product identification. There are also other coding systems such as the European Article Numbering (EAN) system and the Japanese Article Numbering (OAN) system (Moselhi and El-Omari, 2006).

The laser scanner is capable of reading information coded on the bar-coding label. These include hand held scanners, pen scanners (or wand scanners), wall-or table-mounted scanners that the bar-coding is passed under or beside, fixed position scanner (an industrial reader used to identify product during manufacture), and PDA scanner with a built-in bar-coding reader. The printer is the last component of the bar-coding systems to print bar-coding labels. In practical usage, the laser scanner scans the bar-coding labels (i.e. applied to materials and equipment) and data is entered into computer systems for processing. However, for bulk materials (such as gravel) which require to be uniquely identifiable, the bar-coding label can be stored in containers. For the purpose of labour control, every worker is provided an ID card which includes personal and project information.

![Figure 3.3: Anatomy of a Bar-coding (source: Wyld, 2006)](123456789012)
3.5.4.3 Radio Frequency Identification

Radio Frequency Identification (RFID) is also a category of auto-ID technology. According to RFID Journal (2007a), RFID can be described as a system that transmits the identity of an object or person wirelessly, using radio waves. RFID can also be viewed as data carrier technology and can facilitate data exchange between the carrier and a host information management system (Furness, 2000). The RFID systems consists of two main components which are the tags (or transponders), and the reader that includes an antenna. The RFID tags and readers work together to provide the user with a non-contact solution to uniquely identify items and the locations. Further discussion of the RFID system components will be further discussed in Section 3.6.2.

RFID technology was used for the first time during World War II to identify aircraft (Logistic Magazine, 2005). The applications of the RFID systems are being used to track goods in warehouses, luggage through airports, and vehicles (Caron et al., 2006). The implementation of RFID have been effectively utilised for several years in retail, consumer products, transportation, agriculture, manufacturing, and other industries. In the construction industry, RFID can offer a significant improvement over bar-coding for materials tracking (Wood and Alvarez, 2005). Unlike bar-coding, RFID tags can be automatically scanned simultaneously, whereas bar-coding must be manually separated, located, and scanned individually. According to Schneider (2003), RFID has the capability to identify and track products and equipment in real-time without contact or line-of sight. They provide a higher rate of security because each tag is unique and impossible to duplicate, also RFID tags are able to read a 99.9 percent read rate (compared to an 80 percent read rate for bar codes). This is because they eliminate manual data entry and can be read through almost all materials.

Moselhi and El-Omari (2006) state that the main differences between RFID and bar-coding are as follows: (A comparison between RFID and bar-coding is summarised in Table 3.2)

- The scanning capabilities in case of RFID can be much faster and also save more labour hours due to the fact that there is no need to approach the item at
a very close distance to read its tag as in bar-coding. In the construction industry this difference would save time and cost when comparing the cost of implementing both technologies.

- The main disadvantage in bar-coding is that tags can be easily damaged due to the harsh conditions of construction sites. These disadvantages can be overcome by applying RFID tags under such conditions.
- The cost of the labels is an important factor especially on large projects when thousands of labels are needed. This is one of the main reasons why RFID cannot entirely replace bar-coding.
- Changing information stored in tags might be needed. Working hours stored on a worker’s ID as well as the location, for example, can be changed as needed when using RFID systems.

Table 3.2: Comparison between RFID and Bar-coding (source: Wyld, 2006)

<table>
<thead>
<tr>
<th>Bar code</th>
<th>RFID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bar codes require line of sight to be read</td>
<td>RFID tags can be read or updated</td>
</tr>
<tr>
<td></td>
<td>without line of sight</td>
</tr>
<tr>
<td>Bar codes can only be read individually</td>
<td>Multiple RFID tags can be read</td>
</tr>
<tr>
<td></td>
<td>simultaneously</td>
</tr>
<tr>
<td>Bar codes cannot be read if they become dirty or damaged</td>
<td>RFID tags are able to cope with harsh and dirty environments</td>
</tr>
<tr>
<td>Bar codes must be visible to be logged</td>
<td>RFID tags are ultra thin and can be printed on a label, and they can be read even when concealed within an item</td>
</tr>
<tr>
<td>Bar codes can only identify the type of item</td>
<td>RFID tags can identify a specific item</td>
</tr>
<tr>
<td>Bar code information cannot be updated</td>
<td>Electronic information can be over-written repeatedly on RFID tags</td>
</tr>
<tr>
<td>Bar codes must be manually tracked for item identification, making human error an issue</td>
<td>RFID tags can be automatically tracked, eliminating human error</td>
</tr>
</tbody>
</table>
Chapter 3: Materials Management - Processes and Technologies

3.5.5 Wireless Technologies

Generally, the term wireless refers to any type of electrical or electronic operation which is accomplished without the use of a 'hard wired' connection. Wireless technologies include cellular telephones, personal digital assistants, and wireless networking to transfer information over a distance without the use of electrical conductors or 'wires'. Implementation of the wireless networks into the construction site can provide real time information (such as project resources, planning and design) between site-based staff to remote project participants. They can allow mobile devices to be located at various places within the construction site and to communicate with each other as well as with the job site offices (Wood and Alvarez, 2005).

In the realisation of the wireless networks on construction sites, personnel could be provided with mobile devices to link with wireless systems. The most available popular mobile devices such as mobile phones, PDAs, tablet PCs, and notebook PCs (see Figure 3.4) can be expanded RFID readers, cameras and Global Positioning System (GPS) (Wood and Alvarez, 2005). The PDA can provide the user with storage, it can retrieve addresses and phone numbers, maintain a calendar, and create to-do lists and notes. They can also run a word processing, spreadsheet, phone, e-mail and Internet access with sophisticated PDAs. The tablet PC has a similar operating system with desktop computer, however, it can utilise an electronic pen rather than a keyboard for input.

![Figure 3.4: Examples of Mobile Devices](image-url)
The use of wireless networks is expected to be potential in improving materials management on the construction site. The wireless networks can provide an automatic tracking and give real-time information (such as status and location) of materials, suppliers, and tools. By accessing the materials management system on a mobile computer, supervisors and employee will be able to locate materials and suppliers and also reduce time spent searching an entire site. Labour productivity and lower labour costs are also improved by ensuring the crews in the field have the correct materials to execute work as planned. This will also reduce the cost of replacing materials that have been lost or misplaced.

3.6 RFID Technologies in Materials Management

This section will discuss the RFID technologies in terms of how they work, the system components, and the implementation of RFID systems in construction and other industries.

3.6.1 How RFID Works

There are two primary components of an RFID system as shown in Figure 3.5. The whole RFID system requires the tags and the reader including an antenna to be operated. The RFID tags or transponder are normally located on the object or people to be identified. The RFID reader or interrogator provides, read and write/read facilities through a fixed or mobile reader to communicate data to and from the tags. The following section explains further the components of the RFID system; the tags, readers and antenna.
3.6.2 RFID System Components

3.6.2.1 RFID Tags

RFID tags can be classified into two types: passive and active. Passive RFID tags have no internal power source (they are only active when a reader is nearby to power them) (RFID Journal, 2007b). Generally, passive tags have shorter read ranges of a few inches to 30 feet, but have a long life than active tags. They are also cheaper than active tags from about USD$0.20 to USD$0.40. The passive RFID tags consist of a microchip attached to an antenna and can be packaged in a different way such as mounted on a substrate to create a tag, sandwiched between an adhesive layer and a paper label to create a printable RFID label (or smart label), embedded in a plastic card, a key fob, the wall of a plastic container, and special packaging (to resist heat, cold or harsh cleaning chemicals). One example of the RFID passive tags is shown in Figure 3.6 where the antenna is sealed with the tags to give the tags greater read-write capabilities.

Passive tags can be operated at low frequency (124 kHz, 125 kHz or 135 kHz), high frequency (13.56 MHz) and ultra-high frequency (860 MHz to 960 MHz). Every frequency will provide a different radio wave and application. Low frequency wave can penetrate walls but not metal and passive tags with low frequency are suitable to
be applied when the tags needs to be read through materials or water at close range. Retailers and manufacturers are taking advantage of using the RFID passive tags due to the features and cost in managing their supply chain. The challenge of the passive tags is when reading them, in the centre of a pallet, or on materials made of metal or water.

Conversely, active RFID tags have their own internal power supply and are rewritable. The features of the active tags are much larger and heavier, and more expensive, but have a better noise protection than passive tags. However, they have a shorter battery life of up to 10 years, with read range of 60 feet to 300 feet (20 metres to 100 metres) and are operated at 455 MHz, 2.45 GHz, or 5.8 GHz frequency. The active tags, generally cost from USD$10 to USD$50, depending on the amount of memory, battery life, on-board temperature sensor and ruggedness. The cost will increase depending on housing of each active tags is the thickness and durability of the plastic (RFID Journal, 2007b). The example of the active RFID tags can be shown in Figure 3.7.

Active tags are more reliable in environments such as water (including human/cattle, which are mostly water), metal (shipping containers, vehicles), or at longer distances for generating strong responses from weak requests. They also have larger memories than passive tags and the ability to store additional information sent by the transceiver. Generally, active tags are used on large assets, such as cargo containers, rail cars and large reusable containers which need to tracked over a long distance (for example in a distribution yard). Active RFID tags can be divided into two types:
transponders and beacons (RFID Journal, 2007b). Active transponders are normally used in toll payment collection, checkpoint control and other systems. The active transponder within the car windshield will give the signal to the reader when the car approaches a tollbooth and transponder transmits its unique ID to the reader. Active beacons are used in real-time locating system (RTLS) to track the precise location of an asset in a distribution yard or in large manufacturing facilities. Table 3.3 presents the comparison between some of examples of active RFID tags in the current market.

![Figure 3.7: Examples of Active RFID Tags (source: Identec Solutions, 2004)](image)

Table 3.3: Comparison between Examples of Active RFID Tags

<table>
<thead>
<tr>
<th>Tag Name</th>
<th>i-Q32T</th>
<th>i-Q8</th>
<th>i-D2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy derived from:</td>
<td>Battery powered</td>
<td>Battery powered</td>
<td>Reader's signal</td>
</tr>
<tr>
<td>Read/Write Ability:</td>
<td>Read/Write</td>
<td>Read/Write</td>
<td>Read/Write</td>
</tr>
<tr>
<td>Read Range:</td>
<td>Up to 100m</td>
<td>Up to 100m</td>
<td>Up to 6m</td>
</tr>
<tr>
<td>Data Storage:</td>
<td>32 Kbytes</td>
<td>32 Kbytes</td>
<td>64 bytes</td>
</tr>
<tr>
<td>Frequency of Use:</td>
<td>915 MHz (USA) 868 MHz (UK) Dual Frequency (for transcontinental application)</td>
<td>915 MHz (USA) 868 MHz (UK) Dual Frequency (for transcontinental application)</td>
<td>Any</td>
</tr>
<tr>
<td>Weight:</td>
<td>Bit-heavier than i-D2</td>
<td>Bit-heavier than i-D2</td>
<td>Light</td>
</tr>
<tr>
<td>Size:</td>
<td>Bit-larger than i-D2</td>
<td>Bit-larger than i-D2</td>
<td>Small</td>
</tr>
<tr>
<td>Lifetime:</td>
<td>Up to 6 years</td>
<td>Up to 6 years</td>
<td>Up to 6 years</td>
</tr>
<tr>
<td>Applications:</td>
<td>Identification Tracking/Tracing Localisation Temperature monitoring</td>
<td>Identification Tracking/Tracing Localisation</td>
<td>Identification Tracking/Tracking Localisation</td>
</tr>
<tr>
<td>Cost:</td>
<td>69.80 Euros (£50.26/$103.52)</td>
<td>49.80 Euros (£35.86/$73.94)</td>
<td>22.20 Euros (£15.99/$32.92)</td>
</tr>
</tbody>
</table>
3.6.2.2 RFID Readers

RFID readers or the interrogator typically contain a radio frequency module (transmitter and receiver), a control unit and a coupling element to the transponder (Finkenzeller, 2003). According to Wood and Alvarez (2005), the RFID readers may be fixed or mobile and capable of communicating data to and from the tags to share data with the larger information system they support. The data is exchanged between tags and readers using radio waves. The mobile RFID readers can be integrated (fitted) into PCs, handheld computers (such as PDAs, notebook PCs, tablet PCs), or stationed and positioned at strategic points such as a facility entrance or on an assembly line (Schneider, 2003). The RFID readers included an antenna for sending and receiving signals to give instructions and information to the reader through the scanner. The information provided in the scanner is converted into a digital format by the reader, which the computer can then use for data analysis, recording, and reporting.

Readers such as i-Card 3 and i-PORT 3, which can read 100 tags per second for the identification rate. Figure 3.8 shows a few examples of the RFID readers which i-Card 3 for portable RFID reader and i-PORT 3 for fixed RFID reader. The RFID reader cost range from USD$500.00 to USD$3,000.00 depending on their functionality (RFID Journal, 2007c). Both i-Card 3 and i-PORT 3 can transmits and receives data at distances of up to 6 metres (20 ft) from an i-D tags or up to 100 metres (300 ft) from an i-Q tag. The i-Port 3 operates with up to four antennas, which can be used concurrently for receiving the signals from the tags. It is also fast and reliable for tags identification. The portable i-Card 3 reader can provide real-time information, wherever and whenever it is needed.

Figure 3.8: Examples of RFID Readers (source: Identec Solutions, 2004)
3.6.2.3 RFID Antenna

An RFID antenna is the conductive element that enables the tag to send and receive data (RFID Journal, 2007b). The antenna attached to a reader functions to transmit an electromagnetic field that activates a passive and active tag when it is within reading range. Low-frequency (135 kHz) and high-frequency (13.56 MHz) for the passive tags usually have a coiled antenna that couples with the coiled antenna of the reader to form a magnetic field. Ultra high-frequency (860 MHz to 960 MHz) tag antennas come in a variety of shapes. Normally, high-frequency and ultra high-frequency tag antennas are fabricated from copper and aluminium. They are also practically maintenance free and can be configured in a variety of shapes and sizes ranging in size from a grain of rice to the size of a brick (Schneider, 2003).

It is very common to see transponders and tag antennas packed as smart labels (sealed RFID tags) consisting of an integrated circuit (IC) attached to an antenna in the shape of a coil of wires as in Figure 3.6. Figure 3.9 shows some other examples of the RFID tags antenna such as an antenna integrated with the i-Card 3 (Figure 3.9(a)) and elliptically and linearly polarised antennas (Figure 3.9(b)). The elliptically polarized antennas are desirable when a large quantity of tags needs to be read at one time, or when tags moving at great speeds need to be interrogated. The linearly polarized antennas are more suitable for selective data collection and restriction of read zones (Identec Solutions, 2004).

![An Antenna integrated with the i-Card 3](image)

(a) i-Card 3 with an Antenna

![Elliptically and Linearly Polarized Antennas](image)

(b) Polarized Antennas

Figure 3.9: Examples of RFID Antennas (source: Identec Solutions, 2004)
3.6.3 Implementation of RFID in Other Industry Sectors

In industries such as manufacturing, retailing, supply chain management the implementation of RFID is growing in support of their current practices of running the business. According to the RFID Journal (2007a), RFID has been used in manufacturing plants for more than a decade. RFID is used to track parts and work in process and to reduce defects. In the retail industry, the retailers such as ‘Best Buy’, ‘Metro’, ‘Target’, ‘Tesco’ and ‘Wal-Mart’ are currently focused on improving supply chain efficiency and making sure the available product is on the shelf when customers want to buy it. For supply chain management, the used of RFID is to track shipments among supply chain partners. Another example used is for the payment systems where one of the most popular uses of RFID today is to pay for road tolls tools without the consumers stopping.

These are a few examples of the current usage of the RFID technologies in various industries as follow.

- An Electronic Product Code (EPC) RFID tag used by Wal-Mart
  These types of tags used by the retailer as a product tracking to control their products. The tag is attached on cases and pallets of goods to provide information such as (name, quantity, etc.) of the products.

Figure 3.10: An EPC RFID Tag
• An RFID tag used for electronic toll collection
The tags used in transportation industry for as an automatic toll collection at the motorways toll booths without stopping vehicles. The payment is deducted automatically when vehicles passing through at the toll booths.

Figure 3.11: An RFID Tag

• An Electronic Road Pricing (ERP) gantry in Singapore.
This gantry collects tolls in high-traffic areas from active RFID units in vehicles.

Figure 3.12: An Electronic Road Pricing (ERP) Gantry
- RFID tags used in libraries.
  This technology has started to replace bar-coding for library items (books, CDs, DVDs, etc) for identifying information such as book's title or materials type.

![Figure 3.13: Square Book Tag, Round CD/DVD Tag, Rectangular VHS Tag](image)

- Human implants
  Implantable RFID chips designed for human and animal tagging. The chips are implanted in arm for customer's identification such as in night clubs.

![Figure 3.14: (a) Hand with the planned location of the RFID chip (b) Just after the operation to insert the RFID tag was completed](image)
3.6.4 Implementation of RFID in Construction

RFID technology has grown dramatically in usage by industries such as manufacturing, retail, distribution and etc. Nevertheless the RFID application has a short history in the construction industry. However, according to Innovation and Research Focus (2006) the construction sector in the UK has shown interest in how a number of applications such as tags can be incorporated into boilers and doors, also which can be used by most housing associations and facilities management (FM) for asset management systems. Currently, in the UK construction industry, work has been carried out into the use of RFID in quality control, logistics tracking, system or component build, waste reduction, and asset management. RFID technology is becoming cheaper and should offer construction new opportunities to improve maintenance of assets. It can provide potential savings (money and efficiency) through:

- productivity improvements;
- availability of ‘real time’ data capture;
- job tracking;
- better quality control;
- better stock control;
- reduction in paperwork;
- reducing the incidents and associated cost of sending incorrect products to site;
- improvement in customer information;
- web-enabled customer information system;
- improved health and safety;
- allowing manufacturers to offer new value added maintenance services for their products.

Schneider (2003) states that the RFID systems can also provide the industry with the potential to improve construction productivity, quality, safety, and economy, cutting labour and material costs and enhancing project schedules. According to Wood and Alvarez (2005), the use of RFID in the construction industry such as tracking and
managing unique tagged materials through the supply chain and on the construction site. They also stated that examples of RFID applications in materials management are as follow:

- **Inventory tracking**: RFID systems can enable automatic, real-time, error-free tracking and inventory of unique materials through the supply chain from fabrication, transport, receipt, site storage, and issue to installation. For example, a pipe spool can be automatically identified as they are shipped and received and reduced error-prone in by current manually in identification, updating and immediately downloaded electronically into materials management systems without manual data entry.

- **Streamlined materials tracking and expediting**: an RFID-enabled process can deliver material status information earlier than the current manual processes, provide field planners with reliable advance information, and be able to optimise planning on schedule critical tasks or quickly find available work for crafts that might otherwise be temporarily under-utilised.

- **Accurate material status and inventories**: Provide accurate information about shipping, receiving, and inventory to avoid items missing, misplaces, or not received which can cause schedule disruption. This situation can easily be supported by using a hand-held reader, for example, to confirm possession of material that may have been placed or moved to an incorrect location within a yard.

Many research projects have been conducted for the past few years to explore the possibility of implementing RFID technology in the construction industry. These include:

- The implementation of RFID technology to monitor planning of the materials usage in a water supply project which suffers from poor materials management due to the complex operational environment (Ren et al., 2007);
The application of RFID for tool tracking on construction job sites by developing a tool tracking and inventory system capable of storing operation and maintenance data (Goodrum et al., 2006);

Integrating bar-coding and RFID to automate data collection from the construction site to track project cost and schedule information (Moselhi and El-Omari, 2006);

Development of an automated model for materials management and control with the application of RFID technology (Navon and Berkovich, 2006);

A model to track the progress of percentage completed in construction projects by the adoption of RFID and wireless technologies (Ghanem et al., 2006);

Automating the task of tracking the delivery and receipt of fabricated pipe spools in industrial projects by using RFID technology to address some problems of current methods for tracking pipe spools through automation the current tracking process (Song et al., 2005);

The utilisation of RFID for tracking precast concrete components and their historical information from fabrication to post construction (Akinci et al., 2002);

Implementation of RFID in the construction process to provide a procedure for helping contractors and owners to determine the type of RFID configuration that best fits their applications (Jaselski and El-Misalami, 2003); and

The development of a prototype system for identification and spatial tracking of structural steel members at the construction site (Furlani and Pfeffer, 2000).
3.7 Summary

This chapter has presented a review of materials management processes and technologies in construction projects. It explained what is meant by materials management and discussed the materials management on construction projects. Also discussed were the processes and problems of materials management. The implementation of current technologies and potential to implement RFID in materials management practices were also discussed. It clearly identified that these are important for effectively managing materials management in the construction project in order to provide better handling of construction materials to provide an overall performance of construction projects in terms of time, budget (cost) and quality. The application of ICT to support current practices of materials management in the construction site is considered improving for effective managing construction materials on site. In this chapter, the emerging technologies such as RFID are discovered to be a potential for improving materials management especially for tracking of materials.

The next chapter presents the case studies undertaken. It discusses the findings from the six case studies, focusing on the materials management problems, approaches taken to address these problems, ICT implementation, use of emerging technologies and materials tracking systems.
CHAPTER 4
CASE STUDIES ON CURRENT INDUSTRY PRACTICE

4.1 Introduction

This chapter describes case studies of six construction projects to investigate current materials management processes, problems, implementation of ICT, the possibility of using emerging technologies (such as RFID, wireless technologies) for improving materials tracking practices, and integration requirements of materials management and resource modelling. These involved semi-structured interviews with those responsible for materials management and site logistics to identify the current situation with regard to materials management on construction projects and to prioritise the problems identified. The cases are presented individually and comparison made between them. The key findings from the case studies regarding current problems; how to address the problems and the potential to implement emerging technologies to improve materials tracking are presented and analysed. The chapter concludes with a discussion of the significance of real-time materials tracking using RFID to improve current materials tracking and inventory management processes. The outline features of a conceptual model to integrate RFID-based materials management with resource modelling in project management system are also discussed.

4.1.1 Objectives of the Case Studies

The main objectives of the case studies undertaken were as follows:

- to investigate the current practices and problems of materials management in construction projects;
- to examine the implementation of ICT in materials management processes and the potential of emerging technologies (such as RFID, wireless
technologies) in overcoming the logistical difficulties associated with materials management on large and complex construction projects.

4.1.2 Choice of Case Studies

Case study research was selected for acquiring more insight into the current practices of materials management, problems, ICT implementation and potential use of emerging technologies. They were also used to acquire empirical data on the problems of storage space and materials tracking identified in the literature review. The choice of case study approach and adopted multiple case studies design for this research has been discussed in Chapter 2 (section 2.4.2.1). The case studies were undertaken to span the materials management practices (that incorporate qualitative comparators with observations) on six construction projects (Case A – Case F). The data collected was based on semi-structured interviews with those responsible (e.g. site managers or project managers) for materials management and site logistics. Under semi-structured interviews, the questions were designed in three parts (see Appendix B). Initially, the first part of semi-structured interviews was aimed at capturing general information about site managers such as their role, type of project and experience involved in construction project management. The second part comprises five sections aimed to examine the current practices and ICT implementation in materials management. The third part of the semi-structured interviews was intended to investigate the potential use of RFID for materials tracking and integration requirements of materials management and resource modelling.

For the purpose of this research, the 'unit of analysis' is geared towards achieving the study objective, which is to investigate the potential to implement emerging technologies for improving on-site materials tracking and inventory management processes on construction projects. The ‘unit of analysis’ for this study is based on the six construction projects and with five ‘embedded units of analysis’ as follows:

- **Materials management problems**: This explored the most significant problems that occur in the materials management practices;
• **Approaches to addressing problems:** This aimed to identify strategies used by site managers to solve materials management problems on the construction site;

• **ICT implementation:** This sought to identify the use of ICT in managing materials on the construction site;

• **Use of emerging technologies:** This investigated the potential of the emerging technologies to facilitate materials management practices; and

• **Materials tracking systems:** This sought to identify current methods used by site managers to facilitate materials tracking on the construction site.

Data analysis involved both single case and cross-case analyses as shown in Figure 4.1.
Single case analysis was conducted to produce individual case reports in order to gain the information on current materials management practices, problems and ICT implementation (refer Chapter 2 section 2.4.2.1). Amaratunga and Baldry (2001) suggested that this allows the unique patterns of each case to emerge before pushing towards generalised patterns across cases. Cross-case analysis was used to make a comparison of the embedded unit of analysis across the various case studies (Yin, 2003). This involved the examination of the five 'embedded unit of analysis' between each case study to provide the key findings from an argumentative interpretation.

The details of the case studies undertaken and a summary of the key findings (grouped according to the five main ‘embedded unit of analysis’) are discussed in the following section.

4.2 Case Study Projects

Case studies involving six construction projects were undertaken, to explore current practices and problems faced in materials management and to identify the implementation of ICT to facilitate the materials management processes. The case studies were also used to obtain information relating to materials tracking and the potential use of emerging technologies such as RFID and wireless technologies. Initially, two small projects (Cases A and B) from two different construction companies were identified and interviews conducted. Lastly, four more case studies (Cases C, D, E and F) were made, and focusing on larger and more complex projects. In order to gain the dissimilarity and similarity of materials management issues and the implementation of ICT and emerging technologies, a combination of small and large projects were used.

This research is based on six construction organisations (cases). The most appropriate construction organisations to involve in the case studies were first identified. The case studies were carefully and deliberately selected according to the main criteria; cost of the project (size of the project), attempted to implement new
technologies (such as RFID) for real-time materials tracking, and the willingness of individuals within the organisations to participate and share their experience in managing materials on the construction site. The differences between the costs of the projects provided an opportunity to explore variations in materials management issues for small and large-scale projects. The interviewees under study were all experienced construction professionals with a range of 8 to 32 years experience on the construction site while the cost of projects varied from £1.78 million to £4.2 billion. Background information on the six construction projects involved in the case studies are presented in Table 4.1.

<table>
<thead>
<tr>
<th>Case</th>
<th>Type of Project</th>
<th>Person Interviewed</th>
<th>Construction Experience</th>
<th>Cost (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Training Centre Building Project</td>
<td>Project Manager</td>
<td>32 years</td>
<td>1.78 million</td>
</tr>
<tr>
<td>B</td>
<td>Laboratory Fit-out and Refurbishment Project</td>
<td>Site Manager</td>
<td>10 years</td>
<td>2.8 million</td>
</tr>
<tr>
<td>C</td>
<td>Hospital Building Project</td>
<td>Construction Manager</td>
<td>10 years</td>
<td>333 million</td>
</tr>
<tr>
<td>D</td>
<td>Airport Terminals and Airfield Modification Project</td>
<td>Project Manager</td>
<td>20 years</td>
<td>450 million</td>
</tr>
<tr>
<td>E</td>
<td>New Airport Terminal Project</td>
<td>Materials Manager</td>
<td>13 years</td>
<td>4.2 billion</td>
</tr>
<tr>
<td>F</td>
<td>Residential Development Project</td>
<td>Site Manager</td>
<td>8 years</td>
<td>40 million</td>
</tr>
</tbody>
</table>

The construction organisations were visited, and semi-structured interviews took place with the project manager or site manager, or other personnel involved in materials management on construction projects. The interviews lasted between one and four hours, which included an interview session, site visit and demonstration of their current materials management system. All the data from the interviews were recorded and transcribed verbatim. This was supplemented with the collection of documentary data on the nature of materials management processes on the construction projects.
4.2.1 Case A: Training Centre Building Project

Project A involved the construction of three lecture theatres for a training centre building with a total cost of about £1.78 million. Although not a large project, it was technically complex. The project manager of the main contractor for this project was interviewed in order to understand the current problems relating to materials management practices at the construction site.

(a) Materials Management Problems

Generally, there were several materials management problems faced by the project manager responsible for this project:

- **Late delivery**: There is often a delay in the supply of materials to the construction site (due to inadequate stock or logistics and transportation problems);
- **Incorrect delivery**: Some materials do not comply with standard requirements (not in good condition, poor quality, sent by mistake);
- **Incomplete delivery**: This is due to insufficient materials or damage to materials;
- **Storage constraints**: Problems with inadequate storage (compound space and stolen materials); and
- **Site storage problems**: There is often insufficient site storage space.

(b) Approaches to Addressing Problems

There were several approaches used to address materials management problems in this project. Firstly, all the activities involved in materials purchasing were carefully monitored to make sure the materials supply was correct: complete delivery and compliance with standard requirements. Secondly, suppliers involved in the delivery of materials to site were constantly evaluated to ensure the timely arrival of materials when they were needed. Lastly, the contractors needed to ensure that the materials did not stay for long periods at the site to deal with inadequate site storage, and to
avoid damage or the stealing of materials due to an unsafe and unprotected storage area.

(c) ICT Implementation

Generally, this project fully utilised basic ICT tools such as:

- Fax system;
- An e-mail system; and
- Microsoft Excel Spreadsheet.

The use of the fax machine for purchasing activities, and employment of Microsoft Excel spreadsheet was used to facilitate storing all the materials information as a recording system. The e-mail system used by this project was only for communication purposes between suppliers and contractors.

(d) Use of Emerging Technologies

The project did not employ any emerging technologies (such as RFID, wireless system) to support materials tracking on the construction site. However, the interviewee was aware of the use of tagging technologies such as bar-coding and the potential use of emerging technologies for tracking materials.

(e) Materials Tracking System

Manual practices are currently used in this project for tracking and checking materials delivery and stock inventory, but no specific tools or technique was used to aid the handling of materials on site.
4.2.2 Case B: Laboratory Fit-out and Refurbishment Project

Project B involved the fit-out and refurbishment works for a laboratory building with a total cost of about £2.8 million. This project was also not a large scale project, but it was technically complex regarding the various suppliers. The project included fit-out work, and had two categories: Category A and Category B. Category A involved a fit-out work for air conditioning, electrical services, decorations, carpet and suspended ceilings while Category B involved fit-out work for demountable partitioning and furniture. The site manager was interviewed and their responsibilities covered the overall fit-out and refurbishment work for this project.

(a) Materials Management Problems

In managing this site, the site manager identified several problems relating to materials management as follows:

- **Late delivery**: Delays in supplying materials to the construction site;
- **Materials damages**: Damages to materials during delivery;
- **Lack of materials**: This problem occurred when contractors do not fulfil the supplier's requirement by late payment of the materials purchasing. This affected with the materials delivery and storage level of the construction site.
- **Materials logistics**: This involved problems with the movement of materials by labour to the work place; and
- **Improper handling**: This related to poor handling of materials by site labour.

(b) Approaches to Addressing Problems

Firstly, if there are any problems with the materials delivery (relating to late delivery, materials damages or shortages) the suppliers were advised immediately. There was a second strategy, which involved referral of any problems to the Project's Quality Officer, who solves problems relating to the quality of materials. Lastly, in order to deal with the logistics within the work place, all work by labour is carefully controlled and monitored. In order to avoid double handling and committing the
same mistake by to labour force, the site manager gives clear instructions and delegates certain work processes to the construction workers.

\[
(c) \quad \textit{ICT implementation}
\]

This project makes use of basic ICT tools such as:

- Fax system;
- An e-mail system; and
- Microsoft Excel Spreadsheet.

The use of fax machine and Microsoft Excel spreadsheet in this project was to facilitate purchasing activities and for storing all materials information. The project also used an e-mail system for communication to support materials ordering process, with the fax system being used to send hard copy documents.

\[
(d) \quad \textit{Use of Emerging Technologies}
\]

This project did not use any emerging technologies to facilitate materials tracking on the construction site, but the site manager was aware of the importance of emerging technologies for automated materials tracking.

\[
(e) \quad \textit{Materials Tracking System}
\]

In this project, manual methods were still used to facilitate tracking materials for the purpose of delivery confirmation and inventory checking/management.

\[4.2.3 \quad \text{Case C: Hospital Building Project}\]

Project C involved the construction of a hospital building with a total cost of about £333 million. This was a large and complex project involving numerous work tasks and many sub-contractors. The construction manager of the main contractor for this project, was responsible for the construction of the main building (which had seven
levels including a basement and roof mounted plant room) was interviewed. The
general approach to materials management was identified, but in order to have in-
depth information on materials supply, another interview was organised with one of
the sub-contractors on the project. The construction manager of the sub-contractor
was interviewed and their responsibilities included managing the installation of pipes
and plasterboards in the Acute building comprising 1159 bedrooms and 35 operating
theatres.

(a) Materials Management Problems

In managing the construction site, the construction manager interviewed identified
several problems relating to materials management as follows:

- Inadequate site storage: There was insufficient storage space for materials on
  the construction site;
- Tower crane distribution problems: The high degree of demand for tower
  crane operations made it difficult to move materials that required lifting by
  crane;
- Logistics problems: The storage constraints at the construction site had
  logistics problems (e.g. materials having to be stored in a separate location);
- Small loading area: This led to constraints in the loading and unloading of
  materials; and
- Site access problems: The single site access point led to traffic congestion
  when many vehicles come to the construction site at the same time.

(b) Approaches to Addressing Problems

On such a large and complex project, there was a vital need to have a strategy to
handle the above problems. In order to overcome the logistics and distribution of
tower crane problems, regular discussions and coordination meetings with all sub-
contractors were undertaken. There was also provision for a proper schedule of the
tower crane activities to record all the operations within the construction site. A
security guard was employed on the project, to deal with the single access problems
and to manage the flow traffic into and out of the construction site. The security guard was also responsible for ensuring the safety of materials, equipment and many valuable things at the construction site. JIT techniques were implemented in this project to deal with inadequate site storage space and the small loading area for the delivery of materials to the construction site.

(c) **ICT Implementation**

All the basic ICT tools were commonly used in managing materials in this construction project such as:

- Fax system;
- An e-mail system, and
- Microsoft Excel Spreadsheet.

The use of the fax machine in this project was for purchasing activities, while MS Excel was used for collating materials information and also as a recording system (database), and e-mail for communication purposes.

(d) **Use of Emerging Technologies**

The interviewee was aware of the potential of emerging technologies to speed up ordering, improve materials tracking, reduce paper work, and facilitate the efficient control and checking of materials. However, this project did not employ such technologies to support materials tracking practices.

(e) **Materials Tracking System**

Materials tracking were done manually in this project. However, the interviewee was aware of the significant use of tagging technologies (such as bar-coding and RFID) for materials tracking.
4.2.4 Case D: Airport Terminals and Airfield Modification Project

Project D involved an airport terminal and airfield modification with a total cost of about £450 million. It included the demolition of an old pier and the development of a new pier for aircraft stands. It also involved the construction of an arrival corridor, segregating arriving and departing passengers for improved security. It also involved the construction of a new multi storey car park, and new retail stores. The interview with the project manager was undertaken in order to study the operational and functional implementation of the CC, which provides logistics services to overcome the problems associated with the limited space for storing materials at the construction site.

(a) Materials Management Problems

The most significant challenges faced by the project manager were as follows:

- **Inadequate space:** Insufficient space for use as a storage area for materials at the construction site;
- **Late delivery:** Delivery of materials into the construction site (within aircraft lay down boundary) is affected by delays and time constraints due to aircraft operation;
- **Regulation consideration:** The activities of supplying materials into the construction site had difficulty with security regulation. The contractor had time permission constraints to exit the construction site within airport boundary;
- **Inadequate loading area:** Limited loading and unloading area provided only single operation space at the consolidation centre; and
- **Congestion time:** There were problems when many vehicles were bringing materials in and out from the consolidation centre during peak hours.
(b) Approaches to Addressing Problems

There were several approaches to dealing with all the problems mentioned above. The implementation of the CC into this project to ensure that the correct construction materials were efficiently delivered to the correct construction site at the required time. In this method all materials were transported to the CC before distribution to the construction site, in order to avoid the congestion of materials at the site loading area. The implementation of the CC also solved the problem of a lack of storage space at the construction site. It also provided a solution to the number of issues, such as the improvement of site security and safety, reduced congestion from construction traffic within the airport perimeter, improved delivery reliability, associated environmental benefit, and improved workforce efficiency and reduced materials losses. The airport regulations and time permission for the night operation provided by the airport security should be followed for transportation of materials into the construction site within aircraft lay down boundary.

(c) ICT Implementation

There were several basic ICT tools used on this construction project. These are as follows:

- Fax system;
- An e-mail system;
- Microsoft Excel Spreadsheet; and
- Bar-coding.

A fax system was used in purchasing activities, and Microsoft Excel spreadsheet to facilitate in storing all materials information and as database system. The e-mail system used in this project was for communication purposes only. Bar-coding was used to facilitate the identification of, and validation of, materials delivery.
(d) Use of Emerging Technologies

Through this project the interviewee realised the importance of using emerging technologies in developing their materials management practices for tracking materials. This implementation could help speed up ordering, materials tracking, reduce paper work, and facilitate the more efficient control and checking of materials more efficiently.

(e) Materials Tracking System

In this project, manual practices and bar-coding were employed to facilitate materials tracking activities. The use of bar-coding in the CC operation was to provide materials management effectively. It was not only used for the identification of materials but also for the validation of materials delivery to the construction site.

4.2.5 Case E: New Airport Terminal Project

Project E involved the construction of a new airport terminal, with a total construction cost of about £4.2 billion. This project consisted of 16 major projects and over 147 sub-projects on a 260 hectare site. It encompassed a vast and hugely complex programme of work. This involved extensive civil engineering works such as excavation, substructure concrete, paving concrete, reinforcement, curtain walling, roofing and tunnelling. Other works included a network of new roads, car parking, waste management, retail and airport facilities. In order to gain the information of materials management practices from client and main contractor perspectives, interviews with the client’s materials manager and the business improvement personnel of the main contractor were undertaken for this project.

(a) Materials Management Problems

In managing this project, the main problems faced by personnel involved in materials management were as follows:
• **Site storage constraints**: Inadequate storage area for materials on the construction site;

• **Supply chain challenge**: The variety and vast amount of suppliers and materials, created challenges with the commitment of suppliers and contractors to do the job;

• **Project size challenge**: The scale/size of the project and physical access problems with traffic overflow and surrounding local roads near the construction site;

• **Late delivery**: This project had difficulty with delays in supplying materials into the construction site due to the huge amount of materials and dealing with various suppliers. These delays also included suppliers from outside country which require more time to delivery; and

• **Incorrect delivery**: Problems with materials not complying with specific standard requirements, which needed to be returned back to suppliers, which affected the processes of materials delivery into the construction site.

(b) **Approaches to Addressing Problems**

This project developed a Project Flow System to provide a transparent workflow management system to better coordinate project team member’s team, share resources and identify efforts to improve performance. The implementation of a Logistics Centre (LC) to facilitate the huge amount of materials was employed in this project. The LC was responsible for materials logistics within the construction site and used as buffer before vehicles loaded with materials were supplied into the construction site. The JIT technique was also applied in this project to ensure that the right materials were in the right place at the right time. This arrangement was used to avoid congestion of vehicles and materials approaching the construction site. The LC and JIT techniques were also used to overcome many problems related to materials handling on the construction site, such as late delivery, loss, not complying with standard requirements, site congestion, site storage constraints, traffic overflow into the construction site, and surrounding local roads near the construction site.
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(c) **ICT Implementation**

The used of ICT tools in this project includes:

- Fax system;
- An e-mail system;
- Microsoft Excel Spreadsheet;
- Bar-coding; and
- Project Flow System.

This was a massive project, but it had basic ICT tools (such as fax system, e-mail system, Microsoft Excel spreadsheet) together with sophisticated technologies (such as Project Flow System, bar-coding) to support materials management on the construction site. The basic ICT tools such as fax machine and Microsoft Excel spreadsheet were utilised in this project to support managing materials in the construction site and e-mail was used for communication purposes only. This project used bar-coding for tracking rebar materials during materials delivery. Project Flow systems was also adopted as a software system tool to provide a transparent workflow management system, to better coordinate project team members, shared resources management and identify efforts to improve performance. Using the Project Flow System the materials could be driven by the system, collecting the team’s demand related to work activities. Assembly packages are created to break down project activities into more manageable units of production, were in line with actual construction methodology. This is allowed all assembly parts to be procured, fabricated and delivered to site only when ready for installation.

(d) **Use of Emerging technologies**

This project used emerging technologies such as RFID and PDA. However, the implementation of emerging technologies was only used for the specific task, for example, the use of RFID for tracking precast columns and the PDA to assist checking daily construction activity.
(e) Materials Tracking System

This project employed manual practices of tracking materials with supported tagging technologies such as bar-coding and RFID. This project used bar coding for rebars checking during materials delivery also tracking and controlling practices at the LC. There were also testing RFID for tracking precast column at the beginning stage of their construction process.

4.2.6 Case F: Residential Building Project

Project F involved the construction of a residential building with a total cost of about £40 million. This project comprised a total of 316 apartments building which included 58 affordable housing units and 258 private apartments. The interview was carried out with the main contractor's site engineer.

(a) Materials Management Problems

In managing this project, the site engineer identified several problems relating to materials management as follows:

- **Project location:** This project faced project location problems due to the project being situated in a hectic location, which affected the activity of materials delivery at the construction site;

- **Logistics Problems:** The project had logistics problems as the construction site was surrounded with public infrastructure such as schools, railways and local roads. It was therefore especially difficult to transport large materials and concrete into the construction site;

- **Congestion time:** There was difficulty with many vehicles arriving at one time (peak time), and materials delivery due to waiting time for unloading materials at specific storage area;
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- **Site access constraints:** This project required site access permission from local authority for transportation and materials delivery into the construction site during school operations;
- **Regulation consideration:** The contractor had to take into consideration the regulations and seek permission from local authority to deal with materials delivery into the construction site.

(b) **Approaches to Addressing Problems**

The main contractor conducted meetings everyday to co-ordinate the subcontractor's daily activities. The biggest concern with respect to logistics was bringing large materials and concrete onto the construction site, which was 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. The Project Flow system was implemented to integrate resources planning with the work programme to properly manage all of the activities and resource information.

(c) **ICT Implementation**

Generally, the materials management on this project was supported by several ICT tools, including:

- Fax system (for purchasing activities);
- E-mail system (for communication);
- MS Excel Spreadsheet (for storage of materials information); and
- Project Flow System (for resource planning and project management).

(d) **Use of Emerging Technologies**

This project was not supported by emerging technologies. However, the interviewee was aware of the important use of RFD for automatic materials tracking and providing efficient controls of materials at the construction site. The implementation
of RFID required many considerations such as collaboration within the manufacturers or suppliers (for tagging purposes), skill requirements needed (for construction workers) and standardisation (for materials labelling).

(e) Materials tracking system

This project utilised manual methods to facilitate materials tracking activities on the construction site. The interviewee was aware of and supports the potential use of tagging technologies (such as RFID and bar-coding) to improve on-site materials tracking.

4.3 Key Findings from Case Studies

The problems identified from the case studies revealed that each case study experienced similar problems with inadequate storage area at the construction site. The problems and approaches to materials management, ICT implementation, use of emerging technologies, and materials tracking are summarised in Table 4.2 and discussed below. The discussion involves a cross-case analysis between the six case studies and grouped into five ‘embedded units of analysis’ investigated as follows:

- *Embedded Unit of Analysis 1*: Materials Management Problems;
- *Embedded Unit of Analysis 2*: Approaches to Addressing Problems;
- *Embedded Unit of Analysis 3*: ICT Implementation;
- *Embedded Unit of Analysis 4*: Use of Emerging Technologies; and
- *Embedded Unit of Analysis 5*: Materials Tracking System.
<table>
<thead>
<tr>
<th>ELEMENT OF ANALYSIS</th>
<th>CASE A</th>
<th>CASE B</th>
<th>CASE C</th>
<th>CASE D</th>
<th>CASE E</th>
<th>CASE F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials Management Problems</td>
<td>Late delivery, Incorrect delivery, Incomplete delivery, Constraints storage compound, Site storage problems</td>
<td>Late delivery, Materials damages, Lack of materials, Materials logistics, Improper handling</td>
<td>Inadequate of site storage, Tower crane distribution problems, Logistics problems, Small loading area, Site access problems</td>
<td>Inadequate of site storage, Late delivery, Regulation consideration, Inadequate loading area, Congestion time</td>
<td>Site storage constraints, Supply chain challenge, Project size challenge, Late delivery, Incorrect delivery</td>
<td>Project location, Logistic problems, Congestion time, Site access constraints, Regulation consideration</td>
</tr>
<tr>
<td>Approaches to addressing problems</td>
<td>Monitor and constant evaluate, Standard form, Minimum stay control</td>
<td>Quick respond, Quality Officer, Monitor and clear instruction</td>
<td>Regular discussion and meeting, Provide enough storage and monthly stock checking, Record scheduling, Just-In-Time</td>
<td>Consolidation Centre (CC), Undertake airport security requirements</td>
<td>Project Flow System, Logistics Centre (LC), Just-In-Time</td>
<td>Everyday meeting, Regulation comply, Project Flow System</td>
</tr>
<tr>
<td>ICT implementation</td>
<td>Fax system, E-mail system</td>
<td>Fax system, E-mail system</td>
<td>Fax system, E-mail system</td>
<td>Fax system, E-mail system</td>
<td>Fax system, E-mail system</td>
<td>Fax system, E-mail system</td>
</tr>
<tr>
<td>Use of emerging technologies (RFID, wireless)</td>
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<td>Microsoft Excel Spreadsheet</td>
<td>Microsoft Excel Spreadsheet</td>
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<td>No</td>
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<td>No</td>
<td>No</td>
<td>Yes (RFID, PDA)</td>
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</table>
4.3.1 Materials Management Problems

Generally, the findings from the case studies reveal that the major problems in terms of materials management activities relate to constraints on site storage, site logistics with regards to materials handling and distribution, and also with ordering and delivery of materials to the construction sites (see Table 4.3). It is evident that late delivery problems and site storage constraints were the highest occurring problems, with four cases (Case A, B, D, E) suffering late delivery problems, and another four (Case A, C, D, E) with site storage constraints. Logistics problems were the second highest occurring problem with three case studies (Case B, C, F). Previous research highlighted similar materials management issues such as improper storage (Canter, 1993), requirement for large storage capacity (Agapiou et al., 1998), additional inventory cost due to early materials delivery (Dey, 2001), transport difficulties (Zakeri et al., 1996), and late delivery (Aibinu and Odeyinka, 2006).

Incorrect delivery, inadequate loading area, site access problems, regulation consideration, and congestion time were also problems for two cases. The cases were Case A and E for incorrect delivery, Case C and D for inadequate loading area, Case C and F for site access problems, and Case D and F for regulation consideration and congestion time problems. Other issues such as: incomplete delivery, and storage compound constraints affected Case A; materials damages, lack of materials, and improper handling (Case B); tower crane distribution problems (Case C); supply chain and project size problems (Case E); and project location problems (Case F) were only evident in one case study each.

Previous research indicated that the shortage or lack of materials can result in delay and loss of productivity in construction activities (Mansfield et al., 1994; Ogunlana et al., 1996; Abdul-Rahman et al., 2006; and Aibinu and Odeyinka, 2006). Manual processes (excessive paperwork) and non-compliance with specifications were not highlighted directly, but remain problems in the case studies. This was indicated in previous research identifying them to have an effect on material management processes in construction projects (Aibinu and Odeyinka, 2006; Zakeri et al., 1996; Dey, 2001).
Table 4.3: Materials Management Problems from Case Studies

<table>
<thead>
<tr>
<th>MATERIALS MANAGEMENT PROBLEMS</th>
<th>CASE A</th>
<th>CASE B</th>
<th>CASE C</th>
<th>CASE D</th>
<th>CASE E</th>
<th>CASE F</th>
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<tr>
<td>Late delivery</td>
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<td>Site storage problems</td>
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<td>Logistics problems</td>
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<td>Incorrect delivery</td>
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4.3.2 Approaches to Addressing Problems

The initial feedback identified that the issue of late delivery has been experienced by many construction companies. There were many approaches to addressing the late delivery problems which differed from one case to another. In dealing with these problems, Case A used monitoring and constant evaluation approaches, while Case B used quick response to inform suppliers if any unexpected event happened. Case D provided a CC and follow airport security requirements in order to solve late delivery of material. While, Case E implemented a LC to provide a temporary storage compound for materials delivery, and adapted JIT approaches to overcome late delivery problems. Excellent collaboration was noted as being needed between contractors and suppliers in order to achieve better management of materials delivery to construction sites.

The lack of adequate site storage to store materials on site was experienced by all construction companies interviewed and affected both small and large projects (Case A, C, D, E). However, this problem needs more consideration for large scale projects due to the size of the projects, and the variety and of large amount of materials utilisation. Some approaches that have been undertaken to overcome these problems.
include: minimum stock control on site (Case A), implementation of JIT techniques (Case D, E), and implementation of the CC (Case D). Materials logistics problems are affected by the activities of transportation of materials to the construction site due to single access, constraints of public regulations and congestion of materials during peak time. In overcoming these problems there are a few approaches implemented such as: to monitor and provide clear instructions (Case B), to undertake regular discussions and coordinate meetings, implement JIT (Case C), and carry out everyday meetings by Case F.

The JIT techniques have been implemented to overcome incorrect delivery, supply chain challenge, and project size challenges (Case E), inadequate loading area (Case D), and site access problems (Case C). The consolidation centre and logistic centre has been set-up in order to overcome the inadequate loading area and congestion time for (Case D), congestion time, supply chain challenge, and project size challenge for (Case E). In order to deal with regulations requirements, many projects should comply with the local authority regulations to overcome site access problems, regulation consideration, and Case C, D and F to dealing with project location challenge.

Monitoring and constant evaluation and minimum stay control have been applied as approaches to overcoming some of the problems related to incomplete delivery and storage constraints for Case A. Case B appointed a Quality Officer to facilitate the inspection of materials delivery to avoid materials damages, a quick response to the supplier if the level of materials on-site was low, and in order to overcome improper handling of materials, the contractor would monitor and give clear instruction to construction workers. Case C provided a proper record scheduling to manage tower crane distribution operation on construction sites.

4.3.3 ICT Implementation

Generally, all projects utilise the basic ICT tools such as fax (for purchasing activities) and Microsoft Excel (to facilitate the storage of all materials information). In small scale projects such as cases A and B, the used of such tools mentioned
above were common practices in managing materials in construction project. However, these types of tools are still utilised in the current practices in the large scale of the construction projects such as Case C, D, E and F. Case B used the e-mail system for communication and for materials ordering purposes, but still uses a fax system for hard copy documents. The e-mail system used by Cases A, C, D, E and F was only for communication purposes.

Case E implemented the Project Flow system as a tool to provide a transparent workflow management system, to better coordinate project team members, share resources and to identify the effort to improve performance. Through the Project Flow system the materials management could be driven by the system which collects the team’s requirements relative to work activities. Case F also implemented the Project Flow system in their operations to integrate resource planning with the work programme and to centralise and properly manage all activities and resource information. Bar-coding was used in Cases D and E to facilitate materials tracking on the construction site. Case D also used bar-coding for materials tracking and for validating the location, time, and date of materials delivery on site. In Case E, bar-coding was used to facilitate tracking and control of the rebar.

4.3.4 Use of Emerging Technologies

Inadequate use of emerging technologies (such as RFID) and PDA was revealed from the case studies, with most case study companies not using them. However, the interviewees realised the importance of using new technologies such as wireless communications, and RFID technologies in their materials management practices. The implementation of emerging technologies can help speed up ordering, improve materials tracking, reduce paper work, and facilitate the efficient control and checking of materials. This was revealed by Case E, where the implementation of emerging technologies such as RFID into their materials management practices. Case E used RFID for tracking precast column to facilitate controlling materials delivery at logistic centre; and also PDA used to assist checking construction daily activities at the construction site.
In the adoption of RFID and PDA there are few additional requirements which affected the construction worker. This is involved the training requirements to improve ICT knowledge and technical capability, and increasing discipline and willingness to learn and accept emerging technologies. The construction industry needs to support the retraining and education of construction workers, and provide adequate ICT technical expertise. The significant advantages by the adoption of such technologies can create overall changes throughout the materials management process. These can give a better solution to the current issues in handling materials such as: late delivery, inappropriate materials delivery, storage, materials damages (wastage), materials shortages, logistics, improper handling, manual process, non-compliance with specifications, materials congestion, and regulation considerations.

4.3.5 Materials Tracking System

Handling and monitoring activities on site such as materials tracking is still facilitated by manual operations in all of the case studies (Case A, B, C, D, E and F) and it is challenge many human errors and excessive paperwork. The case studies have been recommended to overcome all those problems by using bar-coding and RFID for suggestion of good practices. There are required the contractors to upgrade their current practices of materials tracking by implementation of tagging technologies such as bar-coding and RFID in order for easily, quickly, efficiently and less paperwork for materials handling in the construction site.

In Case D, bar-coding is utilised in the consolidation centre operation to facilitate effective materials management. The process involves the identification and validation of materials delivery in order to know the specific location, time and date. Moreover, in Case E bar-coding was used to aid tracking and controlling of the rebar at the logistic centre during rebar delivery. Throughout Case E, the implementation of RFID was implemented for tracking precast column and PDA was used to assist checking construction daily activities.
4.4 **Synthesis of Good Practices**

Table 4.4 below represents the suggested solution from the case studies to improve their current practices of materials management on construction sites. This shows that all the cases recommended upgrading their current practices in materials tracking by the implementation of tagging technologies (such as bar-coding and RFID) for easy, fast, efficient and less paperwork in handling materials on site. Case E suggested the use of ICT tools which can integrate materials, labour and plant utilisation into one system. In order to overcome site storage problems, Cases A, C and D suggested providing more storage area on the construction site and providing a proper storage compound for better materials handling at the construction site.

<table>
<thead>
<tr>
<th>CASE STUDY</th>
<th>SUGGESTED SOLUTIONS</th>
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| Case A     | • Additional site storage  
             • Additional investment on proper storage  
             • Additional workers to monitor materials  
             • Implementation of ICT (easy and fast tracking of materials and less paperwork) |
| Case B     | • Avoid double handling and similar mistakes  
             • Implementation of ICT (easy activities) |
| Case C     | • Additional access to construction site  
             • Additional storage area  
             • Implementation of RFID and bar-coding (materials tracking (such as steel)) |
| Case D     | • Additional loading area at Consolidation Centre  
             • Implementation of ICT (easy, fast and efficient in checking and controlling of materials) |
| Case E     | • Standardisation and discipline in construction industry  
             • Implementation of ICT (link materials, labour and plant usage)  
             • Improve collaboration (standardisation of suppliers labels) |
| Case F     | • Implementation of RFID (automatic tracking materials delivery, easy and efficient control of materials)  
             • Collaboration (standardisation of suppliers labels for materials tracking) |

Issues regarding collaboration and standardisation among manufacturers, suppliers and contractors were also suggested to improve the overall supply chain. These are recommended by Case E and F to standardise the supplier’s materials labels in order to facilitate better materials tracking and collaboration within and across multiple supplier for effective management of the supply chain. Case B suggested avoiding
double handling and doing the same mistakes for efficient materials handling, and Case C suggested providing more access at the construction site for materials logistics.

4.5 Limitations of Current Practices

Limitations on site storage area at the construction site has been experienced on all construction projects from case studies and affected both small and large scale projects. Other constraints include: single access to construction site; surrounding public infrastructure (such as schools and railways); congestion of materials' vehicles during peak time; and regulation considerations. The implementation of JIT and consolidation centre techniques could solve logistics and storage problems for materials management processes. These techniques can provide the solution to materials congestion due to inadequate storage space at construction sites. Nevertheless, the techniques are not being used to overcome human error such as double handling and paper-based reports as these are mostly used to record and exchange information related to the materials components within supply chain.

Generally, all cases used manual methods for the tracking of materials delivery, identification of materials at storage area and controlling materials from any damages. All these activities involved several human errors and massive paperwork in materials management on the construction site. However, the case studies undertaken only revealed the widespread use of basic ICT tools (such as fax machine and spreadsheet) to support purchasing activities and for database systems. There is an inadequate use of modern ICT tools such as RFID to assist with an automatic identification and material tracking, which could provide a real-time information of materials usage. There is also a lack of ICT tools that can associate materials, labour and plant in one system with high level programming and scheduling technology.
4.6 Requirements for Real-Time Materials Tracking

There are important to transform manual practices to automatic practices to improve the overall practices in handling materials to become more efficient and effective, and also provided with real-time information. Emerging technologies (such as RFID, wireless system) are expected to help in tracking activities to overcome human error in materials identification and reduce congestion time due to constraints of site storage. Materials management in large scale projects is required to be efficient and effective (Kasim et al., 2005b), and also has the potential to employ RFID to facilitate materials management processes for complex projects, particularly with regard to storing a large amount of data compared with bar codes (Jaselskis and El-Misalami, 2003). Accordingly, there is scope to make more use of computer-based systems to improve materials management in construction sites (Faniran et al., 1998).

However, from the literature review and case studies findings there is a lack of positive examples of such tools having been used effectively. From the case studies, aspects of ICT implementation in materials management practices have been identified. The site managers have difficulties about tackling materials management problems on the current practices. The key findings from case studies includes: inadequate techniques to overcome human error and inadequate use of modern ICT tools such as RFID to assist materials tracking. An integrated framework for real-time materials tracking is required in order to provide an intelligent system for materials management on the construction site.

The development of the real-time materials tracking process is intended to improve materials tracking and overall process of materials management on the construction site. The process consists of: (1) Materials Delivery; (2) Materials Storage; (3) Materials Use; (4) On-site Control Centre; and Report Transmission. The description of the overall real-time materials tracking process as follow:

- **Materials Delivery**: This stage can be divided into order delivery confirmation and delivery status. First, delivery of purchased materials with
RFID tags are detected by RFID reader at the main entrance of the construction site, and the arrival of materials delivery will be confirmed. Materials delivery information (e.g. materials name, quantity, etc.) will be written within the tags and saved into the database (MS Access). Next, the site managers/subcontractor checking materials delivery status either to be stored or used immediately, and considering meet specifications. The integration with a project management system (MS Project) can help the site manager in making a decision to store, use, or return to the supplier for each specific material within certain project task.

- **Materials Storage**: At the storage area, site manager/subcontractor records the storage out date materials into the attached tags and the database. The site manager also periodically checks the availability of materials at the storage area required for installation. This is required integration with the database to store storage information data and the work programme to retrieve an installation date for specific materials.

- **Materials Use**: At this stage, the site manager/subcontractor checks the required information on materials to be used or installed by integration with the database and work programme. The installation data for certain materials can be retrieved from the database and records into the tags attached with specific materials. There is also can provides actual start and finish date of the materials and save into the work programme. In the MS Project, it can generate the reports to establish the necessary resources (materials and personnel) are available to carry out the specified tasks.

- **On-site Control Centre**: The site office can be established as an on-site control centre. The materials delivery, storage and use data will be gathered and analysed in the database.

- **Report Transmission**: All the information on real-time materials tracking is sent to the main office via e-mail.
4.7 Summary

A total of six case studies have been undertaken in order to investigate the current issues and problems in materials management, and also the implementation of ICT, and the potential use emerging technologies in overcoming the logistical difficulties on construction sites. Findings from the analysis show that many of the cases have similar problems with storage constraints. Handling and monitoring activities on site (such as materials tracking) are facilitated by manual operations in most of the case studies, with the potential for human errors and excessive paperwork. The suggestion for good practice includes the use of tagging technologies such as bar-coding and RFID to upgrade current practices materials tracking. In order to improve the materials tracking system and overall process of materials management in both small and large scale construction projects, there were suggestions to have a transformation from current manual practices to automated tracking of materials delivery, identification of materials at the storage area, control of materials to reduce damage, and reduction massive paperwork. It was also suggested to provide the ICT tools which can integrate materials, labour and plant into one system.

Regarding the above findings, this research will focus on the development of a prototype system to integrate RFID-based materials management with resources modelling in project management systems to improve on-site materials tracking and inventory management processes. The next chapter discusses the real-time materials tracking processes.
CHAPTER 5
REAL-TIME MATERIALS TRACKING PROCESS

5.1 Introduction

This chapter discusses the importance of real-time materials tracking process. This is a system which promotes an automatic approach for materials tracking on the construction site. The chapter starts with an introduction to components of the real-time materials tracking process including materials delivery, materials storage, materials use, on-site control centre, and report transmission. It then describes the process for real-time materials tracking and discusses the key features of the processes.

5.2 Real-Time Materials Tracking Components

The development of the real-time materials tracking process is based on the findings from the literature review and case studies (refer to Chapter 2 section 2.5.3). It is shown that it is important to change from manual to automatic processes and that there is potential to employ RFID to facilitate materials management on construction projects. An integrated approach for real-time materials tracking to provide an intelligent system is therefore proposed. The components of the real-time materials tracking system rely on the use of emerging technologies such as RFID as depicted in Figure 5.1.

The five main components for real-time materials tracking are as follows:

- Materials Delivery;
- Materials Storage;
- Materials Use;
- On-site Control Centre; and
- Report Transmission.

Figure 5.1: Components of Real-Time Materials Tracking
The main components of the real-time materials tracking process represent a conceptual approach to real-time materials tracking on the construction site. These components are briefly described as follows:

- **Materials Delivery:** This stage involves the tracking of the materials delivery and delivery status at the construction site. The RFID tags attached to purchase materials are detected by portable RFID reader during delivery at the entrance of the construction site. The materials delivery and delivery status information will be written to the tags and recorded to the database. This stage also involves the integration with the resource modelling in the work programme so as to check the use status of specific materials;

- **Materials Storage:** This stage tracks the materials and identifies the availability of the storage area at the construction site. It is also recorded and verifies inventory utilisation during taking into and out of materials from the storage area. This require the integration with work programme in order to identify specific materials for related work tasks;

- **Materials Use:** This stage is required for tracking the materials used in the construction project. The work programme provides the status of materials to be installed for specific work tasks;

- **On-site Control Centre:** The site office acts as an on-site control centre and will be involved in collecting and analysing all the materials information in the database; and

- **Report Transmission:** The main office will be involved in receiving all the materials information from the site office to generate the information required to produce reports.
5.3 Real-Time Materials Tracking Process

The process of real-time materials tracking is intended to improve materials tracking and the overall process of materials management in construction projects. Automated data collection using RFID for tracking materials involves the use of a tag (as a transponder) and a reader (as an interrogator). The type of RFID tag used includes an i-Q32T/i-Q8, and the portable i-CARD III for the RFID reader. The portable RFID readers can be attached either to PDA or to a laptop for collecting and transmitting the data from the construction site to the site office.

The literature review findings revealed that, there is lack of positive examples of modern ICT such as RFID having been used effectively to facilitate materials tracking. The case studies found that there are inadequate techniques to overcome human error such as double handling and paper-based report of materials tracking on construction projects and inadequate use of modern ICT tools such as RFID to assist with an automatic identification of materials tracking. The real-time materials tracking process provides a structured approach to integrate RFID-based materials management with resource modelling in a project management system. Figure 5.2 shows the main stages of real-time materials tracking process, which includes five key components: materials delivery (for automated materials tracking); materials storage (inventory tracking); materials use (materials usage tracking); on-site control centre (collecting and analysing materials data); and report transmission (producing reports).
Chapter 5: Real-Time Materials Tracking Process

MATERIALS DELIVERY
- Transportation of materials from supplier with RFID tags (i-Q32T/i-Q8) to the construction site
- Purchased materials with RFID tags (i-Q32T/i-Q8) delivered to the construction site
- Materials with RFID tags detected by portable RFID readers (i-CARD 3) at the main entrance of the construction site
- Site Manager/Subcontractors checked required information of materials delivery by using PDAs/laptop

Send materials back to supplier/manufacturer IF NO

Do materials delivered meet specifications/requirements?

IF YES

Should materials be stored or used immediately?

Store

USe

MATERIALS USE
- Preparation to use materials at the construction site
- Site Manager/Subcontractors check required information of materials to be used by using portable RFID reader and PDAs/laptop base on resource modelling in the master work programme

Note:
Materials flows Information flows

REAL-TIME MATERIALS TRACKING PROCESS
- Send reports of Real-Time Materials Tracking to the main office
- Reports of Real-Time Materials Tracking
- Reconciliation with programme requirements
- Real-Time Materials Tracking Database
  - Materials Order (MO)
  - Delivery Status (DS)
  - Storage Information (SI)
  - Use Status (US)

ON-SITE CONTROL CENTRE
- Periodically check inventory using RFID Reader and PDAs/laptop
- Identify materials for use and transport to location on site

Figure 5.2: Real-Time Materials Tracking Process
5.4 Processes

The real-time materials tracking processes consists of five key components and can be described as follows.

5.4.1 Materials Delivery Process

The process illustrates the case of materials delivery into the construction site, through the automation of the materials tracking and identification of the materials' delivery status. Suppliers or manufacturers should provide purchased materials with attached RFID tags before transporting the materials to the construction site. Here, collaboration is required between suppliers, manufacturers and contractors in order to standardise the types of tags to be attached to the materials. The standardisation of RFID tags for all suppliers are important in order to identify suitable readers for use in detecting RFID tags on arrival at the construction site. It is assumed that construction site managers will track the delivery of high value materials. The materials delivery scenario is illustrated in Figure 5.3.
At this process, the new approach for tracking of materials during delivery of materials into the construction site by the implementation of RFID and PDA or laptop will be undertaken. The following is the descriptions of the materials delivery process as illustrated in Figure 5.3.

1. **Transportation of materials:** Purchase orders for specific materials requested from main office are accepted and prepared for delivery to the construction site. In a real-time materials tracking system, it is required that the materials have RFID tags attached by the suppliers or manufacturers. By the employment of RFID, there is demanding collaboration between contractors and suppliers or manufacturers for the standardisation of the use of the RFID tags. For the purpose of this case, the type of RFID tag used is i-Q32T/i-Q8, which can transmit and receive data at distances of up to 30 metres (100 feet) from a handheld device or up to 100 metres (300 feet) from a fixed interrogator. After that, the purchased materials attached with RFID tags will be ready to be transported from the supplier's storage yard to the construction site.

2. **Materials delivery tracking:** The delivery of tagged materials can be tracked on arrival at the site entrance using portable RFID readers. A site manager or subcontractor with a portable RFID reader can detect the delivery of the tagged materials at the main entrance. The i-CARD 3 portable RFID reader (or as interrogator) can be used to do this. The i-CARD 3 can transmit and receive data at distances of up to 100 metres (300 feet) from an i-Q tag. The i-CARD 3 with an external antenna can easily be integrated with a laptop or PDA to read and write data to the RFID tags.

3. **Materials Order (MO) data collection:** At this stage, the site manager can write some information about the purchased materials to the RFID tag. The materials order data will be saved to the database of the PDA or laptop before transmission to the main computer located in the site office. The data can be used later for identifying the materials delivery information. The transmission of the data can be made either through a wireless network or by direct connection between the PDA or laptop and the main computer at the site.
Chapter 5: Real-Time Materials Tracking Process

office. Materials Order (MO) data that should be stored in the process include the following:

- Materials_ID;
- Materials_Name;
- Suppliers_ID;
- Suppliers_Name;
- Unit_Price (GBP);
- Quantity (unit); and
- Invoice_No.

4. **Delivery Status (DS) data collection:** After records all the materials order data, the delivery status is written to the RFID tags. At this stage, the site manager or subcontractors need to make a decision on the purchase materials whether they should be stored or used immediately. They are also required to confirm that the quality of the materials delivered meets the standard requirements. Order confirmation will be notified to the site office and supplier for record purposes. The Delivery Status (DS) information will be stored on the RFID tags and saved to the database include:

- Delivery_Date;
- Delivery_Status (e.g. Accepted & Use, Accepted and Store, Damaged and Rejected);
- Materials_Status (e.g. Use, Storage, Inform & Return to Supplier); and
- Remarks (e.g. Use Materials Immediately, Store at Storage Area, Reorder and New Delivery on 14/06/2007).
5.4.2 Materials Storage Process

In the case of the materials storage process, the site manager or subcontractor needs to check periodically the availability of materials by using either portable RFID attached to the PDA or the laptop computer at the storage area. This process is required to check the availability of purchased materials at the storage area for installation purposes. Figure 5.4 illustrates the materials storage process as follow.

Figure 5.4: Materials Storage Process
Chapter 5: Real-Time Materials Tracking Process

1. **Materials at the storage area**: At this stage, when the purchased materials arrive at the construction site and the decision is made for it to be stored before use/installation, the site manager or subcontractor will check the availability of the storage and make the decision either to store materials at the storage area or off-site (if storage space is not available). They are also required to identify materials needed for immediate use depending on the work schedule. The materials attached with RFID tags will be temporarily stored at the storage area until there is a demand for them to be installed.

2. **Storage availability checking**: The site manager or subcontractor periodically checks the inventory status at the storage area using the portable i-CARD reader in order to establish the availability of required quantity materials.

3. **Materials identification for use**: The use of materials can be checked through interrogating the project programme to determine which materials should be installed on a specific date or as part of a given task. This allows the RFID reader to track materials to identify those that should be taken out of the storage area for installation purposes. When specific tagged materials are ready to be installed, the transportation of the materials will be arranged to move them to the required location in the construction site. They also need to write information to the RFID tags about the storage information such as name of storeman etc. The date of materials taken out from the storage area is written to the RFID tags. The Storage Information (SI) that should be stored on the RFID tags and saved to the database includes:

   - StorageOUT_Date (e.g. specific storage out date); and
   - Storeman_Name (e.g. specific storeman name).
5.4.3 Materials Use Process

Throughout the materials use process, the site manager or subcontractor is required to check for information on materials usage. In this process, the site manager or subcontractor checks for information about the installation schedule of the purchased materials from the work programme. The materials use process is illustrated in Figure 5.5 and the description of the process is as follows.

1. Materials preparation for use: From the master work programme, the information about the materials can be identified such as which work or part of the building, quantity to be installed and the specific date. It is provided and can be checked easily from the work programme for the use of the specific materials.
2. **Checking installation programme:** At this stage, the site manager or subcontractors check required information of materials attached with the RFID tags to be installed by using a portable RFID reader. This stage provides the right materials for the specific task for installation requirements.

3. **Record Use Status (US) data collection:** The use status data collection needs to be written to the RFID tags and saved to the database. This stage also provides the information about the actual start date and actual finish date for specific task related to materials installation. The following are the Use Status (US) data includes:

   - Task_Name
   - Duration (day)
   - Start_Date
   - Finish_Date

### 5.4.4 On-site Control Centre Process

At this process, the site office is established as an on-site control centre. Figure 5.6 illustrates the process involved at this level in order to gather all the required information about materials delivery, storage and usage at the construction site.

1. **Exchanging real-time materials tracking data:** This stage involves exchanging all data collected at the construction site, such as Materials Order (MO), Delivery Status (DS), Storage Information (SI) and Use Status (US) to be transferred at the on-site control centre. This can be transmitted through the wireless network or through the PDA/laptop, to connect to the site office and main computer.

2. **Records real-time materials tracking database:** The on-site database provides the materials requirements or demands of the real-time materials tracking. The site manager or subcontractors gets up-to-date information of the
Chapter 5: Real-Time Materials Tracking Process

materials order such as the quantity of materials arriving for a certain day, allocation of the materials, either storage area or immediate use on site etc. They are also updating the delivery status data (e.g. delivery date, delivery status, materials status and storage status), and storage information for specific date of materials have been moved out from the storage area, and the name of the storekeeper. In addition, the use status is included, which can give information such as the task name, duration, start date and finish date. The integration with MS Project is able to amend the Actual Start Date and Actual Finish Date immediately during installation of specific materials for the certain work task.

![Image of RFID tags and materials tracking process]

Figure 5.6: On-site Control Centre Process
5.4.5 Report Transmission Process

Figure 5.7 illustrates the report transmission process in order to describe the transmission of real-time materials tracking reports from site office to the main office.

1. **Exchanging real-time materials tracking reports:** At the site office, real-time materials tracking reports will be prepared and sent to the main office via e-mail. These reports will be gathered to the main office in order to produce the information for materials utilisation.

2. **Receiving real-time materials tracking reports:** The main office will receive all materials information from the site office to provide a progress report for related construction projects. Materials information includes: materials order (MO), delivery status (DS), storage information (SI) and use status (US). The main office administration will keep all the materials information for record purposes. They can also plan for future materials purchases.
5.5 Summary

This chapter has presented the processes of the real-time materials tracking framework for improving materials tracking practices in the construction site. The real-time materials tracking processes consists of five main components which derives from the literature reviews and case studies findings. The proposed processes are intended to promote the employment of RFID for automatic materials tracking with the integration with other technologies such as the PDA and the laptop. It is considered that by transformation from the current manual practices to automatic practices of materials tracking could improve materials management on construction projects. The real-time materials tracking process also link with the resource modelling in the project management system in order to establish which of the tagged components are required resources for certain project tasks. The next chapter presents the development of the prototype system for the real-time materials tracking with the integration of the associated technologies.
6.1 Introduction

This chapter presents the development of the prototype system, 'RTM - RealTrack Materials', which is based on the process of real-time materials tracking for integration of materials tracking and resource modelling systems into construction materials management presented in Chapter 5. It starts by examining the choice of the system development environment. Next, it discusses the system architecture and the process of the development of the real-time materials tracking system. Lastly, the chapter demonstrates the operation of the prototype system and concludes with the testing of the prototypes system.

6.2 Development Environment

In software development, the choice of the development environment is very important. The considerations that guide the choice of the hardware and software components of the prototypes system are discussed below.

6.2.1 Hardware

The hardware selected for the development of the prototype system included a laptop, an RFID system (tags and reader), and PDA. The laptop was a TOSHIBA brand with Microsoft Windows XP Professional operating system. The RFID equipment included i-Q8 and i-Q32T active RFID tags with a range of 100 metres/300 ft (read/write range), and an i-CARD 3 (with adjustable output power for
a read/write range that is tuneable up to 100 m/300 ft) for the RFID reader (interrogator). The PDA was an HP iPAQ Pocket PC h5550 with 128 MB of memory. All the hardware used for the prototype system is shown in Figure 6.1.

The RFID products, which were selected, are from and Austrian company called Identec Solutions. The i-Q32T and i-Q8 tags have been selected based on the large memory capacity and make them suitable for use for all the proposed processes. The use of i-Card 3 RFID readers because it is a mobile RFID reader, which can be connected to the PCMCIA slot of a laptop or a PDA. Thus, the i-Card 3 can be easily used to detect tagged materials for different processes have been proposed. The discussion of the components of the RFID system was covered in Section 3.6.2.

Figure 6.1: Hardware for the Prototype System
Figure 6.2 shows the i-CARD 3 components for the RFID reader. The i-CARD 3 resembles a standard PC card with one addition, an external antenna. On the exposed end of the i-CARD 3, there is an antenna connector, a 15-pin serial connector (not used in the PC version of the i-CARD 3) and 3 status LEDs indicating Transmit, Receive and RF Carrier Detect. The LEDs are operational after installation of the appropriate ILR® software. The i-CARD 3 was installed by simply attaching its antenna to the laptop and installing the necessary hardware driver for the specific operating system.

Figure 6.2: i-CARD 3 Components

6.2.2 Software

The integration of RFID-based materials management and resource modelling is required to amalgamate all the chosen software. This entails integrating a database system (such as MS Access) as an intermediate application, MS Project for resource modelling, and MS Visual Basic.Net as a programming language to develop a prototype system. These systems are briefly reviewed below:

- *Microsoft ® Office Access 2003*: MS Access will be used to provide the prototype system with the database application. As a central database for real-time materials tracking system, it can be used to provide the information about Materials Order (MO), Delivery Status (DS), Storage Information (SI), and Use Status (US). It is required a prototype system could read and write data from the RFID tags and integrate it with the database for the purpose of
checking necessary information from related table at the database as mentioned above.

- **Microsoft ® Office Project 2003**: The MS Project will provide the resource modelling facilities with information about materials or components installation such as; task name, duration, start date, finish date and resource usage. The development of the prototype system will allow some data to be downloaded to the database. The integration with the MS Project will occur when the required information from the work programme and add new data of actual start and finish date into the work programme.

- **Microsoft ® Visual Basic.NET 2003**: MS Visual Basic.NET provides the user-interface for the prototype system and provides a graphical programming environment for the interaction with the RFID tags and reader. It will allow the prototype system to detect the RFID tags when the RFID reader is attached to or installed on the PDA or laptop computer. The Identec Solutions Software Development Kit (SDK) has been installed on the laptop computer or PDA in order to provide data exchange between the RFID tags and reader. The user application is capable of developing a user interface using visual programming language (such as Visual C++ or Visual basic.NET and Visual C# to call the functions provided by the Identec Solution (SDK) (Identec Solutions, 2003). The MS Visual Basic.NET was chosen in the design of the prototype system because it can provide a user-friendly wizard and allows the use of a flexible Integrated Development (IDE) for the development of a specific application.

### 6.3 System Architecture

To automate the real-time materials tracking framework, the system architecture of the prototype system illustrated in Figure 6.3 was developed. The 'RealTrack Materials (RTM)’ system architecture was divided into three main components, which are automated materials tracking, database and resource modelling. Each
component plays a different role in the prototype system. The RFID system enabled the automated materials tracking while the central MS Access database provided the information of the ‘Materials Order (MO)’, ‘Delivery Status (DS)’, ‘Storage Information (SI)’ and ‘Use Status (US)’. The MS Project provided the resource modelling function and scheduling information for the system.

![Diagram of System Architecture](image)

**Figure 6.3: System Architecture of the ‘RealTrack Materials (RTM)’ Prototype**

### 6.4 Development of Real-Time Materials Tracking System

The main objective of the development of ‘RealTrack Materials (RTM)’ Prototype was to integrate RFID-based materials management with resource modelling for improving on-site materials management. The development of the prototype system was based on the selection of the hardware and software to facilitate the realisation of the proposed real-time materials tracking processes.
6.4.1 Automated Materials Tracking

The implementation of the RFID system for automatic materials tracking involved RFID active tags (i-Q8/i-Q32T) and the i-CARD 3 (RFID reader). Installation of the RFID system was based on application software provided by IDENTEC Solutions' Software Development Kit (SDK). It allowed the i-CARD 3 reader exchange data with the active RFID tags. The design prototype system allows the user to detect materials attached with RFID tags for each of the proposed real-time materials tracking process. All the information of the materials tracking can be written to the tags and can be read for data input checking. An i-Q8/i-Q32T tag can be placed on the materials so an RFID reader can easily tracked them. The portable i-Card 3 RFID reader could be connected to the laptop or the PDA to track tagged materials. Thus, the use of the i-Card 3 reader with laptop or PDA is easy since it requires. The use of the i-Card 3 reader with the PDA requires an extension PCMCIA slot to be attached to the PDA (refer to Figure 6.1).

6.4.2 Resource Modelling and Installation Scheduling

The MS Project gives the information about the installation programme regarding task 'Task_Name', 'Duration', 'Start_Date', 'Finish_Date', 'Use_Status', 'Predecessors', 'Resource_Name' as depicted in Figure 6.4. All the data required must be input manually to provide resource modelling and installation scheduling through the system. The prototype system was designed to be integrated with MS Project in order to find some information about the work task programme for specific materials during materials delivery, materials storage and materials utilisation. It would help the user in making decision of storage location and materials usage based on the work programme in the MS Project. It also provides real-time information of actual start and finish date for specific materials to be installed by the integration with the work programme. By changing the actual start and finish dates in MS Project, the user can take further actions or decisions if the scheduled task is unable to be completed.
6.4.3 Database Design

The MS Access database comprises tables such as Materials Order (MO), Delivery Status (DS), Storage Information (SI), and Use Status (US). Figure 6.5 shows the design data for every related table in the real-time materials tracking database. The database was designed based on the developed real-time materials tracking process for data recoding. All the data collection will be gathered to the database through the system. Data input to the database can be made automatically through the prototype system. The prototype system provides a function, through which materials information can be saved to the database in the same time data have been written to the RFID tags attached with the materials. The system also allows the user to retrieve some information relating to the materials use status from the database. This allows the system to control the real-time material information without need to key in the data manually to the database. In addition, from the database the user can use the application to process the data to produce reports to present real-time materials tracking information.
6.4.4 Graphical User Interfaces

The development of the Graphical User Interface (GUI) is very important to enable the interaction of the user with the RFID tags. The GUI should be easy to use, especially for the people who work on a construction site. A specific GUI interface was designed for each of the proposed processes. Although they are programmed to perform different functions, all the GUI interfaces follow a similar format and use some common buttons. The GUI can be used on a laptop or PDA providing the same functionality but using a different format.

The GUI provides a number of options for the user. The first step allows the user to connect with the i-Card 3 reader. The “i-Card” menu item can provide the site manager either to connect or disconnect with the reader by pressing the button “Connect” and “Disconnect”. The user can also scan for the tags by selecting the
button “Scan!” and the scanning for the tags can occur. For the communication with
the tags, the user is required to select “PingTag!” button in order for the reader to
transmit the information to the tags. The user can then write the data to the
appropriate provided combo box, by selecting the button “Write!” in order for this
data to be written to the tag. The user can read data from an RFID tag by first
defining the RFID tag ID number at the “RFID TagID” list box, which they wants to
read by pressing the button “Read”.

6.5  Operation of the Prototype System

This section describes the operation of the prototype application with the support of
related screenshots. The real-time materials tracking prototype has five main
graphical user interfaces:

- RealTrack Materials (RTM);
- Order Delivery Confirmation;
- Delivery Status;
- Storage Information;
- Use Status;

6.5.1 RealTrack Materials

When the prototype is started, the main screen is displayed (see Figure 6.6). It shows
the forms for ‘RTM - RealTack Materials’ which display the ‘Start’ and ‘Exit’
button. The ‘Start’ button provides a gateway to other forms in the application. The
‘Exit’ button is a close function when the user has completed using the application.
There are other options to close the application by clicking the ‘x’ at the right corner
of the form. Figure 6.6 shows the view of the main screen (a) for the laptop
application and Figure 6.6 (b) for the PDA application.
6.5.2 Order Delivery Confirmation

After clicking the 'Start' button, the user is redirected to the 'Order Delivery Confirmation' form as shown in Figure 6.7 (a) for the laptop view and (b) for the PDA view. This form provides access to the function of the 'File', 'iCard' and 'Database' menu item and the 'Scan!' and 'PingTag!' buttons. The 'File' menu item provides access to the 'Next' and 'Close' functions as shown in Figure 6.8. The 'Next' menu item enables the user to access other forms in the application while the 'Close' menu item is used when the user has completed using the form. Figure 6.9 shows the 'iCard' menu item from which the 'Connect' and 'Disconnect' functions.
enable the system to be connected to or disconnected from the i-Card 3 RFID reader. The 'Database' menu item provides the 'MO' button in order to provide the gateway to the database at MS Access as shown in Figure 6.10.

Figure 6.7: Order Delivery Confirmation Form (a) Laptop View (b) PDA View

Figure 6.8: 'Next' and 'Close' function in 'File' menu item
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Figure 6.9: 'Connect' and 'Disconnect' function in 'iCard' menu item

Figure 6.10: 'MO' button in 'Database' menu item
Throughout the ‘Order Delivery Confirmation’ form, the connection with RFID reader and scanning the RFID tags is undertaken using the ‘Scan’ and ‘Ping’ buttons. It also allows the user to write by using the ‘Write’ button the ‘Materials Order’ data to the RFID tag in the ‘Materials Ordering Information’ group box. Once the data has been written to the specific RFID tag, this will be allowed to read by using ‘Read’ button to access information that has been written into the tags. The ‘Materials Order (MO)’ data to be written into the RFID tag and saved to the database is as follows:

- Materials_ID;
- Materials_Name;
- Suppliers_ID;
- Suppliers_Name;
- Unit_Price (GBP);
- Quantity (unit); and
- Invoice_No.

Figure 6.11 show that the alert box will display the number of RFID tags found - “Count: 3” after clicking ‘Scan!’ button. The ‘RFID Tag ID’ list box shows the list of RFID tags found with ID number 200096703, 200111126, 200111127. Clicking ‘OK’ allows the user to exit from the alert box.
Clicking on the ‘Ping Tag!’ button to communicate with the selected tag (i.e. in this case, the tag with ID number 200096703) for data to be written to the tag. The alert box shows “Ping Success!” if the RFID reader successfully communicates with the RFID tags (see Figure 6.12). Clicking on ‘OK’ exits the alert box.

![ORDER DELIVERY CONFIRMATION](image)

Figure 6.12: ‘PingTag!’ button function

After completing writing information of the ‘Materials Order (MO)’ data in the ‘Materials Ordering Information’ group box, click the ‘Write!’ button to write the appropriate data of the selected RFID tag. The message ‘Data written to tag!’ is displayed if the data is successfully written to the tag as shown in Figure 6.13. Figure 6.14 shows the message ‘Record Inserted Successfully’, which means that the materials delivery information has not only been written to the tags, but also saved to the database (see Figure 6.15). This is shown in the ‘Materials Order (MO)’ table in the MS Access application. This table lists the ‘MO’, which is similar to the data that has been written to the RFID tag. Clicking the ‘Read!’ button enables the user to read the data written to the RFID tags (see Figure 6.16).
Alert box 'Data written to tag!' displayed.

Figure 6.13: 'Write' button function

Alert box 'Record Inserted Successfully' displayed.

Figure 6.14: 'Record Inserted Successfully' alert box
Figure 6.15: Materials Order (MO) Table

Figure 6.16: Data read from RFID tag ID No 200096703
6.5.3 Delivery Status

Figure 6.17 shows the 'Delivery Status' form, which provides additional data such as 'Project Information' and 'Delivery Status (DS)' in the 'Materials Delivery Status' group box that need to be written to the RFID tag. All the scanning, pinging, writing and reading processes are undertaken using similar procedures as those used in the 'Order Delivery Confirmation' form. The 'Project Information' data added to the RFID tags are as follows:

- Project_Name;
- Project_Location; and
- Site Manager/Subcontractor.

'Delivery Status (DS)' information that has to be written to the RFID tag and saved to the database includes:

- Delivery_Date;
- Delivery_Status;
- Materials_Status;
- Storage_Location; and
- Remarks.

Clicking on the 'Read!' button retrieves the initial data, which is the 'Materials Order (MO)'. The user has to go to the 'Project Information' group box to fill in the related project information such as 'Project_Name', 'Project_Location', 'SiteManager / Subcontractor'. Clicking on the 'Write' button ensures the data is written to the RFID tags and the alert box displayed to show 'Data written to tag!' (see Figure 6.18).
Figure 6.17: ‘Delivery Status’ Form (a) Laptop View (b) PDA View

Figure 6.18: Write Project Information
By selecting some data of ‘Delivery Status’ provided in the ‘Materials Delivery Status’ group box and clicking the ‘Save’ button to add new information into the RFID tag and alert box ‘Data written to tag!’ will be displayed (Figure 6.19). Clicking on the ‘OK’ button will exit and the alert box ‘Record Inserted Successfully’ will be displayed as shown in Figure 6.20. The ‘Delivery Status (DS)’ table in MS Access listed the similar data to that which has been written to the RFID tag as shown in Figure 6.21. The user can check the new data added to the tags by clicking the ‘Read!’ button (see Figure 6.22).

![Figure 6.19: Write Delivery Status](image-url)
Figure 6.20: Data Inserted to Database

Figure 6.21: ‘Delivery Status (DS)’ Table
Project Information and Delivery Status adding to the tag

Figure 6.22: ‘Read’ button function

Figure 6.23 highlights the ‘MsProject’ button, which provides the link to the work project programme in the MS Project application. This allows the user to make a decision whether materials should be used or stored by checking the work programme in the relevant project file.
6.5.4 Storage Information

Figure 6.24 shows the ‘Storage Information’ form ((a) Laptop View, (b) PDA View). This form provides the user with the additional ‘Storage Information (SI)’ such as ‘StorageOUT_Date’ and ‘Storeman_Name’, which can be written into the RFID tags. The system performs the scanning process with the RFID tags, which are attached to the materials as shown in Figure 6.25. There is only one tag with ID number 200111126, which has been detected and it means only the materials attached to this tag will be stored at the storage area. The material attached with RFID tag with ID number 200096703 was not detected because it was kept off-site while the material with RFID tag number 200111127 was not detected because it had been rejected and returned to the supplier.
Clicking on the ‘Read!’ button allows the user to read the initial materials information (as shown in Figure 6.26), which includes ‘Materials Ordering Information’ and ‘Materials Delivery Status’. Supplying the relevant ‘Storage Information’ and clicking on the ‘Save’ button writes new data to the RFID tag (with ID number 200111126) and ‘Data written to tag!’ is displayed as shown in Figure 6.27. Clicking on the ‘OK’ exits the message box and immediately the ‘Record Inserted Successfully’ message box appears to inform the user that the data has been successfully inserted into the database (see Figure 6.28). Clicking on the ‘Read!’ button again reads all the data that has been written to the tags as shown in Figure 6.29. It is shown that the new ‘Storage Information’ has been added to the RFID tag. Figure 6.30 (a) shows the ‘SI’ menu item functions while Figure 6.30 (b) shows the ‘Storage Information (SI)’ table in the MS Access application. The ‘SI’ table lists the ‘Storage Information’ data (see Figure 6.30 (b)) with only one record (for RFID tag No 200111126). The ‘MsProject’ button allows the user to identify which task and installation date relate to specific materials (see Figure 6.23).
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Figure 6.28: Data Recorded to the database

Figure 6.29: New information ('StorageOUT_Date' and 'Storeman_Name') has been added and written into the RFID tags.
Figure 6.30: (a) ‘SI’ menu item function (b) ‘Storage Information (SI)’ table in the MS Access Application

6.5.5 Use Status

Figure 6.31 (a) and (b) provides the ‘Use Status’ form for both the laptop and PDA applications. Using this form, additional data on ‘Use Status’ can be written to the RFID tags. The ‘Use Status (US)’ information includes the following:

- Task_Name;
- Duration(day);
- Start_Date; and
The 'Scan!' button function and 'PingTag!' button function in the 'Use Status' forms allow the scanning and pinging process to occur. The tagged materials are identified and the data is written to or extracted from them.

![Image of 'Use Status' form](image)

Figure 6.31: 'Use Status' Form (a) Laptop View (b) PDA View

Clicking the 'Read!' button will read the previous data that has been written to the related RFID tag which includes 'Materials Order (MO)', 'Delivery Status (DS)' and 'Storage Information (SI)'. Figure 6.32 shows the 'Success' message box displayed after clicking the 'LoadData' button. The data has been retrieved from 'Use Status (US)' table in the MS Access application (see Figure 6.33). Choosing the appropriate data of the 'Use Status' and clicking 'WriteUseStatus!' button will write the data to the RFID tags (Figure 6.34). The user can check that the data has been written to the tags by clicking the 'Read!' button (as shown in Figure 6.35).
The successful retrieve data from ‘US’ table in the database.

Figure 6.32: ‘LoadData’ button function (‘Success’ alert box)

Figure 6.33: ‘Use Status (US)’ Table
Figure 6.34: Write Use Status

Figure 6.35: Read Use Status Data
Figure 6.36 highlights the contents of an MS Project file, which stores the project programme. By clicking on the 'ActualStartDate/ActualFinishDate' button, the user can add new information on the 'Actual Start' and 'Actual Finish' thus providing real-time information on the installation of specific materials at the construction site.

6.6 System Testing

Testing is required to examine the complete prototype system before it can be evaluated by end users. According to Laudon and Laudon (2002) system testing is needed to test the functioning of the prototype system as a whole in order to determine if discrete modules will function together as planned. The testing process tries to verify the whole system functionality and whether discrepancies exist between the way the system actually works and the way it was conceived. There are two stages of system testing which are pre-design test and post-design test (Mohamed, 2006). The pre-design test (where no coding yet existed) happened during the design stage where the paper-based system was designed to review the
specification or design document aimed to develop a feasible real-time materials tracking system on the construction project.

Once coding began, 'coding walkthroughs' were used to review the program code tested by computer runs at the stage called the post-design test. Throughout this stage, the debugging process was undertaken for discovering and eliminating errors and defects (bugs) in program code. The debugging process was repeated until all the errors discovered from the code were eradicated. The process of building a prototype system, testing it out, refining it, and trying again and again was an interactive process of system development because the steps required to build a system repeated all over again.

Several tests were carried out in order to examine all the functions of the developed prototype system, so that it could be operated appropriately. After undertaking many debugging tests that showed that the system was running successfully, the final task of the prototype system testing involved self-evaluation by the researcher using several data sets. This was done to examine the appropriate way of handling the RFID tags and readers and the interaction with the prototype system. This involved varying the positioning of the RFID tags on the sample materials and scanning/pinging them from different distances and angles. The user can easily choose provided the data in the prototype system, in order to test the system is working appropriately. The process of the prototype testing could be concluded that generally the system features were working appropriately and necessary to satisfy the main objective of the integration of materials tracking and resource modelling system to improve materials management on construction projects.
6.7 Summary

The choice of the hardware and software for the development of the prototype system was discussed at the beginning of the chapter. This chapter also described the system architecture and the process of system development with a view to establishing the required features of the prototype system. It then presented the operation of the prototype system, which consists of the order delivery confirmation, delivery status, storage information and use status. The chapter concluded with the testing of the prototype system, which examined whether all the functions of the prototype system operated appropriately. The next chapter presents the evaluation of the prototype system. It discusses the results from the evaluation of the prototype system and the requirements necessary for effective use of real-time materials tracking.
CHAPTER 7
EVALUATION OF THE PROTOTYPE SYSTEM

7.1 Introduction

This chapter presents the system evaluation process. It starts with an introduction to the evaluation aim and objectives. This is followed by the evaluation process and the outcomes. It also discusses the benefits and limitations of the prototype system, and the requirements necessary for effective use of real-time materials tracking.

7.2 Aim and Objectives of Evaluation

The aim of the evaluation was to determine the appropriateness and functionality of the developed prototype system to improving materials management practices on the construction site. The specific objectives were:

- To assess the ease with which the prototype system can be used (e.g. effectiveness, practicality and usability);

- To obtain comments and recommendations for improving the prototype system; and

- To determine the requirements necessary for effective use of the prototype system (such as skills and knowledge requirements).
7.3 Evaluation Process

This section presents the process of the evaluation, including the evaluation method and the questionnaire design.

7.3.1 Evaluation Method

Evaluation plays an important part in software development (Gediga et al., 1999). According to Faulkner (1998), the important role of evaluation is to eliminate any problems that may be present in a system. Anumba and Scott (2001) asserted that the evaluation activity involves exploring the code, and examining the reasoning processes, intermediate results and conclusions of the system, to help detect errors as early as possible in the development cycle. In addition, from a practical point of view, the end-users want to be convinced that a system is getting the right answers for the correct reasons; otherwise, they will not use the system.

According to Obonyo et al. (2005) and Gediga et al. (1999), there are two main categories of evaluation of software systems; formative and summative evaluation. The proposed general framework for the life cycle of a prototype system can be depicted in Figure 7.1.

![Figure 7.1: A General Prototyping Framework and Evaluation Approach (adapted from: Mohamed, 2006; Davies et al., 2004; and Smith, 1991)]
The general prototyping framework makes a distinction between two kinds of system evaluation activity, primarily in terms of when they take place in a standard linear model of a system life cycle. Formative evaluation involves assessing the shape of a system whilst in the development process itself. Formative evaluation may be used to make crucial changes to the design of the system, while it will primarily review issues of functionality by notions of a system's usability and utility formulated in the changing context of some organisations. Summative evaluation occurs after a system has been implemented, and can sometimes be referred to as a post-implementation evaluation. Traditional approaches to summative evaluation involve signing off a system against its specification. Summative evaluation may also produce ideas for new systems and/or components.

**Formative evaluation**

Gediga *et al.* (1999) suggest that formative evaluation is undertaken during the development phase in order to improve a system iteratively, until the desired design objectives are reached and the weaknesses of the software are eliminated. According to Remenyi and Smith (1999), the formative evaluation process has three key characteristics:

- Formative evaluation applied correctly is a frequent, if not quasi-continuous process;
- An evaluator's perception of what is being evaluated changes and the value put on his/her perceptions changes as he/she learns more about the project; and
- The objectives of the system development will evolve during the formative evaluation process.

**Summative evaluation**

Summative evaluation is the evaluation of a final design regarding guidelines, standards, or other objectives of the evaluation (Gediga *et al.*, 1999). The purpose of
the summative evaluation is to assess and confirm or refute the value of the realised system (Remenyi and Smith, 1999). Much of the summative evaluation is managed and performed by those who have designed the system being implemented (Davies et al., 2004). The most frequently evaluated criteria seem to be those of information quality (e.g. accuracy, adequacy and appropriateness) along with facilitating criteria, such as user satisfaction and attitudes.

Evaluation Approach

Formative evaluation was an integral part of the evaluation methodology, throughout the development of the prototype system. The summative evaluation approach was used to assess the effectiveness, practicality, usability and recommendation for improvement when the ‘RTM - RealTrack Materials’ prototype system was considered virtually complete. The main aim of the summative evaluation was to test the capability of the prototype for tracking materials in the different processes identified in the real-time materials tracking framework. The summative evaluation was also undertaken to evaluate the requirements for effective utilisation of the prototype system.

There were two stages of the evaluation process. The first stage involved validation of the real-time materials tracking process for the prototype system. The second stage involved evaluation of the prototype system to ascertain how well it met the original development objectives. The advantage of the evaluation of the prototype system based on the feedback from potential users is that it can save cost and unnecessary rework. The evaluation approaches adopted by the researcher are illustrated in Figure 7.2.
Noble (1999) argued that a skilled practitioner should be used to evaluate the effectiveness of a system. For this research, skilled practitioners (i.e. site managers or project managers) involved in managing materials management were interviewed in order to access the usability of the prototype system. Five participants were involved in the evaluation sessions. The evaluation was carried out with the same organisations involved in the case studies stage. The project manager or site manager of six construction organisations were contacted via email and follow-up by telephone explaining the aim of evaluation session. Of these six, two gave final approval with appropriate site managers were suggested to participate. Two of the site managers that participated in the evaluation were among those interviewed at the case studies stage. However, one of the respondents involved in the case studies had moved on to another project.

The participants from the other case study organisations were unable to participate due to unforeseen circumstances and internal constraints in their organisations. Three independent site managers were used to establish whether the developed prototype system was applicable to external organisations to increase the validity of the system in a real-time situation. It should be pointed that the evaluation not only too place on the demonstration regarding its use, but also on the actual software utilisation by the
participants in order to allow them to experience for using the prototype system. Therefore, the respondents were given the chance to test the prototype system and were encouraged to ask questions if they had any difficulties with the system.

The combination (e.g. site managers involved with case studies and randomly selected site managers) provided the opportunity to explore variations in the experts' feedback when evaluating system performance. The evaluation sought the advice of parties internal and external to the system on:

- what they liked about the system;
- what they thought would work; and
- what they thought would not work in a commercial scenario.

In addition, the evaluation sessions were useful in highlighting: areas of knowledge missing from the systems; areas of the system, which were not being used (covered); and whether the knowledge was consistent with that of experts (Anumba and Scott, 2001). A special visit was made to five organisations prior to the evaluation date and a set of questionnaires were used to evaluate the system. Background information about the evaluation sessions and participants involved is presented in Table 7.1.

Table 7.1: Details of Participants Involved and Evaluation Approach

<table>
<thead>
<tr>
<th>Participants</th>
<th>Type of Project</th>
<th>Person Interviewed</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organisation 1</td>
<td>Student Accommodation Project</td>
<td>Project Manager</td>
<td>Evaluation Approach</td>
</tr>
<tr>
<td>Organisation 2</td>
<td>Shopping Centre Project</td>
<td>Project Manager</td>
<td>Interview</td>
</tr>
<tr>
<td>Organisation 3</td>
<td>Building Expansion Project</td>
<td>Senior Building Manager</td>
<td>Presentation on the background to the process and the prototype system</td>
</tr>
<tr>
<td>Organisation 4</td>
<td>Residential Development Project</td>
<td>Project Engineer</td>
<td>Demonstration of the prototype</td>
</tr>
<tr>
<td>Organisation 5</td>
<td>Hospital Building Project</td>
<td>Senior Engineer</td>
<td>Prototype testing by respondent</td>
</tr>
</tbody>
</table>

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7.3.2 Questionnaire Design

The design of the questionnaire was based on the aim and specific objectives of the evaluation stated in Section 7.2. The questionnaire survey techniques have been used to evaluate the prototype system (refer Chapter 2 section 2.5.4). Copy of the evaluation questionnaire is provided in Appendix C. The questionnaire was structured into three main parts as follows:

- **Part A: Background Information**: This part requested information about the participant’s name, job title or position in their organisation, experience in the construction industry, business address and contact number.

- **Part B: RealTrack System**: This part contained four sections, including:
  - Section 1 was aimed at assessing the effectiveness of the prototype system;
  - Section 2 was aimed at assessing the practicality of the prototype system;
  - Section 3 was aimed at assessing the usability of the prototype system; and
  - Section 4 required participants to give general comments on the prototype system with regard to potential improvements, the main benefits and the barriers to the use of the system.

In Sections 1 to 3, participants were required to tick the box that best represented their assessment of the system on a scale of 1 (strongly agree), 2 (agree), 3 (neutral), 4 (disagree) and 5 (strongly disagree). Section 4 required the participants to give their feedback on general comments.

- **Part C: Requirements for Effective Use of Real-time Materials Tracking**: This part required participants to comment on the skills and other requirements for the effective deployment of materials tracking systems such as ‘RTM - RealTrack Materials’.
7.4 Evaluation of Real-Time Materials Tracking Process

Evaluation of the process for the integrated materials tracking and resource modelling system was undertaken to determine the relevance and applicability in improving construction materials tracking practices. Evaluation was undertaken along with the evaluation session of the prototype system. This involved interviews with five respondents from construction organisations as described in Table 7.1. The participants were encouraged to suggest improvements during the evaluation session. During the interviews, the focus was primarily on gathering qualitative data such as the industry expert’s views and opinions on real-time materials tracking process.

The real-time materials tracking process was presented and explained using a PowerPoint presentation. During the interviews, there also a greater challenges to get the interviewees feedback on the potential implementation of the real-time materials tracking system in the construction industry. Therefore, the questions asked were loosely structured. The advantage of loosely structured interviews is that more issues that are complex can be probed, answers can be clarified and a more relaxed research atmosphere may result in more in-depth as well as sensitive information (Bryman and Bell, 2003). There are also disadvantages in that the data is time consuming and difficult to collect and analyse, and there is greater potential for the interviewer’s bias to influence the outcome. During the interviews, the following key questions were discussed:

- How useful do you consider the overall real-time materials tracking process?

- What barriers do you see in the realisation of real-time materials tracking process in the construction industry?

- How well does the system help in avoiding materials tracking problems?

From the evaluation, the key suggestions for improvement of the real-time materials tracking process were as follows:
There were difficulties in utilising emerging technologies in materials tracking practices at the construction site. The most important consideration from the interview was about the cost of the emerging technologies should be allocated into the company budget by the implementation of such RFID system (tags and reader). The construction organisation taking this as long term planning to use, because they must take a correct step to change their current manual practices to be automated materials tracking.

It was also necessary to take into consideration the standardisation of the use of RFID tags in materials tracking practices in construction project. This is important to all parties (clients, contractors, suppliers, manufacturers) involved in the construction project, will be cooperated to employ similar RFID tags to be used for certain project. They are also required to produce a standard procedure in order to implement such a RFID system in a more systematic approach.

An illustrative comment from a project manager interviewed was that, “In the process, how to manage tagging of materials for a million parts in a building”. They are also highlighted the problems with the operatives at workforce are not interested and not appreciated to implement the RFID for materials tracking. This feedback needs to be thoroughly thought through for improving the process of materials tracking through the use of RFID technology.

Consider customisation of the materials management processes. This will be required an appropriate procedure to implement RFID into the materials management process such as planning, ordering and delivery, and use of materials at the construction site.
7.5 Prototype Evaluation Outcomes

7.5.1 System Effectiveness, Practicality and Usability

Table 7.2 shows the results from Sections 1 to 3 of the evaluation questionnaire. The table presents the numbers of respondents associated with each rating on the assessment scale (rating from 1 – Strongly Agree to 5 – Strongly Disagree) for each of the key aspects of the system. An analysis of the responses provided by construction site managers is presented under the specific objectives listed in Section 7.2. The discussion of the results from evaluation based on the objectives is presented as following.

(a) System Effectiveness

Figure 7.3 shows the overall rating from the evaluators on the effectiveness of the prototype system. The findings show that the majority of feedback from the participants on the system effectiveness was ‘Strongly Agree’, ‘Agree’ and ‘Neutral’. The evaluators agreed that the prototype system was a useful application by majority of them (3 out of 5 peoples) selected ‘Agree’ for question E1. They also indicated that the system had the potential to improve the effectiveness of materials tracking in the construction site, with many of them choosing ‘Agree’ (4 peoples) for question E2. Question E3 required the participants give their opinion on the system enhancement for handling materials delivery on site. From the five people that participated in the evaluation session, two participants chose ‘Strongly Agree’ and ‘Agree’ respectively, however one of the participants selected ‘Neutral’ for the level of the agreement to the question. The participants ‘Strongly Agree’ (3 out of 5 peoples) for question E4, which the system can improve inventory management through effective materials tracking in the storage area. The evaluators also ‘Agree’ with the system can facilitate tracking of the materials usage (question E5) and address an important construction industry problem for question E6. As a result, based on the findings most of the participants agreed with the effectiveness by all of them provided an answer for every questions by ‘Strongly Agree’ and ‘Agree’.
Table 7.2: The Responses to Evaluation Questions

<table>
<thead>
<tr>
<th>No</th>
<th>Evaluation Questions</th>
<th>Section 1: System Effectiveness</th>
<th>Rating</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>The RealTrack Prototype System</td>
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<tr>
<td>E1</td>
<td>is a useful application.</td>
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<td>E2</td>
<td>will improve the effectiveness of materials tracking.</td>
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<tr>
<td>E3</td>
<td>will enhance the handling of materials delivery.</td>
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<tr>
<td>E4</td>
<td>will improve inventory management through more effective tracking of materials in the storage area.</td>
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<tr>
<td>E5</td>
<td>will facilitate the tracking of materials usage.</td>
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<tr>
<td>E6</td>
<td>addresses an important industry problem.</td>
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Section 2: System Practicality

<table>
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<tr>
<th>No</th>
<th>Evaluation Questions</th>
<th>Rating</th>
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<tr>
<td>E7</td>
<td>I consider RealTrack a practical solution to improving materials tracking and management.</td>
<td>3</td>
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<td>E8</td>
<td>I am comfortable with the idea of materials tagging using RFID.</td>
<td>3</td>
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<tr>
<td>E9</td>
<td>Information can be easily retrieved from tagged materials.</td>
<td>3</td>
</tr>
<tr>
<td>E10</td>
<td>The system is financially feasible as RFID tags cost less than £15 each.</td>
<td>1</td>
</tr>
<tr>
<td>E11</td>
<td>The system can be highly effective for high value materials.</td>
<td>2</td>
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Improving Materials Management on Construction Projects
<table>
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<tr>
<th>No</th>
<th>Evaluation Questions</th>
<th>Rating</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>1 Strongly Agree</td>
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<td></td>
<td></td>
<td>No</td>
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<td></td>
<td><strong>Section 3: System Usability</strong></td>
<td></td>
</tr>
<tr>
<td>E12</td>
<td>RealTrack is a user friendly system.</td>
<td>1</td>
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<tr>
<td>E13</td>
<td>The system effectively communicates information.</td>
<td>1</td>
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<tr>
<td>E14</td>
<td>The system user-interface is simple enough for a construction team leader to learn and use for daily tasks.</td>
<td>3</td>
</tr>
<tr>
<td>E15</td>
<td>I am convinced that site managers would use the system.</td>
<td>2</td>
</tr>
<tr>
<td>E16</td>
<td>Considerable training will be required for effective use of the system.</td>
<td>2</td>
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</table>
(b) System Practicality

Figure 7.4 shows the overall rating from participants on the practicality of the prototype system with regard to questions E7 to E11. The majority of the evaluators assessed the system as ‘Agree’ and ‘Neutral’. The participants considered the system as a practical solution to improving materials management by 3 out of 5 peoples ‘Agree’ with the question E7. They are also comfortable with the idea of materials tagging using RFID as 3 peoples selected ‘Agree’ for question E8. For question E9, three of the participants assessed ‘Strongly Agree’ for the system practicality, which the information can be easily retrieved from tagged materials. However, one of the site managers selected ‘Disagree’ (for question E10) to the practicality of the prototype system was not financially feasible as RFID tags cost less than £15 each. This situation indicates that some of the site managers will look at different perspectives where either the cost of the RFID or other factors for the system can be practiced in the construction site. The participants also ‘Agree’ (3 people) that the system can be used effectively for tracking high value materials (E11). In terms of the practicality of the system, it can be concluded that the developed prototype system can be practiced in the construction materials management practices.
Chapter 7: Evaluation of the Prototype System

Figure 7.4: Overall rating for System Practicality

(c) System Usability

Figure 7.5 shows the majority of the evaluators judged that the system usability was ‘Strongly Agree’, ‘Agree’, ‘Neutral’ and ‘Disagree’. The participants agreed that the prototype system was user-friendly by many of them (3 people) selecting ‘Agree’ answer for question E12. The system also can effectively communicate with the information provided in the graphical user interfaces agreed by participants with four peoples ‘Agree’ for question E13. The participants selected ‘Strongly Agree’ (3 out of 5 peoples) for question E14, which the system graphical user interface is simple enough for a construction team leader to learn and use for daily tasks. Nevertheless, the site manager not positively agreed with the statement that the site manager would use the system by only two peoples have been chosen ‘Agree’ and other participants selected ‘Neutral’ for question E15. One of the site managers selected ‘Disagree’ (for question E16) to the considerable training will be required for effective use of the system for the system usability. This shows that, construction professionals who have work experience with the ICT environment are confident to use the system. Generally, the overall participants agreed for the system usability.
In general, the five evaluators were satisfied with the effectiveness of the prototype system in addressing on-site materials tracking and inventory management processes, although there were suggestions for improvements to the system. The evaluation results show that the participants agreed that the system offered a useful and systematic approach to solving materials management on construction projects. It shows that the ‘RealTrack Materials – RTM’ prototype system could facilitate the tackling of on-site materials tracking problems.

The following section discusses the general comments on the prototype system by the participants.
7.5.2 Suggestions for Improvement

The participants involved in the evaluation session each made at least one comment on Section 4 (General Comment) in the evaluation questionnaire. The questions in this section were on how to improve the system, the benefits of the prototype system, barriers to the use of the prototype system and further comments.

The suggestions for the improvement of the developed prototype system include:

- The participants suggested that to provide some features on the graphical user interface of the prototypes system in order to tag bulk materials such as over a million components;

- The graphical user interface of the prototype system could provide the identification of the materials usage from programme when specific items are required. The developed prototype system only can be integrated with the work programme in MS Project and requires the user to search related work task for specific materials;

- There is a need to make the system user interface as simple as possible and to include buttons that reveal the details as needed;

- Adding extra features such as the location of stored materials, report generation of materials stored/linked to each RFID tag; and

- Provide more PDA applications rather than laptop or desktop use for materials tracking due to the constraints of some storage areas and site.
7.5.3 Benefits of the Prototype System

The 'RealTrack' prototype system is intended to improve materials management on construction projects through the integration of materials tracking and resource modelling systems. The relevance and capability of the prototype system to improve on-site materials tracking and inventory management processes have been confirmed and verified through the evaluation session. In addition, through the evaluation session, the participants identified several benefits of the prototype system; these include:

- The system does not rely on a gateman or storekeeper for tracking materials deliveries and less control of paper-based reports. This will be able to create the environment in facilitating materials tracking become more easily and effectively;

- The system provides the tools to assist closer tracking of materials delivered to site and less man hours checking on the delivery of materials to site;

- The system enables good control over materials to keep projects moving efficiently;

- The system is a potentially useful tool for logistic management in knowing when materials arrive on site and what has been delivered; and

- The system provides a convenient and easy tracking of materials during materials delivery and inventory management processes.
Chapter 7: Evaluation of the Prototype System

7.5.4 Limitations of the Prototype System

The evaluation sessions also investigated the comments regarding the limitations of the prototype system. There were a few limitations of the prototype system highlighted by the participants during the discussion:

- The participants commented on the difficulties to tag materials such as concrete and aggregates because of the quantities and nature of the materials used;

- There was concern over the cost of the RFID tags and readers, and getting the suppliers and manufacturers to buy the system to facilitate their materials tracking;

- The participants commented on how to tag all materials in a building. There is also the problem with the workforce operatives who were not interested in implementing the new tools for tracking materials;

- There were also constraints on site managers with limited computer literacy. Other restrictions such as size and cost of the project, ease of use and participation from suppliers also resulted in the implementation of the prototype system; and

- Other limitations mentioned included the cost and training needed for the adoption of the prototype system. There was also the appreciation of all contractors and sub-contractors, and the storekeeper with the implementation of the prototype system in the current practices of materials management processes.
7.5.5 Requirements for Real-Time Materials Tracking

This section discusses the requirements necessary to help the uptake of RFID and associated technologies for materials tracking system. This section solicited comments regarding the skills and knowledge requirements for effective use of the real-time materials tracking system. It required the identification of the skills needed for construction workers in order to facilitate materials tracking using RFID and associated technologies. The majority of the participants agreed that some training was needed for the adoption of the prototype system. Only one stated that too much training was necessary. One of the respondents suggested that the prototype system had potential for commercialisation in the future.

The requirements for effective use of the prototype system highlighted by respondents include:

- **Reasonable level of computer literacy**: The system requires the user to be familiar with the basics of MS Access and MS Project. They were required to have basic computer skills in order to understand a menu driven system for effective use of the prototype system. Construction site managers should therefore be provided with basic and advanced ICT skills;

- **Knowledge of emerging or innovative technologies**: Users should have the required skills to operate such technologies e.g. RFID and PDA;

- **Basic knowledge of materials management**: Users needed to have experience and materials managements skills especially in tracking of materials on the construction site;

- **New operating skills**: Users needed to have knowledge of the application of the new system and tools (such as RFID and PDA) in the tracking of materials on the construction site; and
- **Planning skills**: Administrative planning skills were necessary for the implementation of the new materials tracking system on the construction site.

### 7.6 Summary

This chapter has described the evaluation approach adopted for a ‘RealTrack’ prototype system. The research adopted a series of interviews and a questionnaire in the evaluation of the prototype system. The findings from the evaluation show that the participants felt that the functionality of the prototype system was appropriate for addressing on-site materials management problems, although there are some limitations, which would need to be addressed in the future. Finally, the investigation to identify the requirements necessary (such as skills and knowledge) for the adoption of the real-time materials tracking system was undertaken. It was identified that the main limitation to the use of the prototype system (with deployment of RFID) on construction projects was primarily the cost. There was also a need for skills training for the effective implementation of the real-time materials tracking system in construction projects in the future.

The next chapter summarises the conclusions and recommendations of the research.
CHAPTER 8
CONCLUSIONS AND RECOMMENDATIONS

8.1 Introduction

This chapter concludes the thesis. It starts with a brief summary of the research and demonstrates how the aims and objectives were achieved. The key conclusions drawn from the research project are highlighted. The achievements of the research in terms of contribution to knowledge are also presented. Finally, the chapter presents the main limitations of the research and concludes with some recommendations for further research.

8.2 Summary

The aim of this research project was to develop mechanism to improve materials management on construction projects through the integration of materials tracking and resource modelling system. The rationale for conducting the research was the need for a well defined real-time materials tracking system to improve on-site materials tracking and inventory management processes. The aim was achieved through several specific objectives including:

- To review existing literature on materials management processes in construction projects;

- To review current industrial practice in materials management and to establish key problem areas and elements of good practice;

- To establish the requirements for integrating materials management and resource modelling in project management systems (i.e. real-time materials tracking);
Chapter 8: Conclusions and Recommendations

- To develop and evaluate a prototype system for integrating materials management and resource modelling; and

- To investigate requirements necessary for effective use of the system, such as skills and knowledge requirements.

The specific tasks undertaken in this research, with respect to the research objectives are summarised below.

**Objective 1: To review existing literature on materials management processes in construction projects.**

The review of existing literature on materials management practices identified many problems in managing materials on construction projects such as shortages, delays in supply, price fluctuations, damage and wastage, and lack of storage space. Delays in materials supply and lack of storage areas were identified as the major problems in materials management. There is a variety of approaches currently used to solve these problems. These include proper planning of materials logistics, JIT techniques, and the implementation of ICT such as bar-coding. Generally, technologies are not being used to overcome human error such as double handling in materials tracking imposed on many construction projects. Paper-based reports are mostly used to record and exchange information related to the materials component within a supply chain; this is problematic, error-prone, and inefficient.

The key findings on the materials management processes and technologies implementation has been presented in Chapter 3. The application of ICT to support current practices of materials management on the construction site was considered more effective for managing construction materials on site. Emerging technologies such as RFID have been also discovered to have the potential to improve materials management (especially materials tracking).
Objective 2: To review current industrial practice in materials management and to establish key problem areas and elements of good practice.

Preliminary case studies were used to investigate current materials management practices, problems, ICT implementation, and the possibility of using emerging technologies (such as RFID, wireless technologies) to improve current practices. Details of the key findings from the case studies were presented in Chapter 4. The case studies were based principally on semi-structured interviews with those responsible for materials management and site logistics from each of six different construction organisations. Different types of construction projects provided a chance to explore the current situation of materials management on construction projects and to prioritise the problems identified. The case study findings revealed that many of the construction projects have similar problems with storage constraints. Handling and monitoring activities at site (such as materials tracking) are facilitated by manual operations in most of the case studies, with the potential for human errors and excessive paperwork. The suggestion for good practice includes the use of tagging technologies such as bar coding and RFID to upgrade current practices in materials tracking.

The case studies also discovered the relevant issues for improving materials tracking and the overall process of materials management. It highlighted the importance for each construction organisation to have a transformation from current manual practices to automatic tracking as follows:

- Facilitating tracking of materials delivery;
- Identification of materials at the storage area; and
- Controlling of materials to reduce damage, and reduction of paperwork.
Objective 3: To establish the requirements for integrating materials management and resource modelling in project management systems.

The requirements for integrating materials management and resource modelling in project management systems were investigated, as part of the in-depth case studies described in Chapter 4. The case studies revealed that there was a potential to use RFID to support materials management practices to improve on-site materials tracking (e.g. location/safety, identification, and updating). Also identified was the lack of robust ICT tools, which could integrate materials, labour and plant into one system, and high level programming and scheduling technology. There is significant to transform manual practices to automatic practices to improve materials management practices and provided with real-time information. The requirement for integrating materials management and resource modelling in project management in order to establish real-time materials tracking of the tagged components is available to carry out the specified tasks. The findings from the case studies were used as a guide to developing the prototype system through the integration of RFID-based materials management with resource modelling systems.

Objective 4: To develop and evaluate a prototype system for integrating materials management and resource modelling.

This objective involved the development and implementation of the processes of the real-time materials system for the construction site. The processes consisted of a materials delivery process, a materials storage process, materials use process, on-site control centre process and report transmission process. The materials delivery process identified the automated materials tracking using RFID and to provided the status of the materials delivery to the construction site. The materials storage process identified the information on the inventory at the storage area by automated tracking using RFID. The materials utilisation process sought to provide information about the real-time materials usage at the construction site. It also required the site manager to check the installation schedule of the purchased materials from the master work programme. The on-site control centre provided data gathering at the main computer of the site office and transferring real-time materials tracking reports to the main
office. The report transmission process involved receiving all the materials information from the site office and generating the reports. Explanation of the real-time materials tracking processes was described in Chapter 5.

Based on the materials management issues identified during the literature review and the case studies, the integration of RFID-based materials management with resource modelling, was encapsulated in a computer-based prototype system using MS Visual Basic.NET. The prototype system was named ‘RealTrack Materials (RTM)’. Details of the system development and operation were presented in Chapter 6. The prototype provided automatic updates of the database (MS Access) to ensure real-time accuracy. In general, the prototype can provide the user with materials information in-real time when materials are attached with the RFID tags detected or scanned by a RFID reader. Therefore, whatever information has been written into the RFID tags attached to certain materials, this could be read automatically by the user. The central database also provided the ability to insert and retrieve the data through the prototype system.

The prototype system was evaluated by relevant end-users. The evaluation of the prototype system was carried out when the ‘RealTrack Materials (RTM)’ prototype system was considered virtually complete as presented in Chapter 7. The research adopted a series of interviews and a questionnaire in the evaluation session of the prototype system. The five participants who were involved in the evaluation sessions were selected to provide feedback on the appropriateness and functionality of the prototype system in addressing materials management problems. The results of the evaluation confirmed the effectiveness of the prototype system in addressing materials management problems, although there were some limitations such as the system design and user interface which needed to be improved. The prototype system also provided many benefits, and had great potential to improve materials tracking and inventory management processes, also by integrating with resource modelling.
Objective 5: To investigate requirements necessary for effective use of the system, such as skills and knowledge requirements.

Appropriate requirements for effective use of real-time materials tracking system are presented in Chapter 7. Interviews were carried out during the evaluation session to obtain feedback of the requirements needed for the construction workers to facilitate the prototype system with the deployment of RFID technologies. The results showed that there was a requirement for skills training for the construction workers to effectively implement the real-time materials tracking system in construction projects in the future. There was also a requirement for the construction workers to have knowledge in the RFID technologies and basic computer literacy skills (such as MS Access and MS Project) for the deployment and effective use of materials tracking systems such as the proposed prototype system. The implementation of the system would however demand very different processes around materials management processes.

8.3 Conclusions

This research investigated the improvement of materials management practices through the integration of materials tracking and resource modelling systems. The following conclusions can be drawn from the research:

- The real-time tracking system provides a robust and innovative approach for addressing on-site materials tracking and inventory management problems by the integration of the RFID-based materials management with resource modelling in the project management system.

- The developed prototype system provides a practical approach for automatic updating of the database to ensure real-time materials tracking through the implementation of emerging technologies such as RFID.
Chapter 8: Conclusions and Recommendations

- The integration with the work programme in the Microsoft Project provides the database system with real-time information on the resources for certain project tasks (e.g. the usage of the tagged components).

- The RFID system provides facilities to resolve the problems of current manual practices (e.g. error-prone, excessive paperwork, inefficiency) of materials tracking that may occur in managing materials on the construction site. Other technologies such as PDA are also supportive in making materials tracking more effective by providing for real-time data capture and the easy transfer of information within the construction site.

- RFID is one of the automatic identification technologies with the potential to improve materials tracking system specifically for the overall materials management processes on construction projects. There are advantages in employing the RFID system into materials management such as it is not easily damaged in the harsh conditions (e.g. construction sites). However, the consideration of the cost of the whole RFID system becomes an important factor especially on large scale projects when required thousands of RFID tags are needed.

- In construction projects, MS Excel and fax machine are commonly used to facilitate the procurement process in materials management. They are also limited in providing Internet connection into the construction site due to the site conditions. The implementation of emerging technologies such as RFID could provide automatic materials tracking to improve materials tracking and inventory management processes.

- Materials management processes require a transformation to improve the overall in handling of materials for more efficiency and effectiveness on the construction site. This is because poor handling of construction materials affects the overall performance of construction projects in terms of cost, time, quality and productivity. The minimisation of materials wastage during the construction phases is important in order to avoid loss of profits.
The skills and knowledge requirements for the adoption of the prototype system include RFID system and basic computer literacy tracing to improve on-site materials tracking and inventory management processes.

8.4 Contribution to Knowledge

The original contribution of this research centres around three substantive areas, each of which provides a foundation for follow-on work to further enhance materials management practices and the application of RFID technology:

- **Integration of RFID-based materials management with resource modelling:** This research has demonstrated how RFID-based materials management can be integrated with resource modelling in project management system for improving on-site materials tracking and inventory management processes. The review of the literature reveals that, there is growing use of RFID in the construction industry in order to facilitate materials management practices. However, there is inadequate integration of RFID-based materials tracking with resource modelling. The case studies reveal that, there is limited site storage area and affected both small or large scale projects. Nevertheless, the current techniques implemented (such as JIT and CC) to address logistics and storage problems are not being used to overcome human error (such as double handling and paper-based reports). The prototype implementation demonstrated that, the linkage providing the timely delivery, monitoring, utilisation and inventory management on construction projects. In addition, during the evaluation of the prototype system, the participants could give their opinion about the functionality of the prototype system for addressing on-site materials management problems. This is show that, the RFID technology can be integrated with resource modelling in the project management system to provide better management of material tracking during materials delivery, storage and utilisation at the construction site.
Chapter 8: Conclusions and Recommendations

- The real-time materials tracking information through integration with database and work programme:

The case studies finding reveal that, there is an inadequate use of RFID technology to assist with an automatic identification and materials tracking during site activities. There are also inadequate tools that can associate materials, labour and plant in one system. This research has demonstrated the integration of database with work programme in the MS Project in order to provide real-time information of materials usage and automatic updated into the database. The developed prototype system could potentially provide a useful tool for logistics management in order to provide the information of when materials arrive on site and what has been delivered. For example, from the moment the materials (e.g. tagged materials) arrive on the site, the RFID reader automatically tracks it and the tracking continues constantly until the materials has been used. These facilities could provide the database to be updated automatically from time to time and enabling good control over materials to keep projects moving efficiently. From this perspective, this research has contributed to the understanding how database systems and work programmes can be combined to improve materials tracking practices on construction projects.

- Incorporation of mobile capability to enable on-site materials tracking process:

Through this research, the identification of other technologies such as PDA to co-operate with the RFID technology to support materials tracking more effectively also demonstrated. This could present that the incorporation of mobile capability provides real-time data capture and easier transfer of information within the construction site. The developed prototype system shows that, the RFID technology can be integrated with the PDA by attaching RFID reader with the PDA. This combination could provide mobile enabler to assist closer tracking of materials delivery and less man hour checking on the delivery of materials to site. There are also advantages for the site manager in moving independently at the construction site and easily find the information of materials delivery, storage and installation within his hand by using PDA.
8.5 Limitations of the Research

The main limitations of this research were as follows:

- The prototype system was only limited to materials (tagged components) on resource modelling in MS Project. It is essential to provide information of other resources (e.g. component installers or fitters), to identify that certain construction workers are available to carry out the specified tasks.

- It is also important to allow the prototype system to be tested in a real situations (real life cases) involving materials delivery, storage and use to find out the effectiveness of the system.

- It is also recognised that more time is required to fully evaluate the prototype system to help improve the richness of the contents captured. This will allow more participants to be involved to provide constructive suggestions to the improvements of the prototype system through personal experience of using it over a real life situation and over a reasonable period of time.

- The suggestion on requirements necessary for effective use of real-time materials tracking system failed to provide details skills and knowledge requirements to the construction workers. Such requirements should be investigated, as should the socio-technical impact of such systems in the future.

8.6 Recommendations for Further Research

This study has explored the use of RFID to improve materials management practices on the construction site. There is scope for others to build on the work reported in this thesis. There are several recommendations for further research derived from this study.
8.6.1 Recommendations for Researchers

There is considerable scope for further research, which can include the following:

- Further improvement can be made to the prototype system with respect to:
  - Improvement of the user interface by incorporating simple feature e.g. having buttons to reveal the details as needed;
  - Adding more dynamic features to the system with resource modelling to establish the necessary personnel (e.g. component installers/fitters) so that the system automatically provides the personnel information;
  - Generating reports from the prototype system to provide proper documentation of the data from real-time materials tracking.

- Further testing of the prototype on real materials tracking situations on sites with various types of construction projects is considered necessary. The results from these can further demonstrate the system's applicability in different materials tracking problem scenarios;

- Further research on socio-technical systems is required to enable the system to be better integrated into materials management practices in the future. This is required to study the social aspects of people and society, and technical aspects of machines and technology in the adoption of the real-time materials tracking system.

- Further testing on the PDA as data collection techniques can easily update when the relevant information entered during the construction periods. It can also automatically capture and transfer the real-time materials tracking data within the site boundary. Furthermore, this can extend to provide the construction site with the wireless connection for transferring data to the site office easily.
• Integrating the prototype system with other systems (e.g. computer aided design, email system, web-based system, etc.). This would enhance the usefulness of the prototype system and could facilitate commercialisation of the prototype system.

8.6.2 Recommendations for Industry Practitioners

The following recommendations apply to the implementation of real-time materials tracking system in materials management practices on the construction projects:

• It is important to evaluate the site manager’s capability in the adoption of the real-time materials tracking system in the current practices of tracking materials on site. There is also the potential to examine the site manager’s current skills (training) requirements by implementing potential emerging technologies (such as RFID) into current practices of handling materials tracking on site.

• This research manages to integrate RFID-based materials management with resource modelling in project management systems to improve on-site materials tracking and inventory management processes. Further investigation is needed by industry practitioners to examine the impact of integration of RFID into the overall process of materials management.

• The industry could take the advantages highlighted by this prototype system (by implement RFID and PDA) into their current practices in materials management process in order to improve on-site materials tracking and inventory management.
8.7 Concluding Remarks

The scope for improvement in materials management practices was demonstrated through the integration of RFID-based materials management with resource modelling in project management systems. This has the potential to result in significant cost and time savings on construction projects. The industry could take advantage of this.
REFERENCES


REFERENCES (continued)


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REFERENCES (continued)


REFERENCES (continued)


REFERENCES (continued)

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RFID Journal (2007b), The Basic of RFID Technology,

RFID Journal (2007c), RFID System Components and Costs,
APPENDIX A

List of Publications Arising from the Research
Appendix A: List of Publications Arising from the Research

List of Publications

Conference:


Journal:

APPENDIX B

Template for Semi-Structured Interviews for Case Studies
PART 1
BACKGROUND/CONTACT DETAILS

<table>
<thead>
<tr>
<th>Name</th>
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<tbody>
<tr>
<td>Position</td>
<td></td>
</tr>
<tr>
<td>Year Experience</td>
<td></td>
</tr>
<tr>
<td>Company Details:</td>
<td></td>
</tr>
<tr>
<td>a) Name</td>
<td></td>
</tr>
<tr>
<td>b) Address</td>
<td></td>
</tr>
<tr>
<td>c) Contact:</td>
<td></td>
</tr>
<tr>
<td>i) Office</td>
<td></td>
</tr>
<tr>
<td>ii) Fax</td>
<td></td>
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<tr>
<td>iii) Mobile</td>
<td></td>
</tr>
<tr>
<td>iv) E-mail</td>
<td></td>
</tr>
<tr>
<td>Date of Interview</td>
<td></td>
</tr>
</tbody>
</table>

PART 2

A. EXPERIENCE & ROLE
1. What are your functions and responsibilities on this project?
2. How long have you been involved in managing materials on construction sites?

B. MATERIALS MANAGEMENT PROCESSES
1. Do you have a specific department (procurement division or others) for managing materials on your projects?
2. Do you have a specific materials procurement system (e.g. such as purchasing procedures, delivery procedures, follow-up procedures, etc.)?
3. Do you have a specific approach to materials management (e.g. such as recording system, target inventory level, materials tracking, delivery frequency, access & routing, etc.)?
4. How do you manage material handling in terms of transportation and materials tracking on site?
5. How do you undertake inventory management (in terms of storage and site space)?
6. How do you manage logistics (movement or routing) of materials during site activities?
7. How do you manage waste materials on site?

C. MATERIALS MANAGEMENT PROBLEMS
1. What problems do you have in materials management?
2. How do you address these problems? (e.g. using previous experience, consulting, colleagues or seniors, refer to an expert, specific tools and techniques, etc.)
3. How can your materials management processes be improved in the future?

D. USE OF ICT IN MATERIALS MANAGEMENT
1. What technologies do you use to facilitate materials management on your sites?
2. Do you use emerging technologies (such as wireless technologies, bar-coding, radio frequency identification (RFID), tagging technologies, etc) in your materials management? (If NO, answer Q3 and If YES, answer Q4, Q5, Q6, Q7).
IF NO:
3. What factors hinder the introduction of such ICT in materials management processes in your organisation?

IF YES:
4. What benefit has your organisation experienced from the implementation of such ICT tools?
5. How can such ICT tools be used to support current materials management practices on large and complex construction projects?
6. How could the use of emerging technologies improve on-site logistics and tracking of materials?
7. What are the implications for construction workers in the adoption of these emerging technologies? (e.g. such as upskilling, training, organisational/human factors, etc)

E. THE FUTURE OF MATERIALS MANAGEMENT
1. What are the key ingredients in a successful materials management system?
2. What tools/techniques do you wish you had to improve your materials management practices?
3. Who would be best placed to manage the use of emerging ICT in materials management?
4. Which of the emerging ICT tools (such as wireless technologies, bar-coding, RFID, etc) has the most potential to improve your materials management practices?

PART 3

A. MATERIALS TRACKING PRACTICES
1. What is your specific approach to tracking materials on site?
2. How do you address particular problems in managing tracking of materials on site?
3. What methods of reporting are used for tracking of materials in inventory management on site?
4. How do you undertake problems on safety of materials at storage area?

B. ICT IMPLEMENTATION IN TRACKING SYSTEM
1. What technologies do you use to facilitate tracking of materials on site?
2. How does the current ICT tools support tracking of materials on site?
3. What are the potential impact of the emerging ICT tools (such as wireless technologies, bar coding, RFID) on logistics and tracking of materials on site?
4. What is your comments regarding the implementation of the emerging ICT tools (such as wireless technologies, bar coding, RFID) to improve materials tracking practices.

C. INTEGRATION MATERIALS MANAGEMENT AND RESOURCE MODELLING
1. How do you integrate materials management/tracking system with project management system (work programme)?
2. What do you use (tools or techniques) to integrate materials management/tracking system with project management system?
3. What information needed to facilitate the integration of RFID-based materials management and resource modelling in project management systems (such as MS Project)?
APPENDIX C

Evaluation Questionnaire
Evaluation Questionnaire

RealTrack – A Prototype System for Real-Time Materials on Construction Projects

This questionnaire is intended to elicit the views of construction professionals on a prototype system for real-time materials tracking. It should be completed following a demonstration of the prototype system.

Part A: Background Information

1. Name(Optional): ________________________________
2. Job Title/Position: ______________________________
3. Experience in Construction Industry (in years): ________________
4. Company Name & Address: ______________________________
5. Contact Number: ________________________________

Part B: RealTrack System

Please tick (✓) the box that best indicates your level of agreement with each of the statements below, where:

1=Strongly Agree 2=Agree 3=Neutral 4=Disagree 5=Strongly Disagree

Section 1: System Effectiveness

The RealTrack Prototype System

<table>
<thead>
<tr>
<th>Statement</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 is a useful application.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2 will improve the effectiveness of materials tracking.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3 will enhance the handling of materials delivery.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4 will improve inventory management through more effective tracking of materials in the storage area.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5 will facilitate the tracking of materials usage.</td>
<td></td>
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<tr>
<td>1.6 addresses an important industry problem.</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Section 2: System Practicality

<table>
<thead>
<tr>
<th>2.1</th>
<th>I consider RealTrack a practical solution to improving materials tracking and management.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2</td>
<td>I am comfortable with the idea of materials tagging using RFID.</td>
</tr>
<tr>
<td>2.3</td>
<td>Information can be easily retrieved from tagged materials.</td>
</tr>
<tr>
<td>2.4</td>
<td>The system is financially feasible as RFID tags cost less than £15 each.</td>
</tr>
<tr>
<td>2.5</td>
<td>The system can be highly effective for high value materials.</td>
</tr>
</tbody>
</table>

## Section 3: System Usability

<table>
<thead>
<tr>
<th>3.1</th>
<th>RealTrack is a user friendly system.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2</td>
<td>The system effectively communicate information.</td>
</tr>
<tr>
<td>3.3</td>
<td>The system user-interface is simple enough for a construction team leader to learn and use for high daily tasks.</td>
</tr>
<tr>
<td>3.4</td>
<td>I am convinced that site managers would use the system.</td>
</tr>
<tr>
<td>3.5</td>
<td>Considerable training will be required for effective use of the system.</td>
</tr>
</tbody>
</table>

## Section 4: General Comments

4.1. How can the RealTrack System be improved?

___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________

4.2. What do you think are the main benefits of the RealTrack system?

___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________

4.3. What are the barriers to the use of the RealTrack system in the construction industry?

___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________

4.4. Further Comments (if any)

___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
Part C: Skills and Others Requirement

(1) What level of computer literacy is required by construction workers to adopt new technologies/systems such as RealTrack?

__________________________________________________________

__________________________________________________________

(2) What other skills are required by construction workers for real-time materials tracking?

__________________________________________________________

__________________________________________________________

(3) How much training is required for the users of the RealTrack system?

<table>
<thead>
<tr>
<th>None</th>
<th>Little</th>
<th>Some</th>
<th>Much</th>
<th>Very Much</th>
</tr>
</thead>
</table>

(4) What other requirements (such as upskilling, organisational/human factors, cost, etc.) for the effective use of the RealTrack system?

__________________________________________________________

__________________________________________________________

(5) Further comments (if any)

__________________________________________________________

__________________________________________________________

Thank you for your cooperation and valuable input