Improving construction plant safety using advanced ICT

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IMPROVING CONSTRUCTION PLANT SAFETY USING ADVANCED ICT

ZAINAB RIAZ

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

May 2008

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ABSTRACT

In recent years, a number of advanced Information and Communication Technology (ICT) solutions have been developed to assist in the management of business processes and working environments. Radio Frequency Identification (RFID) tagging technology and mobile computing are two such technologies which have been adopted for use in hybrid systems because they can monitor and manage industrial health, safety and welfare activities.

Within the construction sector, plant and equipment operation has been shown to be one of the leading causes of accidents and injuries, not least because the sector has witnessed an increasing reliance upon mechanical resources. In an attempt to reduce vehicle accidents, this research reports upon a technology application, entitled SightSafety, that utilises advanced ICT solutions to produce a proactive health and safety management system. In addition, the research used case studies, process mapping, scenario planning and prototype evaluation to: produce guidelines for such a technology solution; expand the benefits of the application; and discuss the barriers and issues that can influence system implementation.

The envisaged application consists of a plant Management Information System (MIS) that incorporates ICT such as mobile computing and RFID tagging system to make machine operations more productive and safer. The system encapsulates the desirable attributes of various standalone systems (such as personnel, maintenance, training etc.) into one integral hybrid system which also facilitates the integration of health and safety information for construction plant management. The system can identify operatives in a machine’s operational envelope, notify management and employees of pending danger and report upon the incidents and dangerous occurrences that have happened. This latter feature thereby enabling managers to learn from any mistakes made during the construction project. The integration is presumed to lead to a far-reaching technology platform where plant operator and safety manager information needs are addressed and could go some way to reducing common causes of accidents on construction sites.

KEYWORDS: Site safety, RFID in construction, Construction ICT, Plant accidents.
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<td>AIDC Automatic Identification and Data Collection</td>
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<tr>
<td>CDM Construction (Design and Management)</td>
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<tr>
<td>CHSW Construction Health, Safety and Welfare</td>
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<tr>
<td>CITB Construction Industry Training Board</td>
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<td>CPA Construction Plant-Hire Association</td>
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<td>CPCS Construction Plant Certification Scheme</td>
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<tr>
<td>CRM Customer Relationship Management</td>
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<tr>
<td>CSCS Construction Skills Certification Scheme</td>
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<td>DFD Data Flow Diagram</td>
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<td>ERD Entity Relationship Diagram</td>
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<td>ERP Enterprise Resource Planning</td>
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<tr>
<td>GPS Global Positioning System</td>
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<td>HSE Health and Safety Executive</td>
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<td>ICT Information and Communication Technology</td>
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<tr>
<td>ILR Intelligent Long Range</td>
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<td>IS Information System</td>
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<td>IT Information Technology</td>
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<td>IPAF International Powered Access Federation</td>
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<tr>
<td>LOLER Lifting Operations and Lifting Equipment Regulations</td>
<td></td>
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<td>MCG Major Contractors Group</td>
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<tr>
<td>MEMS Micro-Electro-Mechanical Systems</td>
<td></td>
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<tr>
<td>MEWP Mobile Elevated Work Platform</td>
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<td>MIS Management Information System</td>
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<td>NAO National Audit Office</td>
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<td>PASMA Prefabricated Access Suppliers’ and Manufacturers’ Association</td>
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<tr>
<td>PPE Personal Protective Equipment</td>
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<tr>
<td>PUWER Provision and Use of Work Equipment Regulations</td>
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<tr>
<td>RFID Radio Frequency Identification</td>
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<tr>
<td>RIDDOR Reporting of Injuries, Diseases and Dangerous Occurrences Regulations</td>
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<tr>
<td>SCM Supply Chain Management</td>
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<tr>
<td>SDK Software Development Kit</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>SME</td>
<td>Small and Medium Enterprise</td>
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<td>SN</td>
<td>Sensor Networks</td>
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<tr>
<td>SSADM</td>
<td>Structured System Analysis and Design Method</td>
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<tr>
<td>STRADIS</td>
<td>Structured Analysis, Design and Implementation of Information Systems</td>
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<tr>
<td>WC</td>
<td>Wireless Communication</td>
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<tr>
<td>WLAN</td>
<td>Wireless Local Area Network</td>
</tr>
<tr>
<td>YSM</td>
<td>Yourdon Systems Method</td>
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ACKNOWLEDGEMENTS

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To my Amma,

my eternal source of inspiration, strength and peace
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<td>Figure 7.14:</td>
<td>Screen capture of SightSafety for pedestrian monitoring operation - before scan</td>
<td>156</td>
</tr>
<tr>
<td>Figure 7.15:</td>
<td>Screen capture of SightSafety for pedestrian monitoring operation - after scan</td>
<td>156</td>
</tr>
</tbody>
</table>
CHAPTER 1
INTRODUCTION

1.0 INTRODUCTION

The demand for, and investment in, the construction plant and equipment sector has increased exponentially in recent years (Mintel, 2005). Stimulants for this growth are many and varied but a major factor has been industry's drive for higher productivity, improved performance and lower production costs. However, the UK's Health and Safety Executive (HSE) is concerned about the high and sustained prevalence of plant and equipment accident rates on construction sites. To address this concern, various technological solutions have been implemented in the construction industry for improved management and production of machinery. Presently, there is a need for a more holistic solution that deals with the information needs of a modern plant related workforce and health and safety managers. It is also apparent that industry needs to integrate information for plant management among various standalone plant applications.

This chapter sets out the background for this thesis and introduces the general subject domain. Leading on from this, the research aim and objectives are stated and a summary of the methodology adopted to carry out the study is given. Finally, a summary of chapters is provided to illustrate the content, logic and structure of the thesis.

1.1 BACKGROUND TO THE RESEARCH

The construction industry is the largest industry within the UK as it contributes almost £80 billion annually to national Gross Domestic Product (GDP) and employs nearly 2 million people across 168,000 firms (NAO, 2004). Similarly, this growth has stimulated the demand and investment in the construction plant and equipment sector which has increased exponentially (Mintel, 2005).
However, accidents involving mobile plant and equipment have continually plagued the UK construction industry during the past decade (HSE, 2005). From the 20 accident categories recorded by the Health and Safety Executive (HSE), two categories can be directly linked with plant and equipment operations (Edwards, 2003). These are ‘contact with moving machinery or material being machined’ and ‘struck by moving vehicle’. These accidents have remained relatively consistent year on year, despite the best efforts of industry and academia to reduce them (HSE, 2007a). Indeed, the static accident trend (year on year) involving plant and equipment suggests that current safety mechanisms and procedures employed by contractors have failed to reduce plant related accidents (Edwards, 2004). These safety systems include the use of additional machinery aids (e.g. convex or pencil beam mirrors, rear view cameras, radar systems and audible alarms) or the use of risk control procedures (e.g. training, competence development and risk assessment) (ibid).

Information and Communications Technology (ICT) is a term used to encompass all forms of computing systems, hardware and software, telecommunication and networks (ICL, 2007). Given the fact that plant and equipment utilisation on construction sites has increased, there has been a considerable effort by both academics and plant manufacturers to apply Information and Communication Technology (ICT) solutions for improved machine performance and productivity. For example, some of the applications include: operation control systems (Caterpillar, 2005b); automated motion control (Lytle et al., 2004); safety systems in cranes for collision detection (Abderrahim et al., 2005); equipment maintenance (Durfee and Goodrum, 2002); and tracking systems (Oloufa et al., 2003) etc. These examples show that there has been an explosion of bespoke system applications being developed and often these focus on single applications such as machine maintenance, vehicle tracking or continuous mechanical health monitoring. At present there is no single holistic package that covers the whole scope of machine related activities that could benefit health and safety on a construction site.

In response to HSE statistics and current technology application, a complete re-evaluation of existing systems and procedures should be undertaken and the potential of new technology to augment existing control measures utilised should be explored. Advanced ICT (e.g. Automatic Identification and Detection Collection, or AIDC,
systems and mobile computing) whilst not the total solution for safety issues, can provide practitioners with a useful means with which to monitor, record and learn from the interaction that exists between pedestrians and vehicles on a construction site. In so doing, it is envisaged that exhaustive information management acts as a catalyst for developing more efficient and effective systems and procedures.

RFID is an AIDC technology which has proved highly effective in hostile environments where barcode labels may easily become damaged (COMIT, 2005b). Numerous RFID based solutions are being investigated or have been developed to solve complex business problems in many industries (Su and Liu, 2007) such as retail, manufacturing, airline, transportation and health etc. (Brown, 2007; RFID Journal, 2007). However, the construction industry has mostly investigated the application of RFID technology to enhance supply chain management and material tracking (COMIT, 2005a; Jaselskis et al., 1995; Chin et al., 2007). The true potential of AIDC technology remains undiscovered in a construction context. Hence, the rationale to explore this technology in other sectors of the industry e.g. plant and equipment management, health and safety on construction sites, accident management etc.

It is envisaged that these technologies could support the development of a plant/pedestrian safety mechanism if integrated into a plant Management Information System (MIS). The culmination of such work will provide a far more advanced and comprehensive health and safety management solution than those currently made available by various commercial organisations. In order to develop a site safety system for construction plant that utilised advanced ICT, the following driving factors were taken into account:

- A consistent accident trend amongst construction workers working in close proximity of plant and equipment on a site has been observed by analysing statistics obtained from the HSE. This trend prevails despite the use of safety systems (e.g. mirrors, rear view cameras and audible alarms etc.) and risk control procedures (e.g. training, competence development and risk assessment).
- Government regulations and HSE requirements to improve all round visibility for plant operators particularly where a driver’s vision is impaired at the back or on the blind side of a machine.
1.2 RESEARCH QUESTIONS

Given the foregoing background and the need identified for this research in the previous section, a series of research questions have been outlined. These questions provide unambiguous direction for the research and ensured that the work focused upon specific themes and topics. Questions posed are:

1) What are the most popular plant items and what are the typical operations of these? What are the safety concerns associated with these aforementioned machines on a construction site?

2) What existing ICT solutions are available to improve plant performance, safety and productivity?

3) What are the developments and trends in the field of emerging ICT and what are the applications of these in the construction and other industries?

4) What are the current health and safety practices used for plant and equipment management on a construction site and what are the limitations of the process?

5) What are the information needs of plant managers and operatives and how can these be addressed?

6) What should be the features of an ICT application for effective plant and equipment management in the construction industry?

7) How can the implementation of ICT (i.e. the incorporation of an information system with RFIDs and mobile computing in particular) improve health and safety practices for plant operators, safety managers and workers working within close proximity of machines?

8) What are the barriers to the effective implementation of ICT?

1.3 RESEARCH AIM AND OBJECTIVES

The culmination of research questions identified has led to the development of a research aim which seeks:

*to investigate and capture the current health and safety process associated with construction plant management and to develop emerging ICT applications for process improvement.*
In order to achieve the above aim, the following objectives were outlined for the research:

1) To identify popular plant types; to develop an understanding of standard operations and to determine the existing use of technology to make these machines more productive and effective tools on construction sites.

2) To determine advancements and trends in the use of ICT and to identify the application of these technologies for the industry.

3) To document and understand the existing ‘standard practice’ health and safety processes adopted for plant and equipment on a construction site.

4) To develop implementation scenarios for improved onsite health and safety process for mobile machinery with respect to plant operators, safety managers and pedestrians operating in vicinity of vehicles.

5) To develop guidelines for the effective use of ICT for plant and equipment management.

6) To design, develop and test a prototype application that demonstrates the use of ICT (IS incorporating RFIDs in particular) to augment current health and safety process provisions within the UK construction industry.

In terms of contribution to knowledge, the implications of the aforementioned aim and subsequent objectives upon theory and practice are as follows:

- Process mapping was used to document ‘standard’ health and safety practices adopted for construction plant management.
- The aforementioned process map formed the basis upon which ICT application, entitled SightSafety was developed and evaluated. SightSafety in itself will facilitate improvements to existing health and safety processes and procedures for the workforce associated with plant operations.

1.4 BRIEF OVERVIEW OF THE RESEARCH METHODOLOGY

To achieve the research objectives outlined above, a combination of various research methods (including elements of both qualitative and quantitative) has been employed. These include providing a review and critique of the literature, conducting case studies,
scenario planning, prototyping the *SightSafety* system and finally surveying for prototype evaluation. Table 1.1 presents an overview of research objectives, corresponding research questions posed and the research methods utilised to achieve these objectives.

The research commenced with a comprehensive review of literature on relevant topics within the research domain using databases of journals, textbooks and conference papers in addition to internet searches.

In order to document existing safety processes for plant and equipment a case study design was selected which involved conducting semi-structured interviews whilst simultaneously recording and investigating project documents used by practitioners within the construction sector. Data collected, was then used to develop process maps by employing Data Flow Diagrams (DFD) as a system modelling tool. The process modelling helped in the documentation of a series of business processes currently practiced in construction projects for plant related health and safety.

Furthermore, various applications of emerging technologies identified during the literature review helped to visualise how advanced ICT can be used to improve health and safety practices for workers, plant operators and safety managers. As a result, the scenario planning method was considered appropriate to describe 'alternative future' construction sites by using various technologies such as RFID tagging system and mobile computing integrated with Management Information Systems (MIS). This scenario-planning method was also used as the basis for understanding user needs and requirements for prototype system design by reviewing the various scenarios with the industry practitioners (interviewees within each case study).

Finally, a prototype system was designed and developed in order to demonstrate functionality of a system designed to facilitate improvements to existing health and safety processes and procedures for the workforce associated with plant operations. The requirements for the prototype (entitled the *SightSafety* system) were 'interpreted' from the generated scenarios and the screens were designed using the project documents obtained during site visits. This system was piloted with industry practitioners via a demonstration of the system followed by answering an evaluation questionnaire.
<table>
<thead>
<tr>
<th>Objectives</th>
<th>Research Questions</th>
<th>Research Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>To identify popular plant types; to develop an understanding of standard</td>
<td>What are the most popular plant items and what are the main operations and safety</td>
<td>Literature</td>
</tr>
<tr>
<td>operations; and to determine the existing use of technology to make these</td>
<td>concerns associated with these machines on a construction site?</td>
<td>Review Interviews</td>
</tr>
<tr>
<td>machines more productive and effective tools on construction sites.</td>
<td>What existing ICT solutions are available to improve plant performance, safety and</td>
<td>Document Analysis</td>
</tr>
<tr>
<td></td>
<td>productivity?</td>
<td>Process Mapping</td>
</tr>
<tr>
<td>To determine advancements and trends in the use of ICT and to identify</td>
<td>What are the developments and trends in the field of emerging ICT?</td>
<td>Scenario Planning</td>
</tr>
<tr>
<td>the application of these technologies for the industry.</td>
<td>What are the applications of emerging ICT in the construction and other industries?</td>
<td>Prototyping</td>
</tr>
<tr>
<td>To document and understand the existing 'standard practice' health and</td>
<td>What are the current health and safety practices used for plant and equipment</td>
<td>Interviews (Prototype</td>
</tr>
<tr>
<td>safety process adopted for plant and equipment on a construction site.</td>
<td>management on a construction site?</td>
<td>Evaluation)</td>
</tr>
<tr>
<td></td>
<td>What are the limitations in the existing process and why have the adopted safety</td>
<td></td>
</tr>
<tr>
<td></td>
<td>practices failed to protect workers working in close machine proximity?</td>
<td></td>
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</tbody>
</table>

Continues…
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<table>
<thead>
<tr>
<th>Objectives</th>
<th>Research Questions</th>
<th>Research Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>To develop implementation scenarios for improved on-site health and safety</td>
<td>What are the information needs of plant managers and operatives and how can these be addressed? How can the implementation of ICT (incorporation of information system with RFID and mobile computing in particular) improve health and safety practices for plant operators, safety managers and workers working within close proximity of machines?</td>
<td>Literature Review: S, S, S; Process Modelling: P; Scenario Planning: S; Prototyping: S; Survey (Prototype Evaluation): S</td>
</tr>
<tr>
<td>To develop guidelines for the effective use of ICT for plant and equipment</td>
<td>What should be the features of an ICT application for effective plant and equipment management in the construction industry? What are the barriers to the effective implementation of ICT?</td>
<td></td>
</tr>
<tr>
<td>To design, develop and evaluate a prototype application that demonstrates</td>
<td>How can implementation of ICT (incorporation of information system with RFID and mobile computing in particular) improve health and safety practices for plant operators, safety managers and workers working in close proximity of machines?</td>
<td></td>
</tr>
</tbody>
</table>

Key: P = Primary Method, S = Supporting Method.
1.5 THESIS STRUCTURE

The thesis is divided into nine chapters. Figure 1.1 illustrates the schematic layout of the thesis, and the following text describes the content of each chapter.

Chapter 1 provides an introduction to the general subject domain by presenting the background to the research, establishing the research aim and objectives and providing a brief summary of the methodology adopted to carry out the research.

Chapter 2 provides an overview of general research methodologies followed by an appraisal of various research approaches adopted in the areas of Information Systems (IS) and construction ICT applications. Finally, it details the strategy adopted to achieve the aim and objectives of this research.

Chapter 3 reviews commonly used plant and equipment in the construction industry and provides an understanding of the standard operation of this equipment. It also details the use of technology to make these machine more productive and effective resources on construction sites. Furthermore, the chapter identifies the major health and safety concerns of managers and plant operators working on a construction site and how the industry has exploited certain technologies for the benefit of vehicle safety and management.

Chapter 4 explores the significant advancements and prominent trends in the use of emerging ICT, and investigates how plant managers and operators can further exploit these technologies for the benefit of better plant management and safety on construction sites. The chapter investigates technologies such as MIS, mobile computing, positioning systems and RFID tagging systems.
Figure 1.1: Thesis structure

Chapter 1: Introduction
- Research background.
- Research aim and objectives.
- Brief methodology.

Chapter 2: Research methodology
- Review of key research methods in the context of IS and construction ICT applications.
- Approach used for this research.

Chapter 3: An appraisal of plant and equipment use within the construction industry
Reviews:
- Popular plant types;
- Standard operations;
- Areas of concerns related to health and safety issues; and
- Technology applications for improved performance and management.

Chapter 4: Emerging Information and Communication Technologies (ICT)
Reviews advancements and trends in the use of ICT such as:
- MIS;
- Mobile computing;
- Positioning and tracking systems; and
- RFID applications.

Chapter 5: Current health and safety process for construction plant
- Case study reports the standard safety practices (using DFD as a modelling tool) for plant and equipment in the construction industry.
- Weaknesses in the existing processes are identified.

Chapter 6: Guidelines for effective use of ICT for improved plant management and safety
- Guidelines for improved plant management and safety.
- Architecture and conceptual model of a technology application.
- Scenario generation.

Chapter 7: Prototype Design and Operation
- Choice of a RFID system.
- Presentation of the pilot study.
- System design using activity diagrams.
- Operation of the prototype application.

Chapter 8: Prototype Evaluation
- Evaluation objectives and approach.
- Analysis and discussion of the evaluation process.
- Feedback on system barriers, benefits and improvements.

Chapter 9: Conclusions and recommendation
- Main conclusions of the research.
- Main limitations of the research.
- Recommendations for future work.
Chapter 5 presents findings emanating from case studies conducted on five construction projects. The fundamental aim was to report upon standard safety practices used to manage plant and equipment in the construction industry. Data Flow Diagrams (DFD) were used as a modelling tool to record these safety practices. In addition to the documentation of current processes, practitioners concerns about the existing processes are also identified in order to determine why the adopted safety practices have failed to protect workers working in close proximity to mobile machinery.

Chapter 6 presents guidelines for the application of ICT that may provide practitioners with a useful means through which to improve plant management and safety on a construction site. The chapter details the architecture and conceptual model of a technology application which integrates various components of plant management into one integral hybrid system. Scenarios for future construction sites that deploy ICT application for improved site safety are then presented.

Chapter 7 details the prototype SightSafety application developed for this study, reviews the choice of the RFID system used and presents the findings of a pilot study conducted. During the pilot work, the suitability of the selected RFID product was put to trial. Results of the pilot along with the system design using activity diagrams are presented. Finally, the chapter presents the operation of the prototype application using screens of the system for unambiguous explanation.

Chapter 8 presents the results of the evaluation process using a combination of analytical techniques including summary statistics, t-test and Wilcoxon test. The sample of participants were split into two groups consisting of managers and plant operators. The idea behind this division was to determine whether a significant difference in opinion (at p = 0.05) was apparent between these two users of the system. The evaluation also sought to determine the benefits of SightSafety along with the improvements recommended by system evaluators. The chapter concluded by presenting potential barriers and issues influencing system implementation.

Chapter 9 presents a summary of the key research findings, sets out how the study has contributed to knowledge, presents limitations of the work and provides recommendations for further research.
1.6 CHAPTER SUMMARY

Having provided the background to the research and justified the need for it, this chapter also identified the key questions to be addressed in the research; the aims and objectives of the research; and provided a brief summary of the research methodology adopted.

It can be readily established that plant and equipment use and operation on construction sites has increased considerably over recent years. Alarmingly, accidents involving plant/pedestrian collisions remained unacceptably high. A combination of advanced ICT (such as RFID tagging technology and mobile computing) and IS may provide practitioners with a useful means to improve plant management and safety. The envisaged system not only provides construction managers with necessary information on a regular basis but also focuses on the information needs of plant operators and construction health and safety managers.
CHAPTER 2
RESEARCH METHODOLOGY

2.0 INTRODUCTION

The Oxford Dictionary (1989) defines research as:

“A search or investigation directed to the discovery of some fact by careful consideration or study of a subject.”

Therefore, research is a contribution to knowledge which is concerned with what (facts and conclusions) and how (scientific, critical) components (Fellows and Liu, 2003). A robust piece of research requires skills of inquiry, experimental design, data collection, data analysis by interpretation and by presentation (Greenfield, 1996).

This chapter introduces the various classifications of research available and is followed by a detailed review of the various research approaches embraced in the context of Information Systems (IS) and construction ICT applications. Finally, the strategy adopted for this specific research work to facilitate the achievement of the aim and objectives set for the study is proposed and discussed.

2.1 CLASSIFICATION OF RESEARCH

Research can be classified into different categories depending on the researcher’s viewpoint (Kumar, 1999). One fundamental classification of research is into pure and applied research (ibid); refer to Table 2.1 which illustrates the main difference between the two types of research. The table highlights that pure research seeks to discover theories; whilst on the contrary, applied research is more focused upon practical application of knowledge.
Table 2.1: Pure and applied research (adapted from Fellow and Liu, 2003)

<table>
<thead>
<tr>
<th>Research Type</th>
<th>Pure</th>
<th>Applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undertaken to</td>
<td>- Develop knowledge.</td>
<td>- Develop a practical application.</td>
</tr>
<tr>
<td></td>
<td>- Contribute to/discover theories.</td>
<td>- Help solve a practical problem.</td>
</tr>
<tr>
<td></td>
<td>- Discover laws of nature.</td>
<td>- Use scientific knowledge to determine ‘does it work?’</td>
</tr>
<tr>
<td></td>
<td>- Search for the ‘truth’.</td>
<td></td>
</tr>
<tr>
<td>End User</td>
<td>- Academics.</td>
<td>- Practitioners.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Industrialists.</td>
</tr>
</tbody>
</table>

This research is *applied research* as it investigates the application of ICT for the plant and equipment sector of the UK construction industry; albeit the research findings could equally be of value to an international audience. The *SightSafety* application developed specifically explores how to address health and safety concerns and management issues associated with mobile construction plant.

Research can also be classified as either qualitative or quantitative and the adoption of either approach depends upon different philosophical assumptions and research methods (Creswell, 2003).

### 2.2.1 Qualitative Research

Lincoln and Denzin (2003) described qualitative research as that which:

> "involves an interpretive, naturalistic approach to the world where a qualitative researcher studies things in their natural settings, attempting to make sense of, or to interpret, phenomena in terms of the meanings people bring to them."

The main characteristics of qualitative research and researchers who use this method are provided in Table 2.2. The table highlights that this type of research is pragmatic, interpretive and grounded in the lived experience of people (Marshall and Rossman, 1999).

### 2.2.2 Quantitative Research

Quantitative research adopts ‘scientific method’ in which an initial study of theory and literature generates precise aims and objectives with hypothesis to be tested (Fellows
and Liu, 2003). Table 2.3 underlines the main characteristics of quantitative research and researchers. The table describes that this type of research uses formal instrumentation where variables can be identified and relationships can be measured.

Table 2.2: Characteristics of qualitative research (Source: Marshall and Rossman, 1999)

**Qualitative Research**

- Takes place in the natural world.
- Draws on multiple methods that are interactive and humanistic.
- Is emergent and evolving rather than tightly prefigured.
- Is fundamentally interpretive.

**The Qualitative Researcher**

- Views social world holistically.
- Engages in systematic reflection on their own roles in the research.
- Is sensitive to personal biography and how it shapes the study.
- Uses complex reasoning that is multifaceted and iterative.

Table 2.3: Characteristics of quantitative research (Adapted from: Creswell, 2003; Patton, 2002)

**Quantitative Research**

- It is based on the assumption that social facts have an objective reality.
- Uses standardised measures so that the collected data can fit into limited number of predetermined response categories to which numbers are assigned.
- Involves experiments with variables and treatments (e.g. factorial designs and repeated measure design).

**The Quantitative Researcher**

- Uses literature deductively as a basis for advancing research questions and hypothesis.
- Creates variables that are open to statistical analysis.
- Draws upon quantitative data and use mathematical models, statistical tables and graphs.

This research focuses on the application of ICT in the setting of a construction project which in addition to being a building science also comprises of a ‘social domain’ involving construction workers, managers, designers and architects. As a result of this human participation in this study, a predominantly qualitative research approach is adopted to understand and interpret the requirements of the proposed ICT application.
2.2.3 Triangulation

Table 2.4 provides a comparison of the two types of research. The table indicates that qualitative research provides an insight into a problem and uncovers prevailing trends in that problem domain. On the contrary, quantitative research quantifies data to generalise results from a sample of interest. However, qualitative data can also be analysed more objectively using quantitative techniques in such a way that richness of the data is not lost (Fellows and Liu, 2003).

<table>
<thead>
<tr>
<th>Research Type</th>
<th>Qualitative</th>
<th>Quantitative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>Contextualisation.</td>
<td>Generalisation.</td>
</tr>
<tr>
<td></td>
<td>To describe, decode and interpret the meaning, not the frequency, of certain more or less naturally occurring phenomena in the social world.</td>
<td>Facts and figures or 'what' and 'how many'.</td>
</tr>
<tr>
<td>Area</td>
<td>Social Science.</td>
<td>Natural Science.</td>
</tr>
<tr>
<td>Sample</td>
<td>Often small in number.</td>
<td>Often large in number.</td>
</tr>
<tr>
<td></td>
<td>Non-representative of population selected to fulfil a given requirement.</td>
<td>Representative of the population and based on randomly selected respondents.</td>
</tr>
<tr>
<td>Data Collection</td>
<td>Unstructured or semi-structured e.g. interviews.</td>
<td>Structured e.g. questionnaires.</td>
</tr>
<tr>
<td>Data Analysis</td>
<td>Non-statistical.</td>
<td>Statistical.</td>
</tr>
<tr>
<td>Characteristics</td>
<td>Emergence/generation of theory.</td>
<td>Testing of theory.</td>
</tr>
<tr>
<td></td>
<td>Develops an initial understanding and sound base for further decision making.</td>
<td>Used to recommend a final course of action.</td>
</tr>
<tr>
<td></td>
<td>Data is rich and subjective.</td>
<td>Data is hard and statistical.</td>
</tr>
<tr>
<td></td>
<td>Flexible and unstructured.</td>
<td>Structured.</td>
</tr>
<tr>
<td></td>
<td>Findings are not conclusive and cannot be used to make generalizations about the population of interest.</td>
<td>Findings are conclusive.</td>
</tr>
</tbody>
</table>

Although most research work is conducted using either the qualitative or quantitative approach, there exists a third possibility called triangulation. In order to construct
validity of the research, multiple and different sources (e.g. informants), methods, investigators or theories are employed (Robson, 1996). This approach tends to reject the narrow analytical paradigms in favour of the breadth of information which is provided by the use of more than one method. Moreover, qualitative research is inherently multi-method in focus but employing triangulation (combination of multiple methods, empirical materials, perspectives and observers) as a strategy adds rigor, breadth and depth to any investigation (Lincoln and Denzin, 2003).

2.2 A FRAMEWORK FOR RESEARCH DESIGN

The recent acceptance of a multi-method approach has made research less quantitative versus qualitative and more how research practices lie somewhere on a continuum between the two (Creswell, 2003). Figure 2.1 shows the interrelated levels of a framework that goes into the process of designing a research methodology. Moreover, the highlighted aspects provide a choice of approach, ranging from broad assumptions about the research design to the more practical decisions about how to collect and analyse data.

Figure 2.1: A framework for research design (adapted from Creswell, 2003)

<table>
<thead>
<tr>
<th>Epistemology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theory of knowledge embedded in the theoretical perspective.</td>
</tr>
<tr>
<td>Informs the research e.g. objectivism, subjectivism etc.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Philosophical Paradigm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A theoretical perspective that lies behind the methodology in questions (e.g. positivism, postpositivism, interpretivism, critical theory etc.).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategy or plan of action that links methods to outcomes.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Techniques and procedures.</td>
</tr>
</tbody>
</table>

Guba and Lincoln (1994) propose four epistemological classifications for qualitative research which include: positivism; post-positivism; interpretivism; and critical theory (see Table 2.5 for features of each type of classification). This classification concerns
the questions of what is (or should be) regarded as acceptable knowledge in a discipline (Bryman and Bell, 2003). Awareness of this classification not only helps in determining the type of evidence required and how it is to be gathered and interpreted, but also how it leads to good answers to the key questions being investigated in the research (Easterby-Smith et al., 2001). In social science research, the meaning and understanding of actions and intentions of individuals play a significant role which entails that qualitative data plays a crucial role in this type of research (Wilson and Howcraft, 2000).

Table 2.5: Epistemological classification for qualitative research (adapted from Guba and Lincoln, 1994; Fellow and Liu, 2003; Easterby-Smith et al., 2001)

<table>
<thead>
<tr>
<th>Positivism</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Considers social world exists externally.</td>
</tr>
<tr>
<td>- Advocates application of the methods from natural sciences rather than subjective interpretation through reflection and intuition.</td>
</tr>
<tr>
<td>- Is objective in nature.</td>
</tr>
<tr>
<td>- Used if there is evidence of formal propositions, quantifiable measures of variables, hypothesis testing and drawing of inferences about a phenomenon from the sample to a stated population.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Post-positivism</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Is a recent development of positivist ideas.</td>
</tr>
<tr>
<td>- Recognises that complete objectivity (truth) is unachievable.</td>
</tr>
<tr>
<td>- Results are considered true if all procedures to establish validity have been exhausted.</td>
</tr>
<tr>
<td>- Findings are viewed as not being absolute.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interpretivism</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Indicates that reality is constructed by how human beings interpret and make sense of reality.</td>
</tr>
<tr>
<td>- Is concerned with meanings and experiences that people associate with the real world.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Critical Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Takes the view that human beings are able to critically assess and change society and become emancipated.</td>
</tr>
</tbody>
</table>
2.2 RESEARCH APPROACHES IN IS

The argument between 'hard' positivist and 'soft' interpretivist research paradigms is continuous in the field of information systems (Fitzgerald and Howcroft, 1998). However, with the increasing acceptance of the social nature of Information Systems (IS), there has been a shift towards social science methodologies in IS research (Avison and Fitzgerald, 2003). Howcroft (2000) considers that the drift is because of the positivist belief that IS are purely technical in nature; an approach which tends to ignore the highly social nature of IS existence within organisations, often ignoring the human aspects involved. On the contrary, the author advocates that the interpretivist tradition is concerned with understanding what meaning the social world has for people who live within it; an approach which highlights the social nature of organisations and appreciates the use of qualitative data for evaluation purposes (ibid).

Greater thought regarding the choice of research method is required as one should first consider the nature of IS and what is expected to be gained from undertaking research in the area (Galliers and Land, 1987). The challenge is to find practical ways to combine qualitatively diverse research approaches to support various and partly conflicting goals involved in research efforts (Mathiassen, 2002). Mingers (2001) argues that research results will be richer and more reliable if different research methods, preferably from various existing paradigms, are routinely combined.

The most widely applied research approaches which are used in the IS study are listed in Table 2.6. The table also reviews the advantages, disadvantages and typical applications of these approaches in the field of IS.
Table 2.6: Research Approaches in IS (Adapted from Galliers, 1985).

<table>
<thead>
<tr>
<th>Research Approach</th>
<th>Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Typical application in IS</th>
</tr>
</thead>
</table>
| Action Research   | "Aims to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually accepted ethical framework." (Rappoport, 1970). | - Researcher's bias is made explicit in undertaking the research.  
- Captures the local situation in greater detail and with respect to more variables. | - Places a great deal of responsibility on researchers.  
- Lack of control over variables, openness of interpretation, biases etc. | - To obtain practical results of value to groups with whom the research has allied itself while adding to body of theoretical knowledge. |
| Case Study        | "An extensive examination of a single instance of a phenomenon of interest and is an example of phenomenological methodology." (Hussey and Hussey, 1997). | - Gives a holistic and in-depth view of a particular situation.  
- Helps in achieving greater realism in the research. | - Events may proceed differently because they are being observed (Yin, 1994).  
- Susceptible to partiality due to miscalculations and bias by respondent (Yin, 1994).  
- Lack of control over variables. | - To study IS failures or implementation efforts.  
- To study impact of IT and IS on organisations.  
- Research into the role and effects of IT and IS on society. |
| Survey            | "Operate on the basis of statistical sampling where representative samples are employed for economy and speed." (Fellows and Liu, 2003). | - It provides a description of real-world situation with more appropriate generalizations.  
- a greater number of variables may be studied compared to the experimental approach. | - People's responses may introduce discrepancies to the research.  
- Techniques (questionnaires, interviews etc.) are highly labour intensive for both respondents and researcher.  
- Low response rate in most cases.  
- Survey research on IS has been unable to yield a cumulative body of knowledge.  
- Ill suited for addressing the subtle dynamics of IT in complex social settings (Kraemer, 1991). | - To study IS failures or implementation efforts.  
- To study impact of IT and IS on organisations.  
- Research into the role and effects of IT and IS on society. |
### Research Approach

<table>
<thead>
<tr>
<th>Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Typical application in IS</th>
</tr>
</thead>
<tbody>
<tr>
<td>In this kind of research, different scenarios, or futures, are postulated and the different impacts of IT and IS are identified given these different situations.” (Galliers, 1985).</td>
<td>Captures the stakeholder opinions and insights in greater detail.</td>
<td>Respondent may be unable to comprehend the scenarios or their impacts.</td>
<td>To study impact of IT and IS given different situations.</td>
</tr>
<tr>
<td>Behaviour of processes, situational data and change in critical variables is observed at multiple time points.” (Fellows and Liu, 2003).</td>
<td>It by-passes problems associated with identification of relationships at a particular point in time.</td>
<td>Need to devise measures which can be used repeatedly.</td>
<td>Identification of changing relationships and their causes.</td>
</tr>
<tr>
<td>Takes place in a laboratory/real life situations identifying precise relationship between chosen variables using various quantitative analytical techniques to make various generalisable statements.” (Bryman and Bell, 2003).</td>
<td>Isolate and control a small number of variables that may be then studied extensively.</td>
<td>Extent to which the identified relationships exist in the real world.</td>
<td>To improve the effectiveness of IS in practice.</td>
</tr>
<tr>
<td>Aim to understand a particular phenomenon with a key focus on the subjective experience of the individuals studied.” (Robson, 1996).</td>
<td>Provides means of describing the inter-relationship of many factors found in life.</td>
<td>Despite making the researcher’s prejudice known, it could cloud interpretation of reality and make research conclusions subjective.</td>
<td>To describe a situation with a view to producing results.</td>
</tr>
</tbody>
</table>
2.3 RESEARCH APPROACHES FOR CONSTRUCTION ICT APPLICATIONS

Fellows and Liu (2003) draw attention to the significance of understanding the nature of projects and the management for people when working in a project-oriented industry such as construction. They identify the research styles which are most applicable to construction research; these include: action research; ethnographic research; surveys; case studies; and experiments. In construction research, scientific based quantitative methods have been traditionally adopted particularly for analytical based research (e.g. structural or material behaviour) and more qualitative research methods are used in the area of construction management which involves human participation (Ward, 2004).

However, in the past decade, the number and complexity of research methods available to construction researchers have expanded remarkably, particularly with the introduction of construction ICT targeted research (Bowden, 2005). This expansion provides a wider choice of research tools with which to pursue research questions. It is also important to realise that research into construction ICT differs from the study of ICT as a purely technical phenomenon (Whyte, 2000). In construction ICT applications the focus is not merely on technology, rather issues regarding the appropriateness of technology for various cultural and social factors (that are specific to the construction industry) should also be taken into account (Bowden, 2005). In a critical review, Leslie (1996) highlighted that construction researchers see only the positive side of hard methodology approaches without taking into consideration the complexity of ICT applications. They concentrate their research on technical aspects forgetting how ICT can be accepted and used by construction practitioners. This results in poor alignment of the technology with the construction industry’s needs.

2.4 RESEARCH APPROACH ADOPTED AND METHODS USED

According to Remenyi et al. (1998), the primary drivers for choosing an appropriate research methodology are: the topic to be researched; the specific research questions; and the resources available. The review of research approaches in IS and construction ICT highlights that there has been a shift towards social science methodologies in IS research due to increasing acceptance of the social nature of IS and ICT applications.
This acceptance has generated a move from the positivist position to an interpretivist position; which is used to determine reality as viewed by people and is concerned with meanings and experiences they associate with the real work environment (Easterby-Smith et al., 2001).

This research study focused on the investigation of the applicability of ICT in the plant and equipment sector of the construction industry with the aim of developing an advanced technological solution to address health and safety concerns. The nature of the study implies a highly social nature of technology existence within the construction industry where technology enabled processes are employed by the workforce operating on a construction site. This workforce context signifies the 'people issue', highlighting the fact that for a holistic view it is important to understand the opinions and perceptions of people working with this technology. This leads to a more subjective philosophy for this research and encourages the adoption of an interpretivist approach that appreciates the use of qualitative data for evaluation purposes (Howcroft, 2000; Hussey and Hussey, 1997).

The research objectives and the respective questions posed by these objectives are listed in Table 2.7. An underpinning theme of Table 2.7 is that multiple research approaches within a single study have been adopted to achieve the research objectives. The research questions along with the adoption of multiple research approaches led to the selection of a range of research methods, tools and techniques to be used during the course of this research study. These are highlighted in Figure 2.2 which illustrates the key steps adopted during the research process. The figure shows that more than one research method was taken up in certain approaches in order to provide supporting information and thus enabling triangulation of the results.
Table 2.7: Approaches used to achieve the research objectives

<table>
<thead>
<tr>
<th>Research Objectives</th>
<th>Research Questions</th>
<th>Research Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>To identify popular plant types; to develop an understanding of standard operations and to determine the existing use of technology to make these machines more productive and effective tools on construction sites.</td>
<td>- What are the most popular plant items and their operations?</td>
<td>Literature Review</td>
</tr>
<tr>
<td></td>
<td>- What are the safety concerns associated with these machines on a construction site?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- What existing ICT solutions are available to improve plant performance, safety and productivity?</td>
<td></td>
</tr>
<tr>
<td>To determine advancements and trends in the use of ICT and to identify the potential application and benefits of these technologies for more productive, efficient and safer plant and equipment operations.</td>
<td>- What are the developments and trends in the field of emerging ICT?</td>
<td>Literature Review</td>
</tr>
<tr>
<td></td>
<td>- What are the applications of these in the construction and other industries?</td>
<td></td>
</tr>
<tr>
<td>To document and understand the existing ‘standard practice’ health and safety processes adopted for plant and equipment on a construction site. Components of these recorded practices will then be used to develop a blueprint that will assist in establishing appropriate industry guidelines for effective use of ICT for plant and equipment management.</td>
<td>- What are the current health and safety practices used for plant and equipment on a construction site?</td>
<td>Case Study</td>
</tr>
<tr>
<td></td>
<td>- What are the weaknesses in the existing processes and why have the adopted safety practices failed to protect workers working in close machine proximity?</td>
<td></td>
</tr>
<tr>
<td>To develop implementation scenarios for improved on-site health and safety process for mobile machinery with respect to plant operators, safety managers and pedestrians operating in vicinity of vehicles.</td>
<td>- What are the information needs of plant managers and operatives and how can these be addressed?</td>
<td>Scenario Planning</td>
</tr>
<tr>
<td></td>
<td>- How can the implementation of ICT improve health and safety practices for plant operators, safety managers and workers working within close proximity of machines?</td>
<td></td>
</tr>
<tr>
<td>To design, develop and evaluate a prototype application that demonstrates the use of ICT (IS incorporating RFIDs in particular) to augment current health and safety process provisions within the construction industry.</td>
<td>- How can the implementation of ICT (IS and RFIDs in particular) improve health and safety practices for plant operators, safety managers and workers working within close proximity of machines?</td>
<td>Prototyping</td>
</tr>
<tr>
<td></td>
<td>- What should be the features of an ICT application for effective plant and equipment management in the construction industry?</td>
<td>Evaluation Process</td>
</tr>
<tr>
<td></td>
<td>- What are the barriers to the effective implementation of ICT within the plant sector?</td>
<td></td>
</tr>
<tr>
<td>To develop guidelines for the effective use of ICT for plant and equipment management in the construction industry.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 2.2 illustrates the key steps in the research process. Various research steps and tools used during this process are discussed in more detail in the following section.

**Figure 2.2: Research process**

1. **Literature Review**
   - Review on Plant and Equipment
   - Plant and Equipment Type: Attachments; Operations; Sales; Existing Technology Applications; Health and Safety Concerns.

2. **Technology Review**
   - Emerging ICT: Automatic Identification and Data Collection (AIDC); Mobile Computing; Positioning Systems; and MIS.

3. **Field Work**
   - Case Studies
     - Interviews with Management & Plant Operators
     - Comments on Scenarios (Application of Technology)
     - Site Visits and Observation

4. **Process Analysis**
   - To identify
     - Practitioners' plant related safety concerns, and
     - Causes of plant related incidents on sites.

5. **Guidelines for effective use of ICT for Plant and Equipment sector**

6. **System Evaluation**
   - **Qualitative Analysis**
     - To identify:
       - Barriers to implementation;
       - Technical and social challenges to implementation;
       - Potential benefits of system application, and
       - Improvements in the prototype (SightSafety) application.
   - **Statistical Analysis**
     - To identify:
       - System effectiveness;
       - System Practicality;
       - System Usability; and
       - Differences in opinion among the workforce (managers and plant operators) on the technology application (SightSafety).

---

**Themes Identified**

- **Health and Safety of Plant/Workers**
  - Existing processes for health and safety of plant, their operators/workers;
  - All round visibility of machines;
  - Accident reporting and records;
  - Health and safety information communicated to operators/workers.

- **Technology**
  - On-board computers, software and information systems currently in use for construction plants;
  - Computer based system used by managers for plant operations; Information maintained;
  - Information on plant communicated to plant operators;
  - Any other technological solutions/MIS in use.

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**Process Analysis**

- **To Identify**
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2.4.1 Literature Review

A literature review primarily serves to: define and understand the topic; highlight previous research and alternate views; reveal issues in previous research; and suggest areas for further research (Fellows and Liu, 2003). The literature review for this research mainly consisted of two sections (see Figure 2.2). The first section reviewed various plant and equipment types, typical operations, sale trends and the application of technology for improved performance. This review provided a detailed knowledge of popular plant types, an understanding of typical standard operations and established the use of technology to make machinery more productive and effective tools on construction sites.

The second section reviewed various emerging ICT solutions that have the potential to make construction plant more productive, efficient and safer. A referenced summary was prepared, and is presented in chapters 3, 4 and 5. The literature review also helped in the identification of problems and concerns relating to plant and equipment management and helped to formulate areas for further research.

Data for the review was mainly sourced from academic journals, conference proceedings, books, on-going research projects, Health and Safety Executive (HSE) documentation and various government legislations. Additionally, for technology review various technology applications and company websites were also taken into account.

2.4.2 Case Study

Yin (1994) suggests a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context where: the boundaries between phenomenon and context are not clearly evident; multiple sources of evidence are used; and ‘how’ and ‘why’ questions require an answer. Table 2.7 documents research posed research questions posed during case studies:

- What are the current health and safety practices for plant and equipment on a construction site?
How can the existing health and safety process for plant and equipment benefit from ICT implementation?

What are the information needs of plant managers and operatives?

In order to find answers to these questions and to document existing safety processes for plant and equipment, a multiple-case design was selected. According to Yin (1994), a multiple design follows a replication logic rather than sampling logic where generalisation is made to the theory and not to the population. In addition, multiple cases strengthen the results by replicating the pattern-matching; this increasing the confidence in the robustness of theory (Tellis, 1997). Consequently, five construction projects were selected across the UK using a list provided by members of the Major Contractors Group (MCG). The MCG represents most of the largest construction contractors working with the UK construction industry and are influential in both industry and government. Often the MCG members are pioneers of innovative systems and adoption of advancements within the group stimulates others within the industry to follow suit. The details of the selected five cases are provided in Table 2.8. Other reasons for the selection of these projects were based on the following factors:

- major contractors are technology aware and are ready to integrate various technological solutions for process improvement to offer better value and a higher level of quality during a complete project lifecycle (Skanska, 2006).
- major contractors recognise the importance of health and safety on construction sites and are actively promoting a culture where appropriate steps are taken to enhance the business processes to create a future free of incidents and injuries (MCG, 2005).
- in all instances, the projects are at a stage where plant items (specifically, material handling equipment e.g. excavators and telescopic handlers) were in operation.

The case study preposition was: "The employment of emerging ICT by plant operatives and managers improves the health and safety practices for plant and equipment on a construction site".

The unit of analysis for the study was the health and safety process(es) adopted for plant and equipment management on a construction site.
Table 2.8: Case Description

<table>
<thead>
<tr>
<th>Case</th>
<th>Project Type</th>
<th>Project/Company Description</th>
<th>Job Title of the Interviewee</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Hospital project</td>
<td>Case A is the largest healthcare scheme to be signed in the UK. The 42-year contract includes a construction programme which covers a built area of 270,000 square metres and costs around £1 billion. The contract period for the 1,248 patient bed facility commenced in July 2006.</td>
<td>Health and Safety Manager (Principal Contractor).</td>
</tr>
<tr>
<td>B</td>
<td>Airport terminal project</td>
<td>Case B is a construction project of an airport terminal which started in September 2002; phase one of the project is scheduled to be completed and operational by April 2008 with the second phase opening in 2011. The project is requiring an estimated investment of over £4.2 billion. The large infrastructure of the project involves over 60 contractors, 16 major projects and 147 sub-projects on a 260 hectares site.</td>
<td>Health and Safety Manager (Principal Contractor). Foreman with plant H&amp;S duties (Principal Contractor). Project Manager (Earthworks Contractor). Supervisor (Earthworks Contractor). Excavator Operator (Earthworks Contractor). Telehandler Operator (Earthworks Contractor).</td>
</tr>
<tr>
<td>C</td>
<td>Hospital project</td>
<td>Case C is the construction project of a hospital with a total contract value of £484 million. The hospital project, which spans a quarter of a mile in length and five storeys high, is equipped with 1,212 beds and a clinical sciences teaching facility. The work started in 2002 with the main building completing in July 2006.</td>
<td>Health, Safety and Environmental Manager (Principal Contractor). Construction Manager (Principal Contractor). Supervisor (Earthworks Contractor). Plant Operator (Earthworks Contractor).</td>
</tr>
<tr>
<td>D</td>
<td>Retail, leisure and residential construction project</td>
<td>Case D is a 2.5-acre site located in a busy city centre and includes 17,650m² of retail units, a multi-storey 480-space car park and 700 student accommodation units. The project costs approximately £47 million.</td>
<td>Health and Safety Manager.</td>
</tr>
<tr>
<td>E</td>
<td>NA</td>
<td>Case E is one of the top foundation companies in the UK. The group specializes in provision of the design and construction of substructure work packages, with a speciality in piling works. All specialised plant and equipment is designed and built “in-house” at the company’s 40 acre headquarters. In addition, the training division of the company provides external training on health and safety requirements and plant operator training on most types of construction machines.</td>
<td>Group Health and Safety Manager. Senior Training Manager.</td>
</tr>
</tbody>
</table>
Triangulation was achieved by conducting semi-structured interviews, direct observation on construction sites and investigation of project documents.

A semi-structured interview was used in preference to a structured or unstructured interview because this enabled the researcher to probe for further insights and clarification while maintaining some structure in the recorded views of participants. For the interview, a frame of dialogue was prepared that mainly comprised of two sections (see Appendix A1):

i. health and safety on a construction project; and
ii. technology used for plant management.

Both themes and corresponding questions within them surfaced from a comprehensive literature review (Chapter 3 and 4 respectively). However, few questions regarding current health and safety practices on a construction site in general, and plant specific safety practices in particular, were also posed to the interviewees. The investigation aimed to understand and interpret the standard health and safety practices adopted for construction plant management and to develop process maps for these. The interviewees included both health and safety managers and plant operators because this target audience would ultimately be the end users of the final system.

The interviews were analysed using the technique of 'constant comparative analysis'. The technique involves taking a single piece of data (one interview, statement or theme) and comparing it with all others that may be similar or different in order to develop conceptualisations of the possible relations between various pieces of data (Thorne, 2000). For example, by comparing the accounts of two different people who had a similar experience, a researcher might pose analytical questions such as why the two accounts are different? Alternatively, the researcher may need to establish how are these two related (Ibrahim, 2007)?

Key developments that came out of the multiple sources of data were used to develop process models by employing Data Flow Diagram (DFD) as a system modelling tool. The process modelling helped in documenting information flow through a series of business processes currently in practice for plant related health and safety in
construction projects. In addition, the models helped gather requirements to translate into an effective prototype design and development.

**Rationale for using Process Modelling (Information Flow):**

System models provide pictorial representations of reality and clearly distinguish between logical (what a system is or does) and physical (how a system is physically and technically implemented) design of a system (Whitten, 2004). Whitten (2004) defines process modelling as:

> "a technique for organising and documenting the structure and flow of data through a system's processes and/or the logic, policies, and procedures to be implemented by system's processes"

Process modelling originates from structured system analysis and design methodologies. While structured analysis and design has lost approval as a methodology, process modelling remains a viable and important practice that uses models of business process requirements to drive effective software designs for a system (Avison and Fitzgerald, 2003). There are techniques for process modelling that are also featured in Business Process Reengineering (BPR). Skidmore and Eva (2004) describe process mapping as one such technique which depicts:

- component tasks within the process;
- the functions/users roles which perform those tasks; and
- any relationships between the tasks.

However, this mapping only captures details of the processes and not about the data that are used in these processes *(ibid)*. Nevertheless, DFDs are adopted in various methodologies (e.g. Structured Systems Analysis and Design Method, SSADM; Structured Analysis, Design and Implementation of Information Systems, STRADIS; and Yourdon Systems Method, YSM) as a modelling tool to illustrate the graphical flow of data through a series of business processes and provides the analyst with the ability to document the current and required systems (Yeates and Wakefield, 2004). Logical DFDs represent data flows and is not concerned with how it flows i.e. physical aspects (Avison and Fitzgerald, 2003) and provides a sound basis for the process of system
design or redesign (Yeates and Wakefield, 2004). DFD is a graphical representation and is composed for four elements as described in Table 2.9.

Table 2.9: DFD elements and their notations

<table>
<thead>
<tr>
<th>Element Name</th>
<th>Description</th>
<th>Notation (Yourdon &amp; Coad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Flow</td>
<td>It is represented by an arrow and depicts the fact that some data is flowing or moving from one process to another process.</td>
<td>Data Flow ➔</td>
</tr>
<tr>
<td>Process</td>
<td>The process transforms the data flow by either changing the structure of the data or by generating new information from the data.</td>
<td>Data Process</td>
</tr>
<tr>
<td>Data Store</td>
<td>This can be envisaged as a file, although not necessarily a computer file or even a manual record in a filing cabinet. It can be a temporary repository of data.</td>
<td>Data Store</td>
</tr>
<tr>
<td>External Entity</td>
<td>External entity lies outside the context of the system's boundary. It is usually a person or a organisation but it could be another system.</td>
<td>External Interactor</td>
</tr>
</tbody>
</table>

The main advantages of the data flow approach are given in Figure 2.3 which stratifies these advantages in terms of competitive viewpoints (i.e. technology, social and process) and roles within and outside an organisation. The figure highlights that DFD provides system analyst with the ability to understand and specify a system at the logical process level. This specification can be translated into a technical design of the system and its physical implementation at a later stage. In addition, the figure shows that DFD enables communication among system users, analysts and designers. For this research, DFD were used as a communication tool between the researcher and health and safety managers/staff to identify and document the health and safety processes adopted for plant and equipment on a construction site. This was followed by interpretation of the developed diagrams into system guidelines and the SightSafety ICT design.

However, DFD style and notations are not standardised and as a result, there may be great differences between two DFDs of the same system drawn by different analysts (Saldarini, 1989). Conversely, there is generic guidance that details the number of steps that can be followed while producing a DFD. These steps are summarised in Figure 2.4 where processes, data stores and external entities (agents external to the examined
system) are identified. This classification is used to develop a basic context diagram which is later revised into more comprehensive DFDs, where major process activities are identified and decomposed further. For this research a higher level DFD is prepared for the process of on-site health and safety. Further levels are generated for major activities such as: health and safety process of plant related operations and management; accident investigation; and employee training.

**Figure 2.3: Advantages of the data flow approach**

<table>
<thead>
<tr>
<th>Roles within and outside an organisation</th>
<th>System Analyst/ System Designer</th>
<th>Client/User/Management</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technology</strong></td>
<td>Definition of necessary data and processes</td>
<td>Analysis of required output and processing logic</td>
</tr>
<tr>
<td><strong>Social</strong></td>
<td>Communication of current system knowledge</td>
<td>Comments/Feedback on the accuracy of the analysts’ conceptualisation</td>
</tr>
<tr>
<td><strong>Process</strong></td>
<td>Understanding of system and subsystem interrelatedness</td>
<td>Conceptual Freedom</td>
</tr>
</tbody>
</table>

![Diagram showing the advantages of the data flow approach](image)
2.4.3 Scenario Planning

The encompassing theme of this research is the application of emerging ICT (in this case mainly Automatic Identification and Data Collection or AIDC technology, such as RFID tags, and its integration with MIS) for the plant and equipment sector of the construction industry. From this viewpoint, future research methods (as discussed in Table 2.6, section 2.5) are considered relevant to address the research question:

"How can the implementation of ICT improve health and safety practices for plant operators, safety managers and workers working within close proximity of machines?"

From the various future research methods, listed and described in Table 2.10, scenario-planning was considered the most relevant for this research. The justification of this selection is provided in Table 2.11. The table shows that scenario planning method is considered the most appropriate for uncertain, complex and fast developing situations.
where the future cannot be predicted accurately enough to identify a single forecast; and it cannot be reasonably expected to be a continuation of present and past trends (Godet 2001; Dyson 1990). This research also uses the scenario-planning method as the basis for understanding user needs and requirements for prototype system design.

**Scenario Planning Method:**

Michael Porter (cited in Ringland, 1998, p2) defines scenarios as:

"an internally consistent view of what the future might turn to be – not a forecast, but one possible future outcome."

According to Schwartz (1991) scenarios are descriptions of possible or probable futures. They are not projections, predictions or preferences, rather they are coherent and credible stories, describing different paths that lead to the alternative futures (Davis, 2002). The underpinning philosophy of scenario-planning methods is that the future cannot be foreseen, however some of the forces that will shape the future can be (Heijden, 1996). When these driving forces are identified, and the ways in which they are likely to interact and affect other key variables are considered, then futures built by intuition and logic can be constructed (Verity, 2000).

Scenario planning is not a single well-defined methodology but rather a set of principles for strategic analysis and planning that may be applied using a combination of various qualitative and quantitative research methods and techniques (Sideris, 2002). Disciplines and practices that have influenced scenario planning include mental models, cognitive mapping, systems analysis, stakeholder analysis, conceptual thinking, decision analysis, facilitation techniques and storytelling (Davis, 2002).
<table>
<thead>
<tr>
<th>Research Method</th>
<th>Description</th>
<th>Typical Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Future Extrapolation Methods</td>
<td>Methods based on the belief that future represents a logical extension of the past.</td>
<td>• Trend Analysis.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Time Series.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Regression.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Econometrics.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Simulation Modelling.</td>
</tr>
<tr>
<td>Exploratory Methods</td>
<td>Methods concentrate on structuring possible futures, typically using qualitative descriptions.</td>
<td>• Morphological Analysis.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Relevance trees.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Mind-mapping.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Future Wheel.</td>
</tr>
<tr>
<td>Participatory Methods</td>
<td>Methods based on expert and stakeholder opinions and insights about the future.</td>
<td>• Delphi Technique.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Focus Groups.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Future Search Conferences.</td>
</tr>
<tr>
<td>Future Modelling</td>
<td>Methods describe the future by identifying the determining mechanisms of past events and how these influence the future.</td>
<td>• Analogy analysis.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Technological Sequence Analysis.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Stakeholder analysis.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Structural analysis.</td>
</tr>
<tr>
<td>Scenario Planning Methods</td>
<td>A key assumption is that future is essentially unpredictable. Considering the uncertainties included in the future, modelling will not lead into one future rather too many different futures, each of which may be described in the form of a scenario.</td>
<td>• Scenario methods combine aspects of other tools with the aim of creating several scenarios.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Typical method is back-casting. Objectives that are very discontinuous from the present trends are defined and then the normative method moves backwards to the present to identify the necessary steps for reaching these objectives.</td>
</tr>
<tr>
<td>Normative Method</td>
<td>Methods investigate how we want the future to be and how to obtain this goal.</td>
<td>•</td>
</tr>
</tbody>
</table>

Table 2.10: Research methods for 'Future Studies' (adapted from Glenn and Gordon, 2003; Galliers, 1985)
Table 2.11: Justification of adopting ‘scenario planning’ for this research

<table>
<thead>
<tr>
<th>Reason for Scenario Planning selection</th>
<th>Suitability for this research</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Out of the Box Thinking</strong> (Sideris, 2002)</td>
<td>During the requirement analysis process, scenarios can open up new areas of thinking and viewpoints, thus helping towards a comprehensive set of guidelines for the effective use of ICT (RFID and MIS in particular) for the plant and equipment sector in the construction industry.</td>
</tr>
</tbody>
</table>
| **To Augment Understanding**  
According to Fahey and Randall (1998) Scenarios help to see  
- What possible futures might look like (end states)?  
- How these futures might come about (plots and stories)?  
- Why they might occur (logics)? | The approach will help in the identification of how plant related workforce (operators, pedestrian and managers) can use emerging ICT for improved health and safety on a construction site. |
| **Easy Communication** (Heijden, 1996) | Visual description of technology implementation scenarios in real construction situations will be chosen as the best method to test scenarios with industry experts at an early stage, prior to the system implementation. This will be due to the following reasons:  
- The construction industry experts have the most comprehensive knowledge about the construction industry dynamics. However, it is possible that these experts are not fully aware of the possibilities offered by certain emerging technologies and their possible applications.  
- The communication will help to illustrate the system design issues that are important to users/designers, specific problems or strengths in the current technology, or the kinds of situations that are required to be experienced or avoided. |
| **Deals with Complexity and Uncertainty**  
(Heijden, 1996; Schoemaker and Mavaddat, 2000) | In this research scenarios are used to study the construction plant sector needs and acts as a key input to prototype system design process. It is envisioned that this input will:  
- provoke and capture user perspective.  
- enhance user involvement at requirement analysis stage.  
- validate the system specification and requirements analysis. |
| **Envisioning Technology in System Development**  
Carroll (1995) identifies the role of scenarios in the system development lifecycle:  
- Envisionment and requirement analysis with a focus on user perspectives.  
- User-Designer communication to evaluate possibilities for usability and functionality of the system and to establish a design rationale.  
- Scenarios can be analysed and translated for software design, implementation, evaluation, training and documentation. |  
Use of scenario-planning methods in the IT projects demonstrates applicability for ICT research in the construction industry. |
| **Scenario-Planning Applications**  
- Scenario planning techniques have successfully been used in future study exercises in mobile computing and their use is recommended for research in this area (Sideris, 2002).  
- Some technology based companies are using scenario-based methods as part of customer engagement practice (IBM, 2005). |  
|
Peter Schwartz (1991) in his book "The Art of the Long View" proposed an eight-step methodology for scenario-planning. These steps include:

1. Identify the key issue that will influence the future;
2. Identify the key factors in the micro-environment;
3. Identify the driving forces in the macro-environment;
4. Rank key factors and driving forces by importance and uncertainty;
5. Select scenario logics;
6. Flesh out the scenarios;
7. Draw implications; and
8. Select leading indicators and signposts.

This method starts by identifying particular key factors and driving forces, which are the elements that move the plot of a scenario. The method does not rule out completely the use of other formal techniques, however it is a highly informal approach (Sideris, 2002) as it relies almost entirely on the facilitator to mediate productive debate within a group of experts. Also, scenarios are known to offer greater advantages over other forecasting methods when uncertainty is high and historical relationships unstable (Fahey and Randall, 1998). The key disadvantage of scenario planning approach is that developing an initial set of scenarios is a lengthy and time consuming process.

The Scenario Generation Process

Scenario planning was considered the most appropriate approach to address the research question:

*How can the implementation of ICT improve health and safety practices for workforce associated with plant and equipment on a construction site?*

The key challenge in applying the scenario planning method was to generate an initial set of scenarios for application of ICT (RFID technology and its integration with MIS) for improved health and safety practices in the construction plant and equipment sector. The scenario generation was expected to spur new ideas and themes and to understand the plant operator, management and pedestrian needs for such technology applications.
Several methods for scenario generation have been suggested by different authors and there is no single way of constructing a scenario nor can the same method be applied similarly in all cases (Masini et al., 2000). Schwartz's approach (discussed in the earlier section) to scenario planning is relatively less prescriptive and offers a greater level of flexibility compared to other approaches (such as other future methods, as discussed in Table 2.10). Cole et al. (1978) described three possible sources of the initial set of scenarios:

- **Analyst input:** the analyst undertaking the study generates the scenarios based on the individual's experience and research;
- **Expert input:** expert informants contacted by the analyst contribute ideas in various ways such as via free-form discussions, interviews, Delphi procedures, workshops or other techniques;
- **Analyst and expert input:** this method combines both analyst and expert informant input.

The third method (analyst and expert input) was adopted for this research in order to understand the industry problems and practitioners perspective on technology application. This was combined with the researcher's expertise in the technology domain.

The literature review (Chapters 3, 4 and 5) was used to systematically gather information about emerging technologies and plant related issues on a construction site. Applications of similar technologies in other industries were also reviewed. A conceptual model for technology application was developed from this review. It was later shaped into a set of scenarios through an iterative process by carrying out a series of semi-structured interviews with industry experts. The experts were requested for an analytical feedback on the explained set of scenarios. This combination of analyst and expert input and the study of literature was used to develop and refine realistic user scenarios; in which the capabilities of various emerging ICT were mapped to the information needs of plant related construction workforce. The key objective of generating realistic scenarios was to take the focus away from the underlying technology and to find out more about the effectiveness, utility and barriers of ICT.
applications from the construction industry perspective. This understanding led to drawing up user needs, gathering system requirements and eventually system design.

2.4.4 Prototype Development

Prototype development involved the development of a prototype system in order to demonstrate system functionality. The requirements for the prototype were ‘interpreted’ from the process maps developed during case studies and from the scenario generation processes. The prototype was not entirely a bespoke development. In software engineering communities it has long been recognised that developing a new system from scratch is expensive in terms of time, money and effort. Also, new developments tend to be error prone and too expensive to maintain (Apperly et al., 2003). Thus off-the-shelf components for automatic identification and data collection purpose were purchased from IDENTEC Solutions (an Austrian company).

The prototype used the following development and database environments:

- Microsoft Visual Studio 2003 .NET;
- Microsoft SQL Server 2005; and
- Identec Solutions Intelligent Long Range (ILR) technology (RFID technology).

The choice of these development environments are detailed in Chapter 7. The prototype development addressed the key objective of developing an ICT (IS incorporating RFIDs) application that facilitates the health and safety process for the plant and equipment workforce. The application concentrated on monitoring the workers operating in close proximity of plant and equipment on a construction site and to automate the incident/accident investigation process.

2.4.5 Evaluation

An evaluation process was carried out to:

- have a more credible and concrete validation of scenarios; and
- elicit end-user and industry expert perspectives on the prototype system.
A total of five construction projects across the UK were visited to evaluate the prototype. To ensure collection of data from the representative user group of the ICT application, the relevant users of the system were identified (details are provided in Chapter 8) i.e. safety managers and plant operatives (drivers and supervisors).

During the evaluation process, a questionnaire (see Appendix A2) was designed to get the feedback from industry experts on themes identified through literature on evaluation of ICT applications. These themes were:

- system effectiveness;
- system proactiveness;
- practicality;
- usability;
- financial feasibility;
- future improvements;
- benefits; and
- implementation barriers.

A prerequisite for completing the questionnaire was to attend a presentation on the prototype application. The open-ended questions of the questionnaire (addressing future improvements, benefits and implementation barriers) were analysed through 'constant comparative analysis'. Alternatively, the closed questions were coded to produce statistical analysis on the data using SPSS (a software tool for statistical analysis). The analysis was performed to measure the differences in sample mean for the responses of both managers and operators. Additionally, to measure the relationship among the variables a correlation analysis was carried out.

2.5 CHAPTER SUMMARY

The chapter has presented a discourse on the topic of research approaches in the disciplines of IS and construction ICT applications. Qualitative and quantitative research approaches were discussed in terms of philosophical lineage and process. The adopted combination of both approaches (triangulation) was also discussed and the actions taken to minimise the effects of the limitations of individual approaches.
Various data collection and analysis techniques were outlined and the ones relevant to construction ICT research were briefly discussed.

Finally, the chapter provided an overview of the multi-methodological approach adopted for this research study to facilitate the achievement of the aims and objectives set for the research. The techniques for data collection and analysis used in this research were also highlighted in the chapter.
CHAPTER 3

AN APPRAISAL OF PLANT AND EQUIPMENT USE WITHIN THE CONSTRUCTION INDUSTRY

3.0 INTRODUCTION

Whilst the construction industry uses extensive labour resources, it is becoming increasingly reliant upon mechanisation (Harris, 1994). These mechanical resources are used in various operations on a construction site e.g. earthmoving (equipment such as excavators, loaders, tractors etc.) and lifting (equipment such as telehandlers, forklifts, cranes etc.). This chapter provides an insight into popular plant types, an understanding of standard operations and the use of technology to make machinery more productive and effective tools on construction sites. Moreover, this chapter identifies areas of concern for plant managers particularly related to health and safety issues on a construction site and how the industry has exploited certain technologies for the benefit of vehicle safety and management.

3.1 TYPES OF PLANT AND EQUIPMENT

The demand and investment in the UK construction plant and equipment sector has increased exponentially over the years (Mintel, 2005). The value of construction equipment within the UK market rose by 4% in 2004 to £1,069.5 million and has risen by 39% since 2000 (see Table 3.1).

Table 3.1: Value of construction equipment in the UK market (Mintel, Apr 2005)

<table>
<thead>
<tr>
<th>Year</th>
<th>Value (£million)</th>
<th>%Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>766.9</td>
<td>+5 %</td>
</tr>
<tr>
<td>2001</td>
<td>853.2</td>
<td>+11 %</td>
</tr>
<tr>
<td>2002</td>
<td>959.0</td>
<td>+12 %</td>
</tr>
<tr>
<td>2003</td>
<td>1030.0</td>
<td>+7 %</td>
</tr>
<tr>
<td>2004</td>
<td>1069.5</td>
<td>+4 %</td>
</tr>
</tbody>
</table>
Plant and equipment on construction sites may be categorised in several ways (Harris, 1994). It may be grouped by the function it performs during the construction process for example, scrapers, front-end loaders and belt conveyers can be classified as equipment that loads, carries and dumps loose material respectively (Day and Benjamin, 1991). Alternatively, equipment may also be classified by the construction operation it performs e.g. earthmoving and lifting etc.

Table 3.2 groups the generic plant and equipment on the basis of general operations i.e. earthmoving and lifting. The table also discusses various attachments that can be chosen to maximise machine performance. Over 6,000 attachments are available to be fitted with machines and these vary in terms of weight, width, capacities, hydraulic flows and pressures (JCB, 2005). However, Table 3.2 provides information on the most commonly used attachments only and considers standard operations for the purpose of generalising the plant type.

Table 3.2 verifies that the term earthmoving covers a range of construction activities from grading, to excavating and earth fills. The general type of earth moving equipment designed to perform or help with one or more of the basic earthmoving operations include: dozers; loaders; scrapper; hydraulic excavators; haulers; graders; trenchers and compactors. Selection of these machines is usually done on the basis of: site conditions; volume of material to be moved; type of material; and time available (Nunnally, 2000). Machines may utilise attachments such as face shovels, backactor (backhoes) and draglines where excavating material is required to be loosened up and loaded while remaining stationary (ibid). Alternatively, the excavated material may be removed, transported and deposited in a cycle, for example, as done with bulldozers, loaders, scrapers etc. (Harris, 1994). Table 3.2 also summarises lifting equipment operation, which generally includes vertical load lifting, repositioning and release of the load around a construction site.
<table>
<thead>
<tr>
<th>Generic Plant Categories</th>
<th>Attachments</th>
<th>Generic Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tractors and Dozers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Types:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crawler-tractors.</td>
<td>Blades (straight, angle, universal, cushion, V clearning, Rome K/G clearing etc.).</td>
<td>Land clearing, bulldozing, ripping, towing, earth moving and spreading, knocking down vegetation.</td>
</tr>
<tr>
<td>Wheel-tractors.</td>
<td>Rakes.</td>
<td>Land clearing.</td>
</tr>
<tr>
<td></td>
<td>Plows, scarifiers, rippers.</td>
<td>Breaking up tough soils for excavation.</td>
</tr>
<tr>
<td></td>
<td>Pushblocks.</td>
<td>Loading scrapers.</td>
</tr>
<tr>
<td><strong>Loaders</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Types:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crawler-tractor-mounted.</td>
<td>Bucket (solid, multi-segment), dozers and snow blades.</td>
<td>Levelling, smoothing and clean up, stockpiling or loading haul units.</td>
</tr>
<tr>
<td></td>
<td>Rippers.</td>
<td>To break up hard soil or ice during ground preparation particularly for pipeline and trenching work.</td>
</tr>
<tr>
<td></td>
<td>Forklifts.</td>
<td>Lifting and moving construction material (boxes and bundles of supplies).</td>
</tr>
<tr>
<td></td>
<td>Trenchers.</td>
<td>For cutting narrow, straight trenches in the soil prior to laying electrical, telephone and cable lines, or water/gas pipe.</td>
</tr>
<tr>
<td><strong>Hydraulic Excavators</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Types:</td>
<td>Face shovel buckets.</td>
<td>To loosen and load material with better operation when work above the tracks against an excavation face.</td>
</tr>
<tr>
<td>Wheeled.</td>
<td>Backhoe.</td>
<td>To loosen and load material with better operation when work below the tracks level; handling operations e.g. pipe-laying, installing trench sheets etc.</td>
</tr>
<tr>
<td>Tracked-type.</td>
<td>Grapples.</td>
<td>For handling loose material, sorting waste and demolition site cleanup.</td>
</tr>
<tr>
<td></td>
<td>Hammers.</td>
<td>For demolishing concrete and oversize rocks; breaking frozen or hard ground; and trenching.</td>
</tr>
<tr>
<td></td>
<td>Pulverizers.</td>
<td>For recycling and processing demolished concrete debris.</td>
</tr>
<tr>
<td></td>
<td>Rippers.</td>
<td>To break up hard soil or ice during ground preparation particularly for pipeline and trenching work.</td>
</tr>
</tbody>
</table>

Continues...
...Continued

<table>
<thead>
<tr>
<th>Generic Plant Categories</th>
<th>Attachments</th>
<th>Generic Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scrapers</strong></td>
<td></td>
<td>➢ Loading, hauling, dumping and spreading soil.</td>
</tr>
<tr>
<td>Types:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single engine.</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Three axle.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All wheel drive.</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Tandem powered.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elevating.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Push-pull.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multi-bowl.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multi-engine etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Compactors</strong></td>
<td></td>
<td>➢ Soil compaction.</td>
</tr>
<tr>
<td>Types:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tamping foot rollers.</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Grid or mesh rollers.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vibratory compactors.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smooth steel drums.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pneumatic rollers.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Segmented pad rollers etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Graders and Finishers</strong></td>
<td></td>
<td>➢ Spreading and sidecasting, grading, shaping, bank sloping, ditching, scarifying, mixing and spreading of soil.</td>
</tr>
<tr>
<td><strong>Trenching Machines</strong></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Types:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheel type.</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Ladder type.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hauling Equipment</strong></td>
<td></td>
<td>➢ To dig utility trenches for water, gas and oil pipelines: shoulder drains on highways; drainage ditches; sewers etc.</td>
</tr>
<tr>
<td>Types:</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Dump trucks.</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Wagons.</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Conveyor belts and trains.</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

Continues...
...Continued

<table>
<thead>
<tr>
<th>Generic Plant Categories</th>
<th>Attachments</th>
<th>Generic Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material Handlers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Types:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telehandlers</td>
<td>Pallet forks and carriages.</td>
<td>To handle palletised loads e.g. bricks, concrete blocks, pipes etc.</td>
</tr>
<tr>
<td></td>
<td>Buckets lifting hooks.</td>
<td>Loading, carrying, dumping and general purpose site clean up.</td>
</tr>
<tr>
<td></td>
<td>Truss booms.</td>
<td>To lift and place objects/portable equipment in construction and plumbing applications.</td>
</tr>
<tr>
<td></td>
<td>Hoppers.</td>
<td>To collect and dispose off-site debris and waste material.</td>
</tr>
<tr>
<td></td>
<td>Mobile Elevated Work Platforms (MEWP).</td>
<td>To provide access to workers at heights.</td>
</tr>
<tr>
<td>Forklifts</td>
<td></td>
<td>Designed for lifting boxes, bundles or pallets of supplies.</td>
</tr>
<tr>
<td><strong>Cranes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Types:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile cranes e.g.</td>
<td>Tongs; grabs; clamps; magnets; and grapples.</td>
<td>Material grabs.</td>
</tr>
<tr>
<td>- Crawler-mounted.</td>
<td>Concrete buckets; skips; load platforms; and bottom dump platforms.</td>
<td>Bulk material lifting.</td>
</tr>
<tr>
<td>- Wheel-mounted.</td>
<td>Skull crackers.</td>
<td>Weights used for demolition and break up of buildings and pavements.</td>
</tr>
<tr>
<td>- Telescopic-boom.</td>
<td>Pile drivers.</td>
<td>To hammer the pile into the soil.</td>
</tr>
<tr>
<td>- Gantry cranes.</td>
<td>Buckets e.g. clamshell, orange peel, shovel and draglines etc.</td>
<td>Digging and excavation, material movement.</td>
</tr>
<tr>
<td>Modified cranes for heavy lift e.g.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Trailing counterweight.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Ring system.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Derricks.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3.2 highlights excavators as one of the most versatile pieces of equipment since common operations of this item not only include excavation work (loosening and loading earth; trench work; footings for small buildings and foundations) but also material handling (pipe-laying, trench sheets), demolition, site cleanup and ripping operations (Nunnally, 2000). Statistics supplied by JCB for the overall sales of equipment for all manufacturers in the UK also confirm the popularity of excavators in the construction industry (see Table 3.3). Mini and crawler excavators have shown a particularly dramatic rise in sales (204% and 93% increase in market volume respectively from 1995 to 2004) and the increased demand for these two types of excavator reflects the significant role that these versatile machines play on a modern construction site (Edwards et al., 2003).

3.2 EXISTING APPLICATION OF TECHNOLOGY FOR PLANT AND EQUIPMENT

Given the fact that plant and equipment utilisation on construction sites can improve organizational efficiency and productivity, there has been a huge effort by both academics and plant manufacturers to apply hybrid ICT solutions for improved machine performance and productivity (Caterpillar, 2005b; Komatsu, 2005; Cobo et al., 1998; Oloufa et al., 2003). Table 3.4 reviews existing technology applications for some generic plant and equipment type. Tabulating information in this way also assists in generalising the most common technology applications developed. This generalisation is given in Table 3.5.
Table 3.3: Sales (in number) for all companies in the UK for 1995 – 2004 (Source: JCB¹)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Articulated Dump Trucks</td>
<td>630</td>
<td>615</td>
<td>570</td>
<td>500</td>
<td>620</td>
<td>520</td>
<td>615</td>
<td>723</td>
<td>591</td>
<td>542</td>
<td>-14 %</td>
</tr>
<tr>
<td>Asphalt Finishers</td>
<td>130</td>
<td>97</td>
<td>75</td>
<td>118</td>
<td>161</td>
<td>148</td>
<td>145</td>
<td>155</td>
<td>150</td>
<td>144</td>
<td>+11 %</td>
</tr>
<tr>
<td>Backhoe Loaders</td>
<td>4,330</td>
<td>4,150</td>
<td>3,550</td>
<td>3,100</td>
<td>2,900</td>
<td>2,625</td>
<td>2,500</td>
<td>2,577</td>
<td>2,600</td>
<td>2,400</td>
<td>-80 %</td>
</tr>
<tr>
<td>Crawler Dozers</td>
<td>197</td>
<td>175</td>
<td>195</td>
<td>243</td>
<td>133</td>
<td>172</td>
<td>235</td>
<td>233</td>
<td>185</td>
<td>183</td>
<td>-07 %</td>
</tr>
<tr>
<td>Crawler Excavators</td>
<td>2,770</td>
<td>2,630</td>
<td>2,800</td>
<td>2,700</td>
<td>3,045</td>
<td>3,100</td>
<td>3,480</td>
<td>3,750</td>
<td>4,150</td>
<td>5,350</td>
<td>+93 %</td>
</tr>
<tr>
<td>Graders</td>
<td>81</td>
<td>51</td>
<td>57</td>
<td>40</td>
<td>49</td>
<td>46</td>
<td>63</td>
<td>45</td>
<td>32</td>
<td>32</td>
<td>-60 %</td>
</tr>
<tr>
<td>Mini Excavators</td>
<td>3,600</td>
<td>2,925</td>
<td>3,450</td>
<td>3,900</td>
<td>5,260</td>
<td>6,375</td>
<td>7,325</td>
<td>8,500</td>
<td>10,130</td>
<td>10,950</td>
<td>+204 %</td>
</tr>
<tr>
<td>RLTls - Masted</td>
<td>770</td>
<td>520</td>
<td>545</td>
<td>550</td>
<td>525</td>
<td>500</td>
<td>200</td>
<td>235</td>
<td>240</td>
<td>290</td>
<td>-62 %</td>
</tr>
<tr>
<td>RLTls - Telescopic</td>
<td>5,280</td>
<td>5,185</td>
<td>4,750</td>
<td>3,900</td>
<td>4,435</td>
<td>4,775</td>
<td>5,320</td>
<td>5,638</td>
<td>5,880</td>
<td>6,600</td>
<td>+25 %</td>
</tr>
<tr>
<td>Rigid Dump Trucks</td>
<td>115</td>
<td>86</td>
<td>130</td>
<td>70</td>
<td>63</td>
<td>38</td>
<td>50</td>
<td>65</td>
<td>89</td>
<td>55</td>
<td>-52 %</td>
</tr>
<tr>
<td>Scrapers</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>8</td>
<td>11</td>
<td>10</td>
<td>14</td>
<td>5</td>
<td>+150 %</td>
</tr>
<tr>
<td>Skid Steer Loaders</td>
<td>1,050</td>
<td>1,025</td>
<td>910</td>
<td>875</td>
<td>865</td>
<td>930</td>
<td>1,020</td>
<td>900</td>
<td>720</td>
<td>800</td>
<td>-23 %</td>
</tr>
<tr>
<td>Wheeled Excavators</td>
<td>309</td>
<td>380</td>
<td>330</td>
<td>375</td>
<td>266</td>
<td>310</td>
<td>400</td>
<td>425</td>
<td>465</td>
<td>480</td>
<td>+55 %</td>
</tr>
<tr>
<td>Wheeled Loaders</td>
<td>1,040</td>
<td>1,005</td>
<td>990</td>
<td>974</td>
<td>855</td>
<td>885</td>
<td>980</td>
<td>895</td>
<td>1,070</td>
<td>1,065</td>
<td>+24 %</td>
</tr>
</tbody>
</table>

Total sales: 20,313 18,858 18,364 17,352 19,184 20,434 22,346 24,151 26,316 28,896

¹ Statistics from JCB were provided by Mr Richard Sharp, Chief Economist.
Table 3.4: Generic plant types and existing technology applications

<table>
<thead>
<tr>
<th>Generic Plant Categories</th>
<th>Available / Existing Technological Application</th>
</tr>
</thead>
</table>
| **Loaders and Dozers**  | ▪ Real time control of bucket hydraulic system to provide a linearizing effect for better operator/machine performance (Cobo et al., 1998).  
▪ Grade Control System (GCS) for precise and accurate grading.  
  o Laser GCS employed machine mounted components and an off-board laser transmitter to provide precise elevation information on an in-cab display followed by automatic blade lift and tilt (Caterpillar, 2005b).  
  o GPS based GCS used the positioning technology to compare the blade position to a three-dimensional computerized site plan and signals the operator/hydraulic system to lift or lower the blade to achieve the design requirements (Caterpillar, 2005b). |
| **Excavators**          | ▪ Development of sensor based intelligent excavation systems e.g. capture of mechanical energy, stress and resistance information from the mining face of the machine with on-board screen display for operators to assess local variation in the bench environment and to make real-time decisions in order to avoid stress build up (Frimpong et al., 2005); force and impedance control depending on whether the bucket was in free space or in contact with the soil during the excavation process (Ha et al., 2000); vehicle speed control for controlled stoppage of engine in dangerous states (Klaus and Urbaniak, 1998).  
▪ Active metal detection and tracking system developed to detect any buried utility line (Huang, 1996) and metals (Lorenc and Bernold, 1998) in its detection range.  
▪ Robotic excavation and pipe installation system to reduce accidents caused due to workers entering deep trenches. Joystick control of hydraulic actuators, data acquisition/processing and CAD interface represent the main software/hardware components (Lee et al., 1999).  
▪ Automatic tool movement and guidance, repetition of realised movements, recognition of specific tool trajectories (Plonecki et al., 1998). |
| **Graders**             | ▪ Grader blade stabilisation system consisted of a blade adjustment hydraulically driven mechanism which was controlled using position signals from the selected points of the machine (Sobczyk and Tora, 1998). |

Continues...
### Generic Plant

<table>
<thead>
<tr>
<th>Available / Existing Technological Application</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cranes</strong></td>
</tr>
<tr>
<td>• Robotic techniques used for a freely programmable handling system to be used in working environments where programmable movement and force patterns are important (Leyh, 1995; Lyle et al., 2004).</td>
</tr>
<tr>
<td>• Motion control for high precision and better safety. Semi-automatic devices were used to assist the foremen, who were situated at suitable points to direct the load to its final destination (Rosenfeld and Shapiro, 1998).</td>
</tr>
<tr>
<td>• Collision detection system where the position and identity of each worker was wirelessly communicated to a central monitoring station to be compared with predetermined tasks and processes carried out at the site (Abderrahim et al., 2005).</td>
</tr>
<tr>
<td><strong>Telescopic handlers</strong></td>
</tr>
<tr>
<td>• Residual vibration in the boom of a telehandler often arises when lifting material to higher positions. A system was developed to detect working condition information through sensors, followed by the application of vibration control algorithm. This helped to improve the productivity and safety of the machine; a less experienced operator could easily operate the boom with controlled vibration occurring (Park and Chang, 2004).</td>
</tr>
<tr>
<td><strong>General</strong></td>
</tr>
<tr>
<td>• Load sensing systems for smooth movements in lifting operations (Komatsu, 2005).</td>
</tr>
<tr>
<td>• Global Positioning Systems (GPS) and sensor technologies were used to monitor and record real time positioning, vehicle tracking and collision detection for improved machine productivity and safety (Oloufa et al., 2003; QinetiQ, 2002).</td>
</tr>
<tr>
<td>• Computer Aided Earthmoving System (CAES) provided the power of on-board computing where the design files could be created in the office and loaded onto the display in the machine or the operator could generate their own level or sloping plane designs to follow. The system could be linked into an integrated information management system and specialised versions are available for both mining and landfill applications (Caterpillar, 2005b).</td>
</tr>
<tr>
<td>• Equipment health monitoring (Komatsu, 2005).</td>
</tr>
<tr>
<td>• Collision-free vehicle travel path planning (Kim and Russell, 2003).</td>
</tr>
<tr>
<td>• Safety systems: Video systems (Everett and Slocum, 1993), Radar based object detection systems (Engineeringtalk, 2005; Perco, 2005).</td>
</tr>
<tr>
<td>• Information Systems (IS):</td>
</tr>
<tr>
<td>• Fleet management systems for advanced plant management e.g. equipment theft control system, Vital Information Management System (VIMS) that provides operators and service personnel information on vital machine functions, production and performance information etc. (Caterpillar, 2005b).</td>
</tr>
<tr>
<td>• Integrated mining information system comprises of a series of component programs for production reporting, truck assignment, health monitoring and fleet analysis, material and machine tracking. The system links the collected information in the field to the office business enterprise systems (Caterpillar, 2005b).</td>
</tr>
</tbody>
</table>
Table 3.5: Available technology applications for plant and equipment

<table>
<thead>
<tr>
<th>Applications</th>
<th>Technology</th>
<th>References</th>
</tr>
</thead>
</table>
| **Operation/Vehicle Specific Control Systems** e.g. bucket, blade, grade, speed, stress, vibration controls etc.; and load sensing systems. | - Laser.  
- Global Positioning Systems (GPS).  
- Sensor based systems. | Caterpillar (2005b); Frimpong *et al.* (2005); Komatsu (2005); Park and Chang (2004); Ha *et al.* (2000); Sobczyk and Tora (1998); Klaus and Urbaniaik (1998); and Greer *et al.* (1997). |
| **Automation** e.g. programmable handling system and motion control; metal detection; tool movement and guidance; and teach and learn capability (repetition/recognition of specific tool trajectory). | - Robotics.  
- Remote controls.  
- Sensor based systems. | Lytle *et al.* (2004); Lee *et al.* (1999); Lorenc and Bernold (1998); Plonecki *et al.* (1998); Greer *et al.* (1997); Huang *et al.* (1996); and Leyh (1995). |
| **Information System** e.g. fleet management systems (information on theft control, machine function, production and performance); operator or operation specific information systems (machine assignment, fleet analysis, production reporting); and operation specific real time data capture. | - Software and On-board computing based IS.  
- WAN.  
| **Safety Systems** e.g. collision detection systems. | - GPS.  
- Video systems.  
- Radar based systems. | Abderrahim *et al.* (2005); Perco (2005); Engineeringtalk (2005); Rosenfeld and Shapira (1998); and Everett and Slocum (1993). |
| **Tracking Systems** e.g. monitor and record real time positioning; collision detection; and navigation systems for collision free path planning etc. | - GPS.  
- Wireless, sensor and web technologies.  
- RFID tags.  
3.3 EQUIPMENT AND WORKER SAFETY CONCERNS

There have been growing health and safety concerns in the construction industry which is regarded as one of the most dangerous industries in the world (see Appendix G). The aforementioned appendix highlights that despite efforts to reduce the risk of occupational injuries and illnesses in construction, the industry continues to account for a consistently high (and sustained) trend in the number of equipment related injuries both in developed and developing countries around the world.

During the appraisal of plant and equipment, several areas of concern for plant managers have been identified. In particular, this includes health and safety issues covering pedestrian protection, collision detection, information management etc. As a result, some further exploration was carried out with regards to health and safety concerns and how the construction industry can exploit emerging ICT for the benefit of vehicle automation and management.

From the 20 accident categories recorded by the Health and Safety Executive (HSE), two categories can be directly linked with plant and equipment operations (Edwards et al., 2003). These are 'contact with moving machinery or material being machined' and 'struck by moving vehicle'. A detailed analysis of plant related accidents incurred by the construction workforce (i.e. employees and self-employed workers) is presented in Table 3.6 for the period 1994-2004 (HSE, 2005). The listed data only includes employees and the self-employed and does not incorporate members of the public. This is because such information was unavailable at the time that this research was undertaken.

The statistics are further sub-categorised into three injury types, namely i) fatal injuries, ii) major injuries and iii) up to 3 days off work. For employees, an average of 3% of all the injuries incurred were caused due to contact with moving machinery and 2% were due to being struck by a moving vehicle. For self-employed persons, the average percentage of all injuries attributable to the two categories was 3.7% and 1.7% respectively. Overall, for both employees and the self-employed, the percentage of total injuries caused due to contact with machinery and being struck by a moving vehicle...
were 4% and 2% respectively. These figures are compelling and the HSE have openly acknowledged that plant related accidents are the second most serious problem in the construction industry after falling from heights (HSE, 2005).

As part of a validation exercise, statistics for the total number of employees and self-employed were also acquired from the governmental Department of Business, Enterprise and Regulatory Reform (BERR), formerly known as Department of Trade and Industry (DTI, 2005). These employment statistics were then used with the accident statistics to calculate, for both employee types, the accidents per thousand individuals working in the industry so that a direct comparison could be made between accident and employee type. Such a transformation is particularly useful where, as in this example, the values of data between two or more trends differ greatly in size. Left unadulterated, perturbations in a trend with smaller values cannot be readily observed on the \( y \)-axis if plotted on a graphic which includes a trend with considerably larger values.

Figures 3.1 and 3.2 illustrate that the plant related accident rate is higher in employees than the self-employed. This may be due to the fact that employees tend to be more in charge of the general labouring duties and are thus ‘semi-skilled’, unlike specialist and ‘highly-skilled’ trade based self-employed operatives who focus on specific tasks and duties that they have been specifically trained for (Edwards, 2003). The workplace risks and hazards associated with workplace activities are therefore known in greater detail. Employees who tend to have general labouring duties become involved in a multi-trade range of work activities and often only ever acquire a broad and superficial knowledge of workplace risks and hazards. In addition, the self-employed have far greater autonomy over daily work activities and the work environment unlike employees who are managed and governed by site management. An alternative theory is that the self-employed simply do not report accidents because unlike employees, time off sick invariably equates to no pay. These are however, working hypotheses and further work will be required to investigate this enigmatic trend more fully.
Table 3.6: Injuries to workers (employees and self-employed) caused due to contact with machines (‘contact with machinery or material being machined’ or ‘struck by moving vehicle’) for the period 1996 - 2004

<table>
<thead>
<tr>
<th>Statistical Period</th>
<th>Kind of Accident</th>
<th>Employed</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Self Employed</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatality Major</td>
<td>Over 3</td>
<td>Total</td>
<td>% of all</td>
<td>Total No of</td>
<td>Accidents</td>
<td>Fatality Major</td>
<td>Over 3</td>
<td>Total</td>
<td>% of all</td>
<td>Total No of</td>
<td>Accidents</td>
</tr>
<tr>
<td></td>
<td>Injury</td>
<td>Day</td>
<td>Injuries</td>
<td>Accidents</td>
<td>Employees (thousands)</td>
<td>per 1000</td>
<td>Injury</td>
<td>Day</td>
<td>Injuries</td>
<td>Accidents</td>
<td>Employees (thousands)</td>
<td>per 1000</td>
</tr>
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<td>81</td>
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<td>739</td>
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<td>20</td>
<td>45</td>
<td>67</td>
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<tr>
<td></td>
<td>S</td>
<td>10</td>
<td>88</td>
<td>117</td>
<td>215</td>
<td>2</td>
<td>3</td>
<td>0.3</td>
<td>19</td>
<td>24</td>
<td>43</td>
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</tr>
<tr>
<td>1997-98</td>
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<td>3</td>
<td>123</td>
<td>215</td>
<td>341</td>
<td>3</td>
<td>839</td>
<td>0.4</td>
<td>0</td>
<td>15</td>
<td>22</td>
<td>37</td>
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<tr>
<td></td>
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<td>94</td>
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<td>245</td>
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<td>3</td>
<td>0.3</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
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<td>14</td>
<td>31</td>
</tr>
<tr>
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<td>99</td>
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<td>6</td>
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</tr>
<tr>
<td>2002-03</td>
<td>C</td>
<td>1</td>
<td>126</td>
<td>240</td>
<td>367</td>
<td>3</td>
<td>994</td>
<td>0.4</td>
<td>0</td>
<td>21</td>
<td>19</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>4</td>
<td>84</td>
<td>102</td>
<td>190</td>
<td>2</td>
<td>2</td>
<td>0.2</td>
<td>1</td>
<td>15</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>2003-04</td>
<td>C</td>
<td>1</td>
<td>149</td>
<td>270</td>
<td>420</td>
<td>3</td>
<td>1011</td>
<td>0.4</td>
<td>0</td>
<td>31</td>
<td>31</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>9</td>
<td>83</td>
<td>100</td>
<td>192</td>
<td>2</td>
<td>1</td>
<td>0.2</td>
<td>1</td>
<td>13</td>
<td>5</td>
<td>19</td>
</tr>
</tbody>
</table>

NB: C = Contact with machinery or material being machined  
S = Struck by moving vehicle
Figure 3.1: Injuries to workers (employees and self-employed per thousand) caused due 'contact with machinery or material being machined' for the period 1996-2004

Contact with machinery or material being machined

<table>
<thead>
<tr>
<th>Year</th>
<th>Injuries per (000's)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996-97</td>
<td>0.6</td>
</tr>
<tr>
<td>1997-98</td>
<td>0.4</td>
</tr>
<tr>
<td>1998-99</td>
<td>0.2</td>
</tr>
<tr>
<td>1999-00</td>
<td>0.6</td>
</tr>
<tr>
<td>2001-02</td>
<td>0.4</td>
</tr>
<tr>
<td>2002-03</td>
<td>0.2</td>
</tr>
<tr>
<td>2003-04</td>
<td>0.6</td>
</tr>
</tbody>
</table>

- employees
- self employed

Figure 3.2: Injuries to workers (employees and self-employed per thousand) caused due to being 'struck by a moving vehicle' for the period 1996-2004

Struck by moving vehicle

<table>
<thead>
<tr>
<th>Year</th>
<th>Injuries per (000's)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996-97</td>
<td>0.4</td>
</tr>
<tr>
<td>1997-98</td>
<td>0.3</td>
</tr>
<tr>
<td>1998-99</td>
<td>0.2</td>
</tr>
<tr>
<td>1999-00</td>
<td>0.1</td>
</tr>
<tr>
<td>2001-02</td>
<td>0.0</td>
</tr>
<tr>
<td>2002-03</td>
<td>0.1</td>
</tr>
<tr>
<td>2003-04</td>
<td>0.0</td>
</tr>
</tbody>
</table>

- Employees
- Self employed
3.3.1 HSE Initiatives to Address Site Safety Concerns

Figures 3.1 and 3.2 illustrate a fairly consistent accident trend amongst employees and the self-employed for both accident categories (i.e. ‘contact with machinery/material being machined’ and ‘struck by moving vehicle’). A recent HSE report concluded that accidents caused by the movement of vehicles on construction sites are among the main sources of injuries in the construction industry (HSE, 2005). Consequently, sites that utilise various kinds of mobile plant and equipment suffer from the risk of vehicles colliding with each other or with pedestrians. To reduce this risk, Regulation 28(e) of the Provision and Use of Work Equipment Regulations 1998 (PUWER 98) states that:

“where the driver's direct field of vision is inadequate to ensure safety then 'visibility' aids or other 'suitable devices' should be provided so far as is reasonably practical.”

According to the HSE (1996), the duties under relevant safety regulations include ensuring a safe place of work and safe means of access to and from that place of work. In particular, Regulation 15, 16 and 17 of the Construction Health, Safety and Welfare (CHSW) Regulations 1996 (HSE, 1996) require contractors to:

i) ensure construction sites are organised in a way that pedestrians and vehicles can both move safely without risks to health;

ii) ensure routes are suitable and sufficient for the use of pedestrian or vehicles;

iii) control the unintended movement of any vehicle;

iv) ensure warnings of any possible dangerous movement e.g. reversing vehicles; and

v) make certain safe operation of vehicles including prevention of riding or remaining in unsafe positions.

Interpretation of these regulations by the HSE inspectorate means that individual inspectors expect contractors to:
i) implement a traffic management plan as part of the health and safety plan;

ii) keep pedestrians separated from vehicle movements e.g. plant slewing and loading;

iii) maintain one-way traffic system(s) for minimised vehicle reversing and use trained banksman for signalling purposes;

iv) use safety and warning devices;

v) adopt appropriate maintenance systems;

vi) train drivers and plant operators; and

vii) ensure that workers wear high visibility clothing and other personal protective equipment (HSE, 2004b).

Here, the overriding emphasis is to provide a culture of safe site, worker and machine in order to create a safer working environment. Yet clearly accident statistics reveal that additional measures are required to reduce accident rates to acceptable levels.

3.3.2 General Reasons for Plant Related Safety Concerns

Reasons for accidents are many and varied but in the context of vehicle/pedestrian collisions these reasons include the following:

i) inadequate training and competence development of staff employed to both manage and operate plant and equipment. For example, a recent report, on the safe use of excavator quick-hitch device, has revealed that CPCS operators are not trained in the use of this basic safety device and hence, cannot be deemed to be competent (Edwards, 2007);

ii) failure to separate mobile plant and equipment from pedestrians by way of designated transportation only routes;

iii) failure to provide fully trained and competent banksmen as and when required;

iv) inappropriate selection of mobile machinery;

v) failure to keep mobile plant properly maintained;

vi) stress and fatigue induced upon an operator due to long operating hours; and
Another important contributor to safety concerns on a construction site is the complicated nature of the industry’s supply chain. Due to high variability in construction environments and the increased complexity of construction processes, supply chain management is critical for successful construction management (Tseng et al., 2006). The contribution of specialist and trade subcontractors to the total construction process can account for as high as 90% of the total value of the project (Nobbs, 1993). This highlights that in a construction project, major contractors are heavily reliant upon subcontractors (medium or small enterprises, so called SMEs) in order to complete the job on time and to a reliable standard. Unfortunately, SMEs in the industry are currently experiencing a dearth of skills within the workforce and the National Audit Office (NAO) has recently cited that only 22,000 people enter the construction industry every year via formal education and training routes (NAO, 2004). In addition, the Construction Skills (formerly known as Construction Industry Training Board or CITB) reported that many major contractors have reduced funding for training and are unlikely to provide any training to labour-only subcontractors (ibid). The supply chain and operatives within it, undoubtedly influence quality standards in the downstream (contractor/subcontractor) supply chain. Low quality subcontractors and reduced process conformity also affects the health and safety processes on a construction site.

Guidance from the HSE (2002a) states that before awarding a contract, major contractors should discuss:

i) a subcontractor’s health and safety performance;
ii) proposed working methods;
iii) equipment brought onto site; and
iv) the health and safety risks identified which the contractor’s operation may create for other workers at the site.

As the information from the subcontractors becomes available, it should be included in the health and safety plan for the construction phase which is required under the CDM
Regulations (HSE, 1994). The problem here is that smaller companies working for larger organisations may not necessarily follow the same guidance to the same level of conformity because their goals may be different to the main contractors. In addition, site managers are under immense pressure to complete work on time and to budget.

### 3.4 CURRENT USE OF ICT FOR SITE SAFETY AND COLLISION DETECTION

As well as promoting the use of various ‘additional’ aids and devices, PUWER advocates the need to identify risk sources (Edwards, 2004). The theory behind Regulation 28(e) is that a ‘specific’ risk assessment (as each construction site is bespoke, with its own unique hazards) will allow industry practitioners to determine which tailor-made aids should be fitted to a machine to reduce the likelihood of an accident occurring. A wide range of aids and devices are currently available and these range from simple pencil beam and convex mirrors to radar (Edwards, 2004) and video systems (Everett and Slocum, 1993). Radar based object detection systems can detect static and moving objects in a pre-defined coverage area (Engineeringtalk, 2005) and will report the distance of the closest object via visual range indicators and an audible signal which alerts the vehicle operator (Perco, 2005). Radar based systems are the most widely used technology for collision detection *(ibid)*. However, they are not particularly suited to work in dirty environments that contain airborne pollution or large objects which can trigger false alarms (Oloufa *et al.*, 2003). To avoid such problems, GPS technology can be used to relay timely information to operators about other vehicles and pedestrians working in their immediate vicinity. GPS does not have the same inherent limitations of radar and the technology could be used to help reduce the occurrence of collision type accidents (Qinetiq, 2002).

Collision detection safety systems developed for vehicles on construction sites can be broadly categorised into two types. These are vehicle collisions with other vehicles and vehicle collisions with pedestrians. To avoid vehicle collision with other vehicles, the Fujita Corporation developed and implemented a Tele-earthwork system aided by GPS, to operate backhoes, bulldozers, trucks and other construction vehicles and equipment without plant operators (Oloufa *et al.*, 2003). During the initial stages of the project,
each operator controlled one vehicle remotely, using several screens which showed images from a camera mounted on the vehicle and cameras located around the site. However, this situation denied true 3D view and required increased vigilance, and frequent verbal warning exchanges between operators, to avoid vehicle collisions. As a result, GPS and wireless communication were used to provide real time tracking, based upon a collision detection algorithm that calculated the intersection point of two vectors representing two moving vehicles. The vehicle and its GPS position (location) defined each vector. Once the intersection point was computed and the vehicles’ speeds (from GPS) determined, the program then calculated the distance from the potential collision point to each vehicle location and the braking distance required for each vehicle. If the braking distance was higher than the tolerance value, then a collision alert message was sent to the vehicle(s) in question.

To address vehicle collisions involving pedestrians, an equally innovative research initiative was conducted by Abderrahim (2005). This collision detection research sought to achieve pedestrian safety by utilising a human safety system where the worker’s helmet contained miniature positioning and communication instruments. The position and identity of each worker was periodically, wirelessly communicated to a central monitoring station where the information was compared to a database comprising of predetermined tasks and processes carried out at the site. If a given worker strayed into a location which the system considered to be hazardous, an alert signal was communicated to the endangered worker, via alarm or voice, using headphones fixed to the helmet.

3.5 JUSTIFICATION FOR EQUIPMENT SELECTION

Earthmoving equipment is a generic class of machines that include dozers, loaders, scrappers, hydraulic excavators, haulers, graders, trenchers and compactors (Edwards et al. 2003). Machine selection decisions on a construction project are based upon the nature of the task, site conditions, volume of material to be moved, type of material and time available (Nunnally, 2000). As exhibited in Table 3.2, amongst various types of machines, excavators are one of the most versatile and diverse pieces of equipment (Harris 1994; Caterpillar Inc. 2005a; JCB 2005). As a prelude to employing emerging
technologies for improved health and safety of plant and equipment, excavators are examined for this research work for three reasons.

Firstly, the diversity of applications (see Table 3.2) has helped in the increased popularity and demand of the machine (Mintel 2005). In particular, mini and crawler excavators have shown a significant rise in sales (see Figure 3.3) reflecting the major role these versatile machines play on a modern construction site.

Secondly, according to the HSE (2004b) the widespread usage of the machine has resulted in increased workplace transport accidents. In a recent HSE report (ibid) the problem of all round visibility was cited as being an underlying ‘causal’ factor of many plant related accidents investigated. Moreover, the HSE reported that accidents involving a range of excavators often include people being struck by cabs, counterweights or backhoes when the excavator is slewing; this reinforces the fact that a driver’s vision is impaired at the back by the counterweights and on the right-hand side (excluding the mini excavator type) by the mast of the machine.

Thirdly, the various makes and models of machines operate differently and therefore causes of accidents may be dissimilar. As a result, in order to reduce variance in the research one machine type was selected where future work may follow the same...
methodology to enhance the proposed system (outcome of this research) into a more
generic system for all plant types.

Thus, taking these three reasons into account, excavators were selected for this
particular research in order to address the health and safety concerns of managers on a
construction site where workers are operating in close proximity of these machines.

3.6 CHAPTER SUMMARY

This chapter has presented classification of plant and equipment, typical operations and
sales. It examined the most popular plant type and the health and safety concerns
associated with them. The chapter has also examined various existing technological
applications for improved machine performance and productivity.

A detailed analysis of plant related accidents incurred by the construction workforce
was carried out for the period 1994-2004. It was highlighted that the extensive use of
plant and equipment has resulted in a consistent trend of workplace transport accidents
on construction sites. In addition, the review has drawn attention to the problem of all
round visibility in certain type of machines where a driver’s vision is impaired. For
instance, in case of telescopic handlers and excavators, the operator’s vision is impaired
on the right-hand side by machine’s mast. Likewise, an excavator operator’s visibility is
minimised at the back of the machine due to its counterweight. The chapter also
reviewed the current use of ICT for collision detection and site safety. It is concluded
that plant related accident rates remain unacceptably high amidst these efforts. It is
proposed at this juncture that emerging ICT systems should not only be explored for
superior plant management on construction sites but also for improved operator
awareness and site safety.
CHAPTER 4

EMERGING INFORMATION AND COMMUNICATION TECHNOLOGIES

4.0 INTRODUCTION

The previous chapter demonstrated the positive correlation that exists between plant and equipment usage on construction sites and accidents involving plant/pedestrian collisions. Worryingly, these accidents have remained relatively high year on year, despite substantial efforts of industry and academia to reduce them. Clearly, this trend reveals that additional measures, controls, systems and procedures are required to reduce accident rates to acceptable levels.

Advanced ICT, whilst not the total solution, may provide practitioners with a useful means with which to monitor, record and learn from the interaction that exists between pedestrians and vehicles on a construction site. This chapter explores the advancements and trends in the use of emerging ICT and investigates how plant managers and operators can further exploit these technologies (and information created by them) for the benefit of better plant management and safety on construction sites.

4.1 EMERGING ICT

Plant and equipment utilisation may improve the productivity, efficiency and cost effectiveness of construction projects (Edwards et al., 2003; Kim and Russell, 2003) but mechanisation is not the only resource at a contractor's disposal. Unprecedented advancements in ICT have resulted in improved business processes and working environments throughout various industries (Chan, 2000) and the construction industry is no exception (Cheng et al., 2006). Practitioners within the industry have capitalised upon these advancements through the adoption of various technologies ranging from mobile communications for on-site collaboration (Bowden and Thorpe, 2002) to e-
tagging of building products for improved information flow throughout the supply chain (Constructing Excellence, 2005).

Given the fact that the use of both ICT and plant and equipment can improve organizational efficiency, some researchers and plant manufacturers have attempted to combine the two resources to produce hybrid ICT solutions for improving machine performance (Beliveau, 1996), increasing productivity (Navon, 2005), providing improved operator support through operator specific information (Caterpillar, 2005a), lowering operating costs (Edwards et al., 2003) and enhancing maintenance management (Network Rail, 2005). Consequently, machines have been fitted with:

- on-board computers, software and integrated Management Information Systems (MIS) for the control and monitoring of mechanical operations (Peyret et al., 2000);
- automated data collection mechanisms for earthmoving performance measurement (Navon et al., 2004), improved operation quality of equipment (Li et al., 1996) and operation analysis to identify critical events occurring in machine production cycles (Hildreth, 2003);
- Global Positioning Systems (GPS) and sensor technologies which are used to monitor and record real time positioning, vehicle tracking and collision detection for improved machine productivity and safety (Oloufa et al., 2003; Qinetiq, 2002), equipment health monitoring and collision-free vehicle travel path planning (Kim, 2003);
- wireless communication technologies for wireless information services and data transmission (Garza and Howitt, 1998); and
- fleet management systems (including aspects relating to finance, inventory and maintenance) for advanced plant management solutions (Caterpillar, 2005a).

More recent technological advancements have witnessed the increased demand for technologies such as: Micro-Electro-Mechanical Systems (MEMS), Wireless Communication (WC) and Sensor Networks (SN) for intelligent sensing (RFID Journal, 2005a; Akyildiz et al., 2002); mobile computing applications for user-centred mobile work environments (COMIT, 2005a); and Radio Frequency IDentification (RFID) tags for tracking and identification (CPI, 2000). The potential application of these latest
clutch of technologies to mobile plant and equipment management has yet to be explored fully, however, the palpable benefits that could be derived are considerable.

Given the wide range of ICT solutions now available and the exponential pace of technological development, it is considered important to first define a scope of discussion on ICT for this research. Figure 4.1 lists the technologies explored for this study; these range from long-established technologies (such as MIS), to relatively recent innovations (such as wireless communication, mobile computing and positioning technologies), to emerging developments (such as Automatic Identification and Data Collection e.g. electronic tagging). These technologies were selected through a literature review because of their inherent potential to address practitioner concerns over plant related health and safety on construction sites. Moreover, application of these technologies could improve vehicle management and site safety. Technology domains referred to in Figure 4.1 are now reviewed to provide a concise critique.

4.1.1 Management Information Systems (MIS)

MIS are integrated, user-machine systems for providing information to support operations, management and decision making functions within an organization (Williams, 1997). In basic terms, MIS is a system into which defined data are collected, processed and communicated to assist managers and business analysts (Collier and Dixon, 1995). Figure 4.2 describes fundamental aspects of a MIS; it depicts a computer based system (consisting of software, hardware and data sources) which may also coordinate with other systems. The system processes data to provide managers with the tools for decision making and performing their tasks more efficiently.
**Figure 4.1: Scope of discussion for emerging ICT**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Perceived System Requirements for Improved Plant Management and Safety</th>
</tr>
</thead>
</table>
| Management Information Systems (MIS)            | • Plant Management  
                                              | • Accident Management  
                                              | • Training and Personnel |
| Wireless Communication and Mobile Computing      | • Collision Detection  
                                              | • Hazard Notification  
                                              | • Position Evaluation |
| Positioning Technology                          | • Tracking and Positioning  
                                              | o Local Positioning  
                                              | o Global Positioning |
| Automatic Identification and Data Collection (AIDC) Technology |                                                                 |

**Figure 4.2: Management Information Systems (adapted from O’Brien, 1999; Lucey, 2005)**

Management Information Systems (MIS) is the application of people, technologies, and procedures (collectively called information systems) to solve business problems. However, MIS are different from regular information systems in the respect that they are used to analyze other information systems applied in operational activities in the organization (O’Brien, 1999)

**Examples**
- Decision Support Systems
- Project Management
- Resource and People Management
- Database Retrieval Applications

**Features**
- Captures information and stores it
- Easy access to stored information
- Manipulates information according to user needs
- Controls information flow in and out of the system
- Records and tracks input/output information
- Produce reports for management
Information systems can play a key role in the construction industry where the rapidly changing nature of the industry is recognised and business processes are constantly reviewed for increased efficiency, speed and quality of service and product and reduced costs (Kelly et al., 1997). Various information systems are available in the construction plant sector of the industry. According to Caterpillar (2005b), these systems maintain a wide range of information on a machine's assignment; production and performance; operation and maintenance. However, the literature highlights that there is a need to develop a more comprehensive management system for construction plant and equipment that shares information among different software applications rather than each application maintaining its own subset of information. The envisaged benefits of such a hybrid system include: integration with other existing systems and industry solutions (e.g. training and personnel information of operatives, maintenance etc.); streamlined operation and improved management of plant and equipment by sharing information readily among various technology platforms; and flexibility with regards to customisation to allow the needs of the plant related workforce to be met.

4.1.2 Wireless Communication and Mobile Computing

According to O'Brien (1999), ICT provides a diverse set of technological tools and resources that offer services ranging from information creation and management to providing business support whilst communicating, undertaking decision making and formulating problem solutions. Within the domain of ICT, Wireless Communication (WC) consists of a communication system where at least one user is always on the move (Shafi et al., 2002). This concept of the mobile user has resulted in paper-based processes being replaced by electronic-based information exchange where timely and relevant information can be accessed wherever and whenever required (Garza and Howitt, 1998).

WC systems deliver computing power to mobile users by combining the assets of two major technologies, namely: platform and transmission technologies (Yen and Chou, 2000). Platform technology (such as portable computers, personal digital assistants and other wireless enabled handheld devices) provides users with mobile desktop application software and intranet/internet access (Symbol, 2005). Transmission technology consists of applications with a communication infrastructure that can send
and receive data to and from the platform devices (Yen and Chou, 2000). For WC, the transmission infrastructure may consist of terrestrial and/or satellite components to form networks such as cellular and satellite systems or Wireless Local Area Networks (WLANs) (Shafi et al., 2002).

Advances made in wireless technologies have underpinned a new concept in computing, entitled mobile computing (Pierre, 2001). In turn, the widespread use of mobile computing has lead to a variety of new mobile applications being developed which enable flexible connectivity between project participants to be achieved (Brandon et al., 2005). The key advantage of mobile computing (over and above access to services, for example, the web, corporate Intranet and databases) is that applications can be developed to meet the specific needs of a mobile workforce (Pierre, 2001). For example, geotechnical engineers at Network Rail, responsible for the maintenance of earthwork structures throughout Britain, had to complete vast amounts of paperwork whilst determining the location and condition of track and supporting earthworks (Network Rail, 2005). Consequently, a Pocket PC application was developed, which enabled the engineers to accurately identify and assess asset location and condition. The data from the application was later imported and synchronised into a database, which not only proved to be a faster way of data collection, but also illustrated a means through which proactive maintenance planning and inspections of the supporting earthworks could be made.

In the construction industry, the need to address the information requirements of a mobile construction workforce has long been understood (Garza and Howitt, 1998). Consequently, in order to exploit the potential of emerging wireless and mobile communication technologies, many research projects have focused on the application of these technologies in a construction context. Some of the most prominent applications are reviewed and listed in Table 4.1. The table shows that there have been consistent efforts to develop a mobile WC system to consolidate the needs for all sectors within the industry. The table also underlines that these attempts have predominantly focused on wireless data: collection; access; transmission; and display to users on construction sites.
Despite this apparent growth in WC research, many reasons have been cited for the lack of widespread adoption of mobile computing in construction (Bowden et al., 2006; Bowden and Thorpe, 2002) including the:

- perceived high initial equipment and operative training cost;
- perceived lack of rugged devices and hardware limitations e.g. screen size, time consuming data entry on handheld devices, battery life etc.;
- perceived negative attitude towards technology in general and resistance to change;
- perceived complexity of application deployment;
- lack of understanding of user requirements; and
- lack of standardisation and integration of technology in the construction industry.

Nevertheless, with the decreasing costs, fast pace of mobile-ICT related technology advancements and successful adoption of technology in other industries, it has become possible to address many of the technology related limitations of mobile ICT deployment in the construction industry.
Table 4.1: Application of wireless and mobile communication technologies in the construction industry.

<table>
<thead>
<tr>
<th>Application</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>For wireless information transmission on construction sites.</td>
<td>Garza and Howitt, 1998;</td>
</tr>
<tr>
<td></td>
<td>Rebolj et al., 2001</td>
</tr>
<tr>
<td>To develop an integrated system to support mobile operations. The COSMOS</td>
<td>Meissner et al., 2001</td>
</tr>
<tr>
<td>project focused on construction sites that lack a permanent network</td>
<td></td>
</tr>
<tr>
<td>infrastructure.</td>
<td></td>
</tr>
<tr>
<td>To provide satellite-based communication between remote construction sites</td>
<td></td>
</tr>
<tr>
<td>using standards such as TCP/IP and IFC/XML (e.g. the SABARECO project).</td>
<td></td>
</tr>
<tr>
<td>To implement a WLAN-based system for wireless data collection for piling</td>
<td>Ward et al., 2002</td>
</tr>
<tr>
<td>works on a construction site (e.g. the SHEPRA project).</td>
<td></td>
</tr>
<tr>
<td>For Optimisation of the Internet use through remote preprocessing of jobs.</td>
<td>Liu et al., 2001</td>
</tr>
<tr>
<td>For 3D visualisation of design components and assemblies of construction</td>
<td>Shiratuddin et al., 2002</td>
</tr>
<tr>
<td>projects.</td>
<td></td>
</tr>
<tr>
<td>For displaying project information.</td>
<td>Rebolj et al., 2002</td>
</tr>
<tr>
<td>For different field activities in the construction industry including punch-</td>
<td>Saidi et al., 2002</td>
</tr>
<tr>
<td>listing, materials management, tracking, drawing access and quantity</td>
<td></td>
</tr>
<tr>
<td>surveying. The investigation focused on time and cost saving potential</td>
<td></td>
</tr>
<tr>
<td>through the use of this technology.</td>
<td></td>
</tr>
<tr>
<td>To develop an inspection support system where RFID tags were attached to</td>
<td>Yabuki et al, 2002</td>
</tr>
<tr>
<td>building components and were used to retrieve relevant inspection data.</td>
<td></td>
</tr>
<tr>
<td>For context sensitive data management by adapting the amount of information</td>
<td>Menzel et al., 2004</td>
</tr>
<tr>
<td>delivered to the device based on the user queries, location, task, time and</td>
<td>Burgy and Garrett, 2002</td>
</tr>
<tr>
<td>IT-infrastructure.</td>
<td>Schilit et al., 1994</td>
</tr>
<tr>
<td>To provide a mobile collaboration support infrastructure and context</td>
<td>Aziz, 2005</td>
</tr>
<tr>
<td>sensitive data delivery to mobile users in order to support construction</td>
<td>Aziz et al., 2004</td>
</tr>
<tr>
<td>collaboration. It was part of the WiSECON (Wireless and Semantic Web-Based</td>
<td></td>
</tr>
<tr>
<td>Integration of Construction Services) project that investigated the</td>
<td></td>
</tr>
<tr>
<td>applicability of Wireless and the Semantic Web technologies in the</td>
<td></td>
</tr>
<tr>
<td>construction industry for the development of a user-centred mobile work</td>
<td></td>
</tr>
<tr>
<td>environment.</td>
<td></td>
</tr>
</tbody>
</table>

Continues ...
<table>
<thead>
<tr>
<th>Application</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>A feasibility study for using wearable computers in the construction industry.</td>
<td>Fuller and Sattineni, 2002</td>
</tr>
<tr>
<td>A wearable computer is the one that can be worn by a user and that interacts with them based on the context of the situation. The study showed that the relatively high cost of rugged industrial wearable computers prevents its wide spread usage in the industry.</td>
<td></td>
</tr>
<tr>
<td>A camera mounted on top of a hard hat with pictures relayed to the site office using a mobile communication system for inspection and reporting.</td>
<td>Thorpe, 1995</td>
</tr>
<tr>
<td>COMIT (Construction Opportunities for Mobile IT) Project has looked into applications such as:</td>
<td>COMIT Project, 2007</td>
</tr>
<tr>
<td>• Intelligent Mobile Office for instant data connectivity at remote or short term construction sites;</td>
<td></td>
</tr>
<tr>
<td>• Monitoring progress to streamline project control and reduce the construction time;</td>
<td></td>
</tr>
<tr>
<td>• Mobile access to Health and safety information to view trends, back-up decisions and produce training material;</td>
<td></td>
</tr>
<tr>
<td>• Data Capture software where photographs, voice notes, formal notes, and sketches will be transferred wirelessly to a central server where access will be provided to main contractors and main designers via an Internet browser; and</td>
<td></td>
</tr>
<tr>
<td>• Other mobile applications e.g. earthworks inspections, time sheets and job allocation, plant maintenance/service scheduling, defect management, monitoring piling activities and fleet management etc.</td>
<td></td>
</tr>
</tbody>
</table>
4.1.3 Positioning and Tracking Systems

Mobile technology and wireless systems can further streamline business processes when combined with positioning systems (Intel, 2005). A positioning system typically determines accurate and real-time position measurement information of points or objects (Beliveau, 1996). However, a basic distinction can be made between tracking systems (where a system of stationary sensors determines the location of a mobile object) and positioning systems (where the location information is determined by a sensor on the mobile object itself) (Sarikaya, 2002). Typical examples of tracking and positioning systems are listed in Table 4.2, these include infrared, ultrasonic, GPS, Wi-Fi, Bluetooth and RFID based positioning and tracking systems.

A distinctive example of a positioning system is a Global Positioning System (GPS). GPS is a commonly used position and navigation system consisting of 24 satellites that act as reference points for receivers on earth (Navon et al., 2004). Using a constellation of satellites that transmit precise microwave signals, the system provides the GPS receiver with real-time positioning, velocity and time determination capability to an appropriate accuracy (Drane and Rizos, 1998). The positioning system is sufficiently flexible and robust, that it can be combined with other auxiliary technologies such as proximity sensors and LANs (Qinetiq, 2002), collision detection algorithms (Oloufa et al., 2003), Geographical Information Systems (GIS) and wide area networks (Li et al., 1996). A very common application of GPS is in real-time tracking systems due to their ability to identify the location of vehicles and/or objects (Qinetiq, 2002; Oloufa et al., 2003).

More recent developments in positioning systems include radio-transmission-based positioning technologies (Yoshitsugu et al., 2007). These technologies use methods of positioning the target (regardless of it being indoors or outdoors) according to the difference in the times of received radio waves and detecting if the target is inside the target area according to the signal strength (ibid). Some of the most commonly used radio-transmission-based positioning technologies are:
<table>
<thead>
<tr>
<th>Application</th>
<th>Description</th>
<th>Type</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Badge</td>
<td>Indoor system which uses infrared technology. Users carry electronic badges which communicate with fixed infrared sensor infrastructure deployed in the rooms.</td>
<td>Tracking system</td>
<td>Sarikaya, 2002</td>
</tr>
<tr>
<td>PARCTab</td>
<td>This system extended the Active Badge with a palm-sized tablet computer. The tab commanded the applications which were executed in the tablet computer. The results displayed on the screen of a tab were transmitted over the infrared network. The microcellular property provided location information on a room-by-room basis making it the first location-based applications on a PDA-class device.</td>
<td>Tracking system</td>
<td>Want and Schilit, 2001</td>
</tr>
<tr>
<td>Active Bat</td>
<td>The Active-Bat system resembles the Active-Badge system, except that it emits an ultrasonic pulse to ceiling mounted receivers. Each ceiling sensor measures the time interval to ultrasonic pulse arrival and computes its distance from the Bat.</td>
<td>Tracking system</td>
<td>Sarikaya, 2002</td>
</tr>
<tr>
<td>Guide Systems</td>
<td>Modern mobile computers can now take advantage of context in the same way as Active Badges and the PARCTab, but with a far richer user interface. For example in the 'Guide Systems', tablet based computers equipped with IEEE 802.11 wireless cards communicate with base stations. Based on the user location, information on maps, shops, cafes, city tours and famous landmarks is provided to the user.</td>
<td>Tracking system</td>
<td>Sarikaya, 2002</td>
</tr>
<tr>
<td>E911</td>
<td>E911 is the term used for emergency-services calls to 911 made from cell phones. Mobile operators are deploying new services to respond to the location of E911 called.</td>
<td>Positioning system</td>
<td>Want and Schilit, 2001</td>
</tr>
<tr>
<td>Cricket System</td>
<td>This indoor system relies on ultrasound which is used to determine distances between mobile tags and known points in the environment.</td>
<td>Tracking system</td>
<td>Hazas et al., 2004</td>
</tr>
<tr>
<td>GPS</td>
<td>This is an outdoor system where a GPS receiver estimates position by measuring satellite signals' time difference of arrival. With the changing position of objects and time, the receiver can triangulate its exact position, resulting in location coordinated, speed and direction.</td>
<td>Positioning system</td>
<td>Hazas et al., 2004;</td>
</tr>
<tr>
<td>Radio-Transmission</td>
<td>By using base station visibility and signal strength, it is possible to locate Wi-Fi or Bluetooth (which offers a shorter range than Wi-Fi) enabled devices. Dedicated Spectrum-based positioning e.g. using Radio Frequency Identification (RFID) tags can also be used for location determination by placing RFID readers at strategic points.</td>
<td>Tracking system</td>
<td>Want and Schilit, 2001</td>
</tr>
<tr>
<td>Based Positioning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technologies</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
RFID based tracking in which RFID-based active or passive tags are activated by proximity to a reader. The location of the moving tag is deducted from the location of the reader (Brown, 2007);

- Wireless LAN (WLAN) based tracking which determines the position of a wireless LAN client based on the arrival time and intensities of radio waves (Yoshitsugu et al., 2007);

- Bluetooth technology which works on the same principle as WLAN-based positioning and is designed as a short-range wireless connectivity solution for personal, portable and hand-held electronic devices (Aziz, 2005); and

- Several cellular-network-based wide-area location systems have been used in recent years, which for location determination involves measuring signal strength, angle of signal arrival and/or time difference of signal arrival (Xiang et al., 2004). However, accuracy of these location systems is highly limited by the cell size (ibid).

Figure 4.3 shows the current and predicted deployment of location tracking technologies. In this figure, the horizontal span of each box shows the range of accuracies the technology covers. The lower end of the vertical axis shows current deployment of technology whereas the top boundary shows the predicted deployment over next several years. It is evident from the figure that the widest existing deployments are based on GPS, wireless networking technologies, Bluetooth and RFID for tracking. Moreover, the increased deployment of RFID technology for location aware applications is notable.
In recent years, research has been conducted to explore the potential of location tracking technologies for construction applications (Giroux et al., 2002). Table 4.3 reviews some of these applications and highlights that GPS based location-tracking technologies have predominantly been used to support field work in the industry e.g. typical applications include real-time tracking, monitoring and control of construction plant, material and/or workers.

However, GPS has certain limitations such as positional accuracy to a few metres range (0.5m to 5m); consequently the technology becomes redundant when objects (e.g. construction vehicles) are closer to each other than the accuracy range (Qinetiq, 2002). In addition, GPS signals become unreliable when it is applied for tracking construction vehicles in a dense urban environment (Lu et al., 2007) and harsh operating conditions (e.g. quarry/mining projects, difficult and varying terrain types, harsh weather conditions etc) (Qinetiq, 2002); such scenarios are prevalent within construction sites. Therefore, other support technologies e.g. RFID and Bluetooth technologies must be explored to fill the capability gap (Lu et al., 2007).
Table 4.3: Location tracking technologies in the construction industry

<table>
<thead>
<tr>
<th>Application</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-time monitoring and control</td>
<td>The locations of equipment and machines are measured, at regular time intervals, with GPS. Automated data collection enables automated measurement of the performance of earthmoving operations and real-time quality control (e.g. monitoring of compaction operations).</td>
<td>Navon <em>et al.</em>, 2004; Li <em>et al.</em>, 1996</td>
</tr>
<tr>
<td>GPS based control and guidance system for dozer operators where precise blade positioning and control information is delivered to the machine cab.</td>
<td>Caterpillar, 2005c</td>
<td></td>
</tr>
<tr>
<td>3D real-time position measurement integrated with CAD for performance improvement within the construction industry.</td>
<td>Beliveau, 1996</td>
<td></td>
</tr>
<tr>
<td>Real-time tracking</td>
<td>Using GPS to track the locations of labour and to measure their performance (time spent on their tasks).</td>
<td>Navon and Goldschmidt, 2003</td>
</tr>
<tr>
<td>GPS based tracking system to determine collision detection among construction equipment. System tracks a single vehicle and relays its information to a central server. The application evaluates collision scenarios and sends cautionary messages to the vehicle if a collision is impending.</td>
<td>Oloufa <em>et al.</em>, 2003; Qinetiq, 2002</td>
<td></td>
</tr>
<tr>
<td>Resource tracking for productivity analysis in real-time using GPS and RFID.</td>
<td>Su and Liu, 2007</td>
<td></td>
</tr>
<tr>
<td>Other applications</td>
<td>Using a mobile device along with a GPS receiver to support fieldwork and for construction damage assessment.</td>
<td>Bachelordor, 2002; Morse <em>et al.</em>, 1998</td>
</tr>
<tr>
<td>Location-referencing field applications such as field data collection forms, control of environmental sampling during site inspection, and on-site training.</td>
<td>Giroux <em>et al.</em>, 2002</td>
<td></td>
</tr>
</tbody>
</table>
4.1.4 Automatic Identification and Data Collection (AIDC) Technology

In recent years automatic identification systems have become increasingly popular in wider industry to provide information about people, animals, goods and products in transit (Finkenzeller, 2003). Figure 4.4 gives an overview of various automatic identification systems in use along with a brief description of each system type.

RFID is an Automatic Identification and Data Collection (AIDC) technology offering non-contact reading and has proved highly effective in hostile environments where bar code labels (that require manual scanning) could become damaged (COMIT, 2005b). The RFID tags are capable of storing data and use radio waves to transmit the identity of an inanimate object or a person wirelessly (RFID Journal Inc., 2005b). More recently the combination of GPS and RFID e-tags has made real-time tracking of inanimate objects or people a reality via an ability to precisely locate e-tagged objects, even in the most remote and inhospitable areas (Collins, 2005).

Figure 4.4: Overview of the most important auto-ID procedures (Adapted from Finkenzeller, 2003).

RFID: Technology Description

A typical RFID system (as part of a complete RFID solution) is shown in Figure 4.5. The figure illustrates that such a system consists of following two basic parts:

i. a transponder (the RFID tag) which is the data carrier; and
ii. an interrogator (the reader) which is a read/write device.
The reader transmits radio-frequency signals which not only provides a means of communication with the RFID tag but also energises the tag to communicate back to the reader. When a tag enters the interrogation zone, it detects the activation signal from the antenna of the reader. This triggers the RFID tag which then transmits the information it carries back to the reader. The figure further highlights that the data collected by the RFID system can be further forwarded and integrated with other enterprise and business applications such as Enterprise Resource Planning (ERP), Supply Chain Management (SCM), Customer Relationship Management (CRM) etc. to support business operations.

RFID tags come in a variety of shapes, sizes and characteristics (COMIT, 2005b). The classification of these tags is given in Table 4.4 which categorises the tags according to their configuration and the means by which they transmit signals back to the reader. This table highlights that tag selection for any RFID application is significant and challenging. The decision takes into account various factors e.g. operating frequency (see Appendix B), cost, storage capacity, communication range, tag reusability, battery life etc.

**RFID: Applications**

Several RFID based solutions have been investigated or have been developed to solve complex business problems in many industries (Su and Liu, 2007). Table 4.5 categorises typical RFID applications along with potential benefits and associated concerns. The table divides these solutions into several types namely: tracking and tracing of items; electronic payment; access control; and telematics. The table also highlights that the tracking and tracing of items is the most widely used application type for RFID because it can uniquely identify the (tag carrying) object along with time, location and any sensor based information (COMIT, 2005b). However, the ability of the technology to trace items and individuals has raised privacy concerns among public and system users. Thus, there is a need to be considerate to these concerns when designing or implementing such systems.

RFID, due to its ability to provide real-time information and range of applications in other industries (as seen in Table 4.5), has also attracted the attention of the construction industry (Jaselskis and El-Misalami, 2003). To date, researchers have
conducted pilot studies and proposed a variety of system deployments for the industry, which have been reviewed in Table 4.6. The table demonstrates implementation of RFID in various sectors of the industry e.g. supply chain management, facility management, maintenance and inspections, resource management etc. However, the reviewed applications clearly highlight that the majority of RFID based investigations have focused on the domain of supply chain management and material tracking. Hence, the rationale to explore RFID applications when applied to other activities within the industry e.g. plant and equipment management, health and safety on construction sites, accident management etc.
Figure 4.5: A typical RFID system as part of an overall RFID solution architecture. (Adapted from: Finkenzeller, 2003; IBM, 2006)
Table 4.4: Classification of tags (Adapted from: Brown, 2007).

<table>
<thead>
<tr>
<th>Tag Type</th>
<th>Active Tags</th>
<th>Passive Tags</th>
<th>Semipassive Tags</th>
<th>Chipless tags</th>
</tr>
</thead>
<tbody>
<tr>
<td>Features</td>
<td>• Have a transmitter for sending signals to reader.</td>
<td>• Activated only when the electromagnetic field is generated by the RFID reader.</td>
<td>• Transmit using the same method as Passive tags.</td>
<td>• Encode unique patterns on the surface of various materials. These patterns reflect the data back to the readers.</td>
</tr>
<tr>
<td></td>
<td>• Capable of operating sensors.</td>
<td>• Broadcast data into the 'backscatter' transmitted back to the reader.</td>
<td>• Can be read at higher speed than passive tags.</td>
<td>• They have no integrated circuit.</td>
</tr>
<tr>
<td></td>
<td>• Performs two way wireless communication.</td>
<td></td>
<td>• Can use battery power for various types of sensors.</td>
<td>• Read only tags with permanent data.</td>
</tr>
<tr>
<td></td>
<td>• Have greater range, data capacity and processing power (performs calculations and logic operations).</td>
<td></td>
<td>• Can transmit in the presence of opaque materials.</td>
<td>• No international standards have been established.</td>
</tr>
<tr>
<td>Cost</td>
<td>• Costly compared to passive tags.</td>
<td>• Low-cost.</td>
<td>• Costly compared to passive tags.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Used for high-value items and processes.</td>
<td>• Economical for item level tracking.</td>
<td>• Used for high-value items and processes.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Cost per tag 15p each.</td>
<td>• Cost per tag may exceed 50p.</td>
<td></td>
</tr>
<tr>
<td>Storage</td>
<td>• Large read/write data storage.</td>
<td>• Small.</td>
<td>•</td>
<td>• Small.</td>
</tr>
<tr>
<td>Power Source</td>
<td>• Battery (internal to the tag and continuous).</td>
<td>• Energised by the reader.</td>
<td>• They have battery which is only used to run chip circuit.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 3 to 10 years battery life.</td>
<td>• No internal battery.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>• Read/Write range is from approximately 5 to 100 feet.</td>
<td>• Read/Write ranges for passive tags are generally less than six feet.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4.5: Different types of RFID applications in various industries. (Adapted from: Brown, 2007; RFID Journal, 2007)

<table>
<thead>
<tr>
<th>Application Type</th>
<th>Applications</th>
<th>Benefits</th>
<th>Issues</th>
</tr>
</thead>
</table>
| Retail           | The retail initiative for supply chain RFID use as first implemented by Wal-Mart. Researchers from University of Arkansas conducted a 29 week study on Wal-Mart's RFID use and found:  
  - a 16% reduction in out-of-stocks at the stores using RFID as compared to the ones not using the technology;  
  - out-of-stock items were restocked 3 times faster than barcodes; and  
  - a significant reduction in excess inventory. | Improved inventory control and out-of-stock reductions (a significant driver in cost reductions). | Suppliers have experienced difficulties due to:  
  - low tag-read rates;  
  - immature RFID standards; and  
  - high tag costs and uncertainty in return on investment. |
| Airline luggage tracking | Airports (European and US) initiative for airline luggage tracking by using RFID tags embedded in reusable containers that carry the luggage.  
  - McCarran Airport (7th busiest in the US) use luggage tags which upon check-in are encoded and details are associated with passenger’s data in a central database. The system routes the luggage first for security check and then to the airplane. | Efficient luggage handling system over a barcode system (Barcodes are not read at times due to luggage orientation or falling off). | Airlines are slow to adopt the technologies due to high costs. |
| Maintenance Support | Various items are tagged to manage maintenance and repair histories.  
  - Boeing introduced RFID tags on maintenance significant parts (life-limited and emergency equipment) of the 787 Dreamliner airplane. | Improved management of the maintenance process and consequently lower costs.  
  - Contactless information retrieval e.g. in planes without removing panels. | Sophisticated tags required by the Airline manufacturers and suppliers. |
| Item Tracking | Item tagging in manufacturing and inventory processes.  
  - Tracking subassemblies and components as they move through various stages of a manufacturing process (e.g. in pharmaceutical company’s manufacturing process RFID tags are used to document the sterilization process at high temperatures).  
  - Items in an inventory are tagged to be able to track receipt, location, use, movement and reorder of these items.  
  - Office, manufacturing, transportation, construction equipment, expensive hospital equipment (defibrillators, wheelchairs, heart-rate monitors etc.); and fixed assets etc. are tagged and monitored every few seconds. Alerts are generated if the item is not in the read zone.  
  - The US Department of Defense (DoD) has taken numerous RFID initiatives including: movement of items into war zones; enhanced visibility of tools and information for decision makers; and equipment maintenance etc.  
  - Tenstar lease their assets (embedded with tags) to other companies and then closely track the location of these tags e.g. the company provided this service to Carlsberg Brewery for their beer kegs and to Kraft Foods for their fruit containers. | Reduction in shrinkage and out-of-stocks.  
  - Improved inventory management.  
  - Reduction in time spent on sorting and counting.  
  - Improved item visibility.  
  - Error reduction.  
  - Reduces costs (inventory and logistics).  
  - Improved customer experience. | Individual item level tagging is very challenging due to wide variety of materials, shapes and sizes in packaging and trade.  
  - Increased flow of data over networks.  
  - Concerns over privacy issues.  
  - Additional technology cost. |

Continues ...
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<table>
<thead>
<tr>
<th>Application Type</th>
<th>Applications</th>
<th>Benefits</th>
<th>Issues</th>
</tr>
</thead>
</table>
| Human and Animal Tracking | RFID based systems to tag students in schools (for attendance and security), patients in hospitals (for easy access to patient records), prisoners (for monitoring) and animals (for tracking pets, wildlife and livestock).  
  - Britan School California initiated a pilot study to automate student attendance tracking.  
  - Jacobi Hospital New York gives wrist-tags to patients to access and update their patient records. RFID systems in Beth Israel Medical Centre (Boston) and Washington Hospital Centre (D.C.) also locate patients, staff and medical equipment in addition to patient records. | • Contactless information retrieval.  
• Reduced time spent on paperwork.  
• Reduction in errors.  
• Reduced operating costs by automating monitoring functions of prisoners and livestock.  
• Improved visibility.  
• Tagging food animals enables to respond to outbreaks. | • Privacy concerns.  
• High system cost. |
| Library Management System | Library materials (books, magazines, videotapes, CDs, DVDs, newspapers etc.) are tagged.  
  - The library of University of Nevada reported £20,000 savings in replacements costs for the 500 items found ‘lost’ on their selves. | • Faster checkouts and self checkouts.  
• Accurate reshelving.  
• Theft control. | • Privacy concerns.  
• High system cost.  
• Read accuracy when many tags are in the read zone at one time.  
• Vandalism. |
| Tracking and Tracking of Item | Retailers are using RFID tracking to improve customer shopping experience and boost sales.  
  - Mi-Tu, a high-end retailer in Hong Kong, has installed RFID-enabled mirrors, catalogs and security systems. The system enables customers to view and locate a wide selection of in-store inventory while they try on and shop for clothes.  
  - Falabella, the Latin American department-store, operator says it learned valuable lessons from its first item-level pilot, yielding an inventory accuracy of 98.4 percent and a 25 percent reduction in out-of-stocks. | • Information for management on which garments were tried on together, and if these combinations were actually purchased.  
• Helps in observing the impact of the positioning and presentation of goods on the sales floor. | • Privacy concerns.  
• High system cost. |
| Interactive Shopping System | Use of RFIDs to create a multidimensional grid.  
  - The Port of Singapore Authority (PSA) has installed thousands of RFID tags in the asphalt to create a grid. A centralised system tracks placement and location of thousands of cargo containers as they are offloaded on the port. | • The position of any tag is known at any point in time.  
• Reduced loss rate. |  

Continues ...
<table>
<thead>
<tr>
<th>Application Type</th>
<th>Applications</th>
<th>Benefits</th>
<th>Issues</th>
</tr>
</thead>
</table>
| Telematics       | Initiative taken by the US Federal Government in 2004 to establish a platform called DSRC (Dedicated Short-Range Communications). The infrastructure is the prerequisite for introducing new roadway applications such as:  
  - issuing alerts to drivers about impending collisions, rollovers, weather issues, or road hazards;  
  - warning the driver that their vehicle is going too fast for an upcoming curve; and  
  - downloading driving maps. | Contactless.  
  - Convenient.  
  - Use for payment as a means of preventing money laundering, black market transactions and even bribery demands for unmarked bills. | Fear that technology will eliminate the anonymity that cash affords. |
| Electronic Payment System | Electronic payment benefits from RFID.  
  - Speed Pass (electronic toll payment systems on many highways throughout Europe and the United States, fare collection systems used by millions everyday on railways and subways).  
  - Smart Cards (Tags used to pay for goods and services e.g. American Express, MasterCard and Chase have released ExpressPay, PayPass and BlinkCard respectively). | Report on the movement of individuals.  
  - Records can be used in logistics and cost analysis, building evacuation plans and generating required government reports.  
  - A number of people can go through the door at the same time. | |
| Access Control System | The system scans the access card, determines whether the individual is authorized to pass and then unlocks the barrier.  
  - Systems that combine biometric data with RFID for use at military bases, nuclear and chemical plants, and other facilities that require multiple levels of security and control. | | |
Table 4.6: Application of RFID in the construction industry

<table>
<thead>
<tr>
<th>Application</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tag and Track</td>
<td>A pilot study system for electronically tagging and tracking construction products throughout the supply chain. A combination of RFID, wireless communications and web applications are used in retail, haulage and the manufacturing sector supplying to the construction industry.</td>
<td>COMIT, 2005a</td>
</tr>
<tr>
<td></td>
<td>Application of RFID in business process reengineering of the existing paper-based supply chain management process. The developed application addresses information sharing in the supply chain among project participants (which includes manufacturing, quality control, logistics, and progress management of items such as structural steel components, precast concrete units etc.</td>
<td>Chin et al., 2007</td>
</tr>
<tr>
<td></td>
<td>Component tracking and capture of component maintenance history records for facility management.</td>
<td>Ergen et al., 2007</td>
</tr>
<tr>
<td></td>
<td>A Mobile RFID-based Facility Management (M-RFIDFM) system to: improve efficiency and cost-effectiveness of facility management; improve communication among participants; and increase flexibility in terms of service delivery and response times.</td>
<td>Hsiao et al. 2007</td>
</tr>
<tr>
<td></td>
<td>RFID application in:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ providing owners and contractors with information for enhancing material control and material receiving operations on construction site;</td>
<td>Jaselskis and El-Misalami, 2003</td>
</tr>
<tr>
<td></td>
<td>▪ cost control system for recording and tracking the activities of workers and equipment;</td>
<td>Jaselskis et al., 1995; Chin et al., 2007</td>
</tr>
<tr>
<td></td>
<td>▪ concrete processing and handling (information of concrete mix, admixtures, time of loading and delivery location are recorded);</td>
<td>Chin et al., 2007</td>
</tr>
<tr>
<td></td>
<td>▪ daily labour control to monitor checking in and out of all the workforce;</td>
<td>Su and Liu, 2007</td>
</tr>
<tr>
<td></td>
<td>▪ resource tracking for productivity analysis in real-time using GPS and RFID;</td>
<td>Song et al., 2006</td>
</tr>
<tr>
<td></td>
<td>▪ efficient location and tracking of requested materials on a construction site (e.g. pipe spools);</td>
<td>Goodrum et al., 2006</td>
</tr>
<tr>
<td></td>
<td>▪ the tracking of tools on construction sites; and</td>
<td>Domdouzis, 2007</td>
</tr>
<tr>
<td></td>
<td>▪ monitoring of hazardous substances on a construction site.</td>
<td></td>
</tr>
<tr>
<td>User Interaction with a building</td>
<td>▪ Use of RFID in structural elements of a building, inspection data (existing and previous inspections) is accessed through a PDA for assistance in the inspection process.</td>
<td>Yabuki, 2002</td>
</tr>
<tr>
<td></td>
<td>▪ Automated tracking of structural steel members through RFID. A steel item is scanned for the identification number and three dimensional data which is used to define the position and orientation of the tracked item in the coordinate system of the construction site. The system supports in the improvement of the steel erection process.</td>
<td>Furlani et al., 2000</td>
</tr>
</tbody>
</table>
4.2 CHAPTER SUMMARY

Within the UK industry, advanced ICT solutions have been developed and implemented to improve business processes and procedures. As a result of this early pioneering work coupled with the declining cost of technology, the construction industry has begun to adopt various emerging ICT solutions. A review and critique of various technologies, that are considered suitable for improved vehicle management and safety, were carried out. The reviewed technologies include:

- **MIS** and the need to develop a comprehensive management system for plant and equipment;
- **wireless communication and mobile computing**, applications of these in the construction industry and perceived barriers to adoption;
- **positioning and tracking systems**, various applications available for location tracking and how the construction industry has benefited from them; and
- further investigation of a tracking and identification technology i.e. **RFID**, how it is employed in other industries and how the construction industry has benefited from it so far.

The review revealed that GPS can become unreliable under harsh and varying nature of construction sites. There is a need to explore other supporting technologies and the potential of these to improve machine safety and productivity performance e.g. RFID for tracking and automatic data collection purpose. Moreover, there is a need to investigate the potential of RFID application for plant management, health and safety on construction sites and accident management.

It can be concluded from the appraisal of the aforementioned technologies that there is a need to develop a comprehensive management system that integrates these recent technologies for the benefit of construction industry in general and for plant and equipment management in particular.
CHAPTER 5
CURRENT HEALTH AND SAFETY PROCESS FOR CONSTRUCTION PLANT

5.0 INTRODUCTION

Health and Safety Executive (HSE) statistics on plant and equipment related accidents in the UK construction industry indicate that a re-evaluation of existing safety systems and processes should be employed. This research therefore examined existing plant and equipment related health and safety practices employed by the UK construction industry. Consequently, a critique of these practices was provided to highlight issues and causes for safety hazards due to construction plant and equipment.

Case studies based upon five construction projects attempts to observe, record and report upon standard safety practices for plant and equipment in the construction industry. Consequently, weaknesses in the existing processes were identified in order to determine why the adopted safety practices have failed to protect workers working in close machine proximity. In order to ensure that the observed work practices could be accurately recorded, Data Flow Diagrams (DFD) were used as a modelling tool. In addition to the documentation of current processes, the modelling technique helped in requirement analysis for any potential process improvements (by using technology in particular).

5.1 METHODOLOGY ADOPTED FOR PROCESS DOCUMENTATION AND ANALYSIS

Case studies of five construction projects (see Table 2.8, Chapter 2) involving members of the Major Contractors Group (MCG) were conducted to investigate: their current health and safety processes for plant and equipment; and to determine the likely causes for unsafe practices on a construction site. One of the strengths of the case study approach was that it allowed the researcher to use a variety of research methods as part
of the investigation (Denscombe, 2003). The methods for this research involved conducting semi-structured interviews, direct observation on construction sites (recorded by keeping a diary) and investigation of project documents.

Key developments that came out of the multiple sources of data were used to develop process models by employing DFD as a system modelling tool, see Figure 5.1. The figure also shows that two types of DFDs were developed for the on-site plant health and safety process, namely: (i) a project level DFD; and (ii) a DFD that depicts standard practices in the UK construction industry. The second type of DFD was discussed with the interviewees as part of a validation exercise which involved an iterative process where the evaluator’s feedback was used to update the process model.

Figure 5.1: Use of a multiple case study approach to map plant health and safety processes employing a DFD as a modelling tool.
A major problem faced during the data collection process related to the fact that health and safety issues are regarded as strictly confidential and controversial by many individuals within highly competitive construction companies. Because of this, it was noted that interviewees often talked about their experiences in general or those of other construction projects rather than being explicit about any health and safety problems/incidents that had occurred on their current site; this despite assurances of total and complete anonymity for all interviewees.

5.2 EXISTING PROCESS FOR ON-SITE PLANT HEALTH AND SAFETY

There is a growing concern within the industry for occupational health and safety despite the implementation of various regulations, initiatives and best practice guidance because the number of deaths and injuries in the construction sector remain unacceptability high (HSE, 2003). The Construction (Design and Management) Regulations 1994 (CDM) set by the HSE require that health and safety is taken into account and managed throughout all stages of a project, from conception, design and planning through to site work and the subsequent maintenance and repair of the structure (HSE, 2004c). The HSE requires contractors to take health and safety management and legislations into account when:

i) preparing for work at the preconstruction phase e.g. planning and organising;

ii) setting up the site during the construction phase e.g. site access, emergency procedures, reporting injuries and dangerous occurrences, site rules; and

iii) managing construction works e.g. site management and supervision, site traffic and mobile plant management, occupational health risks, protective equipment and monitoring and reviewing.

Moreover, health and safety management specifically targets mechanical plant and equipment usage on a construction site (HSE, 2006a). Therefore, management should be fully conversant with both the potential risks faced by employees working with or near to plant and equipment and the effective health and safety systems and procedures employed to mitigate such risks (Edwards et al., 2003).
In this section findings emerging from the five case studies (see Table 2.8, Chapter 2 for the list) are introduced in the form of a ‘standard’ health and safety process for plant and equipment on a construction site in the UK (see Figures: 5.2; 5.2.1; 5.2.2; 5.2.3; 5.2.3.1). The DFDs for individual construction projects are presented in Appendix C.

The DFD was developed from the perspective of a principal contractor, who is normally appointed under the CDM regulations 1994. According to the regulation, the principal contractor is usually the main or managing contractor for the work and is needed to plan, manage and co-ordinate work while construction work is being carried out (HSE, 2007). The HSE (2006a) indicates that the principal contractor has more formal responsibilities for securing health and safety on site. This includes gathering as much health and safety information about the project and the proposed site before work begins.

Figure 5.2 depicts a DFD for on-site plant health and safety processes used on a construction project. The figure highlights that initially the principal contractor puts together a project plan based around the company’s procedures. This plan, along with the risks identified by the risk assessment, help formulate a method statement. Method statements are not required by law but they have proved to be a practical management tool (HSE, 2006a). The statements include a description of all the control measures to be implemented and help to describe (in a logical sequence) how a job is to be carried out safely and without risks to health, safety or welfare (ibid).

The contractor’s plant requirements are derived from the project plan and method statements. They have three main choices available to meet plant requirements and these are: (i) purchasing plant for the contract; (ii) hiring existing company owned plant; and (iii) hiring plant from external sources (Seeley, 1993). A wide range of plant is readily available from external plant hire companies as it is not usually economical for contractors to own plant unless they can ensure a 70-80% utilisation factor during normal working hours (ibid). The Construction Industry Board (CIB) publication entitled “A Code of Practice for the Selection of Subcontractors” specifies the selection process as: (i) qualification; (ii) compilation of tender list; (iii) tender invitation and submission; (iv) tender assessment; and (v) tender acceptance (Evans, 1998).
Figure 5.2: DFD for the process of on-site plant health and safety

Inspection and Audit Reports* may include:
- Weekly Audit Report
- Environmental/Quality Audits
- Scaffold Inspections
- Excavation Inspections
- Welfare Inspections
- Fire Inspections
- Toolbox Talks and Activity Brief Inspection
- Supplier Audits
- Control Of Substances and Hazard to Health (COSHH)

Training** may include:
- First Aid Training
- Fire Protection Training
- Risk Assessment
- Hazard Awareness
- Hands-on Vibration
- CITB/ NVO Courses
Figure 5.2.1: DFD for plant specific health and safety process
Figure 5.2.2: DFD for Accident Investigation
Figure 5.2.3: DFD for Training
Figure 5.2.3.1: DFD for Company Training
To subcontract plant and equipment specific work to a plant company, it was noted that in all the cases an extensive pre-start meeting is carried out where:

- the approved subcontractor is selected;
- a generic risk assessment is carried out to find out the type of plant required and purpose of the deployment; and
- a generic method statement is prepared to identify and highlight all risks.

These documents establish the basic performance requirements of machinery and identify the specific items of plant needed for the project. However, some interviewees highlighted that in practice, plant and equipment can be brought urgently, without planning, to cope with surges in demand or to take into account unforeseen events etc. In such cases, the processes of pre-start meetings and preparation of method statements may not always take place.

It is commonly accepted now that all method statements must address on-site health and safety issues. However, the broad range of risks posed by job specific operations are commonly dealt with in the formulation of a health and safety plan (Evans, 1998). The plan usually develops with the project and involves two distinct phases i.e. pre-construction (design and planning) and construction (HSE, 2006a). The research undertaken also showed that the method statement and project risks are taken into account to develop a health and safety plan. Part of this health and safety plan along with the identified risks and method statements are also exchanged with the subcontractors (see Figure 5.2). Figure 5.2 further highlights that a health and safety plan addresses plant and equipment related risks and highlighted hazards more distinctively. This is discussed in greater depth in the following section.

5.2.1 Plant Specific Health and Safety

Figure 5.2.1 describes in detail the plant and equipment specific health and safety practices currently employed on MCG construction projects (as observed during the case studies). Four major practices were observed, these are: i) plant acceptance test; ii) operator training; iii) risk assessment; and iv) machine maintenance.
i) Plant Acceptance Test
The selection of a plant contractor in a construction project depends upon the company's assessment on equipment health and workforce competence (e.g. Construction Plant Certification Scheme or CPCS cards). To meet plant specific health and safety requirements on a construction site, the interviewees (health and safety managers) pointed out that all machines coming to a site have to undergo an acceptance test completed by the contractors. The machines are checked for 6/12 monthly plant certificates or certificates of conformance in addition to compliance with legislations e.g. Provision and Use of Work Equipment Regulations 1998 (PUWER) and Lifting Operations and Lifting Equipment Regulations 1998 (LOLER). Subcontractors also provide maintenance information with all plant and equipment they supply, to enable machines to be used and maintained safely.

ii) Operator Training
All plant and powered equipment must be operated only by trained operators who are authorised to operate it (Bielby, 1992). It was verified on the MCG member sites that all plant operators/drivers are checked to ensure that they have a CPCS card and are given site induction for the current project. The CPCS is not the only competence scheme but it is considered to be the most prevalent since it is managed by a board of employers and members of industry bodies such as the Construction Confederation, the Construction Plant-Hire Association (CPA) and the Health and Safety Executive (HSE). It is also part of the Construction Skills Certification Scheme (CSCS). The scheme is judged to be a minimum level of conformance albeit other reputable schemes such as International Powered Access Federation (IPAF) or Prefabricated Access Suppliers' and Manufacturers' Association (PASMA) are equally accepted.

Recently, the CPCS scheme was criticised by the HSE who stated that ownership of a CPCS card does not mean that the operator is competent. This as a result of several fatalities involving machine quick hitches because it was apparent that operators had not been trained in the safe use of this device.

iii) Risk Assessment
A robust risk assessment procedure is essential for the control and management of the construction process in order to avoid situations where unplanned events can occur and
cause harm (Clarke, 1999). As part of the observed health and safety process (see Figure 5.2.1), the construction activity is risk assessed including plant risk assessment where machine hazards, people at risk and reliability of existing precautions are identified and reviewed.

Logistics and plant distribution should be identified before work commences on a construction project to provide segregation of pedestrians from vehicle movements and to ensure safe operations of vehicles (HSE, 1996). According to the recommendations by the HSE (2006a) a programme of daily visual checks, regular inspections and servicing schedules should be set up according to the plant manufacturer’s directions and the risk associated with the use of each equipment type. For the studied process, the interviewees stated that once plant operations commence, various methods, systems and procedures are implemented to reduce significant risks associated with these equipment such as:

- effective traffic management plan and transportation routes. In order to separate plant from the roads, rigid and/or cone barriers are used and fixed pedestrian walkways and crossing points on the roads are established;
- environmental plans are developed to reduce machine spillages for fuels and oils;
- maintenance and inspection plans are prepared to ensure that machines remain in a safe operational condition;
- operator induction, training and competence development;
- use of safety equipments for all round awareness by plant operators; and
- establishing written safe working procedures. For instance, a set of site safety rules and requirements for Personal Protective Equipment (PPE) are established and delivered to workers and subcontractors. Banksmen on construction sites and operators on rail works are provided with orange high visibility vests so that they can differentiate them from other workers.

iv) Machine Maintenance

The principal aim of a maintenance department should be to provide an effective service which maintains a high level of machine reliability and availability at the lowest achievable cost (Edwards and Holt, 2004). The adoption of a standardised routine of
periodic inspections, maintenance and record keeping aims at avoiding delays due to breakdowns and seeks to predict the length of machines' working life (Seeley, 1993).

Figure 5.2.1 shows that plant items are referred to the maintenance department/subcontractors either in the event of breakdown or if a periodic service is required for efficient and safe operations. The process highlights that the subcontractor returns weekly plant inspection report which examines the working condition of plant e.g. cleaning and lubrication, oil, lights, safety mechanisms, machine maintenance, tightening or loosening of tracks, buckets tests etc. The plant is also inspected for lifting certification to assess the maximum load limit if the machine is used for lifting purposes. These periodic inspections are performed under the requirements of LOLER.

5.2.2 Accident Investigation

Effective accident investigation is a valuable means of learning from failure (HSE, 2003). The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995 (RIDDOR) require that certain types of accidents (fatal injury; major injury; over 3 day injury), specific cases of occupational ill health and dangerous occurrences have to be reported to the HSE (HSE, 2006b). Thus, reporting and recording these types of accidents, in addition to ill health at work, is a legal requirement. The benefits that accident investigation has to offer, include: (i) identifying the underlying basic causes; (ii) preventing the recurrence of similar accidents; (iii) identifying training needs; and (iv) providing information in case of litigation (Bielby, 1992).

As part of the health and safety plan both general and plant specific accidents are investigated and documented according to HSE regulations. The DFD for accident investigation (Figure 5.2.2) highlights the standard practices for plant accident investigation observed during the case studies. These common practices are:

- Any vehicle incident and near miss incident are reported, recorded and reviewed;
- Once the accident is reported, its category according to a HSE definition is established and an enquiry is carried out by taking into account HSE
legislations, inspection reports, witness statements, training status of employees involved and risk assessments;

- A record is kept of any reportable injury, disease or dangerous occurrence and this includes a method of reporting, the date, time and place of the event, personal details of those involved and a description of the nature of the event or disease;

- A completed accident/disease report form (F2508/F208A) returned to the HSE is a legal requirement. A full investigation is then carried out by the safety department to find out the causes leading to the accident, post accident actions, lessons learnt and summary for the management;

- Management then reviews what actually caused any accidents or incidents, what preventive measures need to be taken for the future and how existing procedures could be improved; and

- The lessons learnt and newly identified hazards are then communicated to all other company projects.

5.2.3 Training and Site Safety Awareness

Training is the planned and systematic sequence of education, under competent supervision, designed to develop or improve the predetermined skills, knowledge and abilities required by an individual to carry out a task to a specific standard (Taylor, 2004). Regulation 9 of PUWER places a strict duty on employers to ensure that all persons who use work equipment have received adequate training. This requirement is for the purpose of health and safety, including: training in the methods which may be adopted when using plant; any risks which such use may entail; and the precautions to be taken (Stranks, 1996).

Consequently, the studied health and safety process for plant and equipment highlighted certain training and site safety awareness aspects (see Figure 5.2.3) which are:

- Training needs analysis and plans are developed which outline in a standardised format the training to be given and the appropriate delivery methods;
Induction training is given to all site visitors including new employees on the project, client(s), members of the public and visitors to the site, delivery drivers and logistic workers;

- Implementation of the training plan; employee training records are also checked to determine the need of any new training; and
- When required, the workers are given external/in-house training (see Figure 5.2.3.1).

The site safety awareness covers various aspects. For example, the research showed that workers dealing with plant and equipment are made aware of their work through daily activity briefs. In addition, the operators are made aware of the banksmen positions.

5.3 THE CAUSES OF SAFETY INCIDENTS INVOLVING MOBILE PLANT AND EQUIPMENT

Whilst the UK construction industry complies with extensive legislation for health and safety of its workforce, in reality one third of all work fatalities happen in the construction industry and construction workers are six times more likely to be killed at work than employees in any other sector (HSE, 2003). A similar situation exists for non-fatal accidents (ibid).

HSE accident statistics for plant related accident categories (i.e. ‘contact with machinery/material being machined’ and ‘struck by moving vehicle’) demonstrate a fairly consistent accident trend amongst construction employees and self-employed workers prevails (Riaz et al., 2006a). A HSE report (2003) highlights some other failures related to equipment use on site, these include problems resulting from:

- inadequate consideration of physical dimensions of machines;
- shortcomings in performance, safety-related features, training and maintenance;
  and
- failure in the interaction between work-teams, workplace, equipment and materials.
The HSE (2003) has reported that accident investigation carried out by employers or supervising contractors is frequently superficial and of little usefulness as far as improving safety is concerned. According to the report (ibid), the investigation emphasises more on safety failures in the activity being undertaken rather than accident investigation procedures implemented to reveal contributing factors earlier in the causal chain. Hence, the rationale for conducting a series of case studies which aim to uncover specific details about the likely causes of accidents involving plant and machinery.

Table 5.1 provides a summary of accidents communicated during interviews carried out for the case studies. The table is developed using the technique ‘constant comparative analysis’ (see Section 2.6.2 for the analysis technique used in the case studies). For Table 5.1, the preferred technique for analysing semi-structured interviews was to develop themes on causal factors for incidents on a construction site (as reported by the respondents). The table was further extended when a similar assessment was carried out on causal factors generated from practitioner ‘concerns’ regarding plant related health and safety issues on a construction site.

To encapsulate and analyse Table 5.1, a cause and effect diagram (also known as fishbone diagram) was generated. The fishbone diagram is an analysis tool for determining the potential causes for a particular problem (or effect) being examined (Simon, 2007). The potential causes of plant and equipment related safety issues on a construction site are categorised in an orderly way in Figure 5.3. The figure provides a logical way of looking at the safety hazards, associated with mobile plant and equipment, in various areas such as machine and process management, machine configuration, training etc.
Table 5.1: Issues highlighted from studied cases

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<th>Case</th>
<th>Incidents</th>
<th>Likely Causal Factors</th>
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<th>Case</th>
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<td>A</td>
<td>Mostly, management mistakenly recognises CPCS as a good standard of operator training and qualification. This is because CPCS is not a qualification. One manager described the scheme as a good benchmark, “but we have to bear in mind that this is just like a driving test, you can become a plant operator of JCB in three days. However, it’s the site experience and type of work that one is doing that counts more. On the site, we are using excavators at the moment for digging but they will become demolition equipments in couple of weeks time. Requirements for demolition drivers are slightly different than the excavation work. I think we as managers need to know not only about qualifications but also the relevant experience and skill set of operators all the time”.</td>
<td>Inadequate training, Failure to manage operatives free machine - operational envelope, Ineffective maintenance, Machine configuration and inadequate all - round awareness for operators, Lack of communication among management and workers, Exhaustive process, Inefficient process</td>
<td>• Maintaining a qualification, employment history and on job training record for all operators. The information should be available to management at the time of job allocation. This will confirm that the level of training is adequate for the assigned job.</td>
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<td>B</td>
<td>Plant management was concerned about health and safety of archaeologists working close to excavation areas. According to the foreman at the excavation site, “they get too excited when they come across something interesting and do not understand the risks associated with this work”.</td>
<td>Inadequate training, Failure to manage operatives free machine - operational envelope, Ineffective maintenance, Machine configuration and inadequate all - round awareness for operators, Lack of communication among management and workers, Exhaustive process, Inefficient process</td>
<td>• Need for a safety mechanism with a possible use of technology in order to reduce human error. • Aside from general induction videos, there is a need to develop an awareness among site visitors and members of the public about the risks associated with plant operations.</td>
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<td>B</td>
<td>Plant management was concerned about 'shortest' walk routes of other contractors and tradesmen. Giving an account of one of the managers mentioned: “we actually stopped working at this site and told them we are no longer carrying out this work unless you get your walk routes out of our working area... you also see many other sites who use these small excavators working in and around people”.</td>
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<td>B, E</td>
<td>Most of the workers and management were apprehensive of the extensive health and safety paperwork that has to be carried out presently. One of the health and safety manager commented that: “There is a lot of paperwork involved, IT and paperwork goes hand in hand. All documents and forms are printed off; goes out on site as hardcopy and comes back as hardcopy. In reality, we have all these big fantastic equipments but the foreman in his van will have this big folder with all these method statements, lifting certificates, testing and examination documents, fire and accident investigation documents etc.... that is all in hardcopy. I think the construction industry is still in the dark age”.</td>
<td>Inadequate training</td>
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<th>Suggested Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Plant operators were conscious of the fact that certain vehicles have ‘blind spots’ in spite of having mirrors on the equipment. A telehandler operator stated that it [safety] all comes down to operator awareness of who is working close to the machine and where. According to the operator: “mirrors on my machine do give me visibility but the boom does impair my vision on the right hand side...According to the book in certain cases you should be driving with your boom lowered if you are working in an area with a lot of people around it. However, I keep the boom up because as far as I am concerned I am driving a machine where people are around the wheels and you have to have the boom raised so that you can be aware of all around you. The people who write these books, if they sit in a forklift they would understand what I am saying. Generally they are correct in what they write but in certain situation the boom has to be raised”.</td>
<td>Inadequate training, Failure to manage operatives free machine operational envelope, Ineffective maintenance, Machine configuration and inadequate all-round awareness for operators, Lack of communication among management and workers, Exhaustive process, Inefficient process</td>
<td>* Need for a safety mechanism to provide all-round visibility for plant operators.</td>
</tr>
<tr>
<td>C, E</td>
<td>Management was particularly concerned about distinguishing less trained personnel from trained workers. They regarded it extremely important to know the training competence of people working close to machines during plant operations.</td>
<td></td>
<td>* Identifying and maintaining operative competence levels drawn from certifications, employment history and on job training records. This information should be available to management all the time (on the move) to confirm that the level of training is adequate for the assigned job.</td>
</tr>
</tbody>
</table>
...Continued

<table>
<thead>
<tr>
<th>Case</th>
<th>Concerns</th>
<th>Likely Causal Factors</th>
<th>Suggested Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>While explaining the extensive employment of plant and equipment on the construction site, one health and safety manager revealed that during the first six months of the project there were about 20 excavators and 60 dumpers. According to the manager, “the site was very busy and since we did not have any intelligent system we had to develop a single way road way system which cost us a few thousand pounds. However, machines were working in close proximity”.</td>
<td>Inadequate training</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>According to one health and safety manager, it is a general practice of an induction process that no worker is allowed to enter a slewing area. However, if they need to enter the area, then they have to make themselves known to the operator first. Additionally, excavator operators are told to slew to the left all the time (into the side where he can actually see) and mirrors are put on the machines as their aid for plant operations. As indicated by the manager, in spite of all these precautions there are days when the operator slews in the wrong direction or a worker is standing at a wrong position.</td>
<td>Failure to manage operatives free machine operational envelope</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ineffective maintenance</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Machine configuration and inadequate all-round awareness for operators</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lack of communication among management and workers</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Exhaustive process</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inefficient process</td>
<td>*</td>
</tr>
</tbody>
</table>

Continues…
Table End.
Figure 5.3: Fishbone Diagram (probable causes for safety hazards for mobile plant and equipment).
Probable and more obvious causal factors (identified in Table 5.1 and Figure 5.3) that contribute towards plant related accidents/concerns, are employed to develop Table 5.2. This table highlights the responsibilities of various parties (roles) involved in the implementation of effective health and safety management (i.e. managers responsible for health and safety, plant manufacturers, workers etc.).

Table 5.2: Responsibilities of various roles to reduce safety hazards for mobile plant and equipment

<table>
<thead>
<tr>
<th>Role</th>
<th>Are required:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health &amp; Safety Management</td>
<td>- Effective implementation of health and safety processes and promoting a culture where workers appreciate the significance of these processes.</td>
</tr>
<tr>
<td></td>
<td>- Perform effective machine maintenance (including onboard safety equipments).</td>
</tr>
<tr>
<td></td>
<td>- Have safety checks before machine use.</td>
</tr>
<tr>
<td></td>
<td>- Manage operatives free operational envelope for on-site plant and equipment.</td>
</tr>
<tr>
<td></td>
<td>- Effective communication of activity briefs to workers along with safety features.</td>
</tr>
<tr>
<td></td>
<td>- Provide adequate and effective instructions and training.</td>
</tr>
<tr>
<td></td>
<td>- Manage employee training records that is accessible uninterrupted and to keep track of their level of competence.</td>
</tr>
<tr>
<td></td>
<td>- Ensure that risks, created by the use of the equipment, are taken care of.</td>
</tr>
<tr>
<td>Manufacturers</td>
<td>- Assess the risks associated with machine configuration. There are certain types of mobile plant (e.g. excavators, telehandlers, dump trucks etc.) that have inadequate direct vision for operators.</td>
</tr>
<tr>
<td></td>
<td>- Provide machines with innovative safety mechanism and devices.</td>
</tr>
<tr>
<td></td>
<td>- Respond to the needs of industry practitioners.</td>
</tr>
<tr>
<td>Workers</td>
<td>- Have adequate training, instruction and awareness on the safe use of the machines on the site. It is important to make them recognise that health and safety education is not a compulsion but is beneficial for their own wellbeing.</td>
</tr>
<tr>
<td>Operators</td>
<td></td>
</tr>
<tr>
<td>Banksmen</td>
<td></td>
</tr>
<tr>
<td>Pedestrians</td>
<td>- Ensure that operators are competent and hold relevant competence qualifications and not necessarily card schemes.</td>
</tr>
</tbody>
</table>

The investigation has generated a list of various possible causes for the safety hazards related to mobile plant and equipment. This indicates that further exploration and remedial actions are required in the area of mobile plant and equipment (i.e. machine design) and its related management and training processes.

5.4 CHAPTER SUMMARY

The chapter has documented and reviewed the current safety practices for the construction plant sector. This was achieved through multiple case studies in which five construction projects across the UK were visited. Semi-structured interviews with practitioners and document analysis on each project were carried out to report upon
standard safety practices for plant and equipment on a construction project. DFDs were used as a modelling tool to record the observed safety practices. It was noticed that these plant specific safety practices take into account: plant acceptance test, risk assessment; machine maintenance; accident investigation; training and safety awareness etc. A re-examination of these existing safety systems and processes is required as analysis of practitioners’ safety concerns have highlighted various shortcomings in the practices. Some of these concerns include ineffective: operative training; machine configuration; machine maintenance; pedestrian free operational envelope; and process management etc.

The documented standard safety processes and data flows investigate the health and safety practices for the plant and equipment sector in the UK construction industry. However, the UK construction sector is one of the safest in Europe (HSE, 2002b) and it may be recommended that the documented practices in this research can be employed by construction industries of other countries who are concerned about their ineffective plant related safety. The DFDs can provide these industries with sound basis for their process design or redesign for improved health and safety in the plant and equipment sector.

The findings emerging from the investigation of current safety processes for on-site plant and equipment lead to developing guidelines for the effective application of technologies for potential improvements in the safety practices.
CHAPTER 6

GUIDELINES FOR EFFECTIVE USE OF ICT FOR IMPROVED PLANT MANAGEMENT AND SAFETY

6.0 INTRODUCTION

The findings emerging from the investigation of current safety processes for on-site plant and equipment lead to developing guidelines for the effective application of technologies for process improvement. This chapter presents these guidelines which may provide practitioners with a useful means with which to improve plant management and safety on a construction site. The chapter also lays out the architecture and conceptual model of a technology application which integrates various components of plant management into one integral hybrid system. The application not only provides health and safety managers with necessary safety information on a regular basis but also focuses on the information needs of plant operators and workers involved in the construction project.

6.1 NEED FOR PROCESS IMPROVEMENT: A CASE FOR ICT APPLICATION

A business process comprises of work, procedures and rules required to complete the business tasks in response to some business events (Whitten et al., 2004). Business Process Reengineering (BPR) is an approach used for ‘radically’ redesigning these business processes for improved company performance i.e. increased productivity, improved quality and greater customer satisfaction (Davenport, 1993; Hammer and Champy, 1993). Recent literature treats the reengineering concept as a broad spectrum of approaches ranging from continuous business process improvement (incremental improvement in process efficiency) to a total clean-slate redesign for rapid achievement of maximum effectiveness (Lee and Chuah, 2001).

Business processes are considered to be independent of any ICT, particularly when technology is used for process automation or support (Whitten et al., 2004). However,
to exploit the potential of ICT, it is increasingly used as an enabler for BPR in order to achieve better operational and decision making support (Marchand et al., 2001). Hence, a blend of process redesign and enterprise wide information systems (an organisation of people and technology) is required for the creation of efficient and effective business processes (Kettinger et al., 1996).

Process reengineering in the construction industry is regarded as an integrated and holistic approach that concentrates on the management and optimisation of process flows and waste eradication (Love and Li, 1998). Despite various industry initiatives, relatively consistent accident rates involving plant/pedestrian collisions substantiate that currently employed safety processes and systems have not helped in reducing the number of plant related accidents; hence, indicating shortcomings in the plant safety process on a construction site. The situation demands a re-evaluation of these existing safety systems and procedures, and to determine how these practices can be improved upon. One way of approaching this process redesign is by exploiting ICT as an enabler (Marchand et al., 2001; Kettinger et al., 1996; Davenport, 1993). It is therefore recommended to utilise ICT solutions to produce an innovative and proactive health and safety management system.

6.2 USER REQUIREMENT ANALYSIS

DFDs are considered to be the 'workhorses' of requirement analysis as they display flow of information from one activity to another (Hay, 2002). The DFDs developed for the studied health and safety process for on-site plant along with the shortcomings in the current process highlighted during case studies, can help 'interpret' system requirements for improved plant management and safety. Accordingly, guidelines are developed for effective ICT application which are proposed below:

Need for information management and integration

The DFDs developed for the current health and safety process for on-site plant (see Section 5.3), captured dataflow between functional partitions of the system. In system design terms, this implies that the process can be decomposed into subsystems such as project plans, personnel and training, audit and inspections, plant management and accident management. The DFDs also highlight the fact that in the process a number of
data stores (manual and/or electronic) are maintained. These data stores along with their major contents are shown in Figure 6.1. The figure lists the stored information for each identified subsystem i.e. project specific information, personnel and training registers, audit and inspections, accident investigation and plant and equipment specific information.

**Figure 6.1**: Standalone data stores used in the plant management process

The presence of a variety of data stores for mobile plant and equipment suggest that if the processes are redesigned by utilising ICT, information integration is then an important feature of the redesigned system. The combining of heterogeneous data sources signifies the need for a MIS that shares information among different software applications rather than each application maintaining its own subset of information. Figure 6.2 illustrates that the envisaged central system for plant management that integrates the existing and planned application platforms. The figure was further expanded into an Entity Relationship Diagram (ERD). The diagram is a specialised graphic representation that illustrates the entities in a database, relevant attributes and interrelationships with other entities (Whitten et al., 2004).

Figure 6.3 shows the ERD for the envisaged plant MIS. The attributes for the schema were identified through document analysis (i.e. highlighting commonly used fields in company documentation on accident investigation, machine inspections, project plan etc.) during case studies and as indicated by interviewees (e.g. information on personnel records).
Figure 6.2: A central management system that shares information among various applications

The ERD also illustrates an organised collection of records where information is shared among various subsystems (such as information on: plant; personnel; accidents; and project etc.). This schema provides the foundation for a backend database layer of the envisaged ICT application.

**Features for an effective ICT application**

In order to develop a sustainable technology platform that lends itself to future business processes, certain features for an effective ICT application for improved plant management and safety should be incorporated.
Figure 6.3: Entity Relationship Diagram for envisaged plant MIS
These features, which are derived from the observed shortcomings in the existing health and safety process (see Table 5.1) for plant and equipment, are presented in Table 6.1.

### Table 6.1: Guidelines to address plant management and safety for effective ICT employment

<table>
<thead>
<tr>
<th>Identified Shortcoming in the Plant Safety Process</th>
<th>Suggested Features of the System</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Machine configuration where certain types of mobile plant (e.g. excavators, telehandlers, dump trucks etc.) have inadequate direct vision for operators;</td>
<td>• The system should enhance the all-round awareness of operators;</td>
</tr>
<tr>
<td></td>
<td>• The system should employ collision detection which alerts the management and plant operators when operatives enter the machine’s safe operational envelope;</td>
</tr>
<tr>
<td>• Failure to manage an operative free operational envelope for on-site plant and equipment;</td>
<td>• The system should maintain training levels of employees. These records should be available to site managers at all instances. This will help managers position only trained staff near the equipment;</td>
</tr>
<tr>
<td>• Inadequate training of machine operators and banksmen;</td>
<td>• The system should help management with alerts on maintenance schedules;</td>
</tr>
<tr>
<td>• Lack of machine (including onboard safety equipments) maintenance; and</td>
<td>• The system should support process automation by making the plant management process simpler and less tedious; and</td>
</tr>
<tr>
<td>• Ineffective process or process implementation.</td>
<td>• The system should help management ‘learn’ from mistakes e.g. in case of accident management the system is needed to:</td>
</tr>
<tr>
<td></td>
<td>• determine injury rates;</td>
</tr>
<tr>
<td></td>
<td>• identify trends and problem areas;</td>
</tr>
<tr>
<td></td>
<td>• permit comparisons;</td>
</tr>
<tr>
<td></td>
<td>• satisfy legal requirements; and</td>
</tr>
<tr>
<td></td>
<td>• identify the basic causes that contributed directly, or indirectly, to each accident.</td>
</tr>
</tbody>
</table>
In addition to information integration, a sustainable technology platform commonly provides support to information capture, management, analysis, dissemination, access and response. Building such a technology platform that addresses business processes in the construction plant sector is envisaged to have characteristics such as being comprehensive, flexible, user-friendly and cost effective (see Figure 6.4).

**Figure 6.4:** Features of a technology platform for plant and equipment

- **Comprehensive**
  - Improved plant management through a principal hybrid system that shares information among various platforms linked to plant management and safety.
  - Supports proactive and reactive solutions.
  - Extends the solution to support broader organizational initiatives and scenarios.

- **Flexible**
  - Customisable according to the needs of the users (managers and construction workforce).
  - Integration with other existing systems and industry solutions.
  - Includes both plant and people.

- **Easy-to-Use**
  - IT application with a focus on user-friendliness and reliability.

- **Cost Effective**
  - Cost effective technology solution to cut costs through streamlined operations of plant and equipment on a construction site.
6.3 SYSTEM ARCHITECTURE

As discussed (in Section 6.2), many individual data stores are currently used by construction practitioners in preference to a fully integrated system. Moreover, various information systems available range from fleet management to tracking systems. However, there is a need to develop a more comprehensive management system for construction plant and equipment that shares information among different software applications rather than each application maintaining its own subset of information.

This research describes an architecture to facilitate the integration of information for construction plant management among various standalone plant applications. Emerging safety issues on construction sites support the need for an information architecture that provides a single, unified data model that stores information and provides an integrated reporting infrastructure. The architecture should deliver the information integrity needed to address compliance and management requirements of plant operators and safety managers respectively. Consequently, the research particularly focuses on how health and safety managers and plant managers on a construction site can use a more comprehensive Management Information System (MIS) for the benefit of vehicle/pedestrian safety.

The proposed architecture employs a combination of emerging ICT for construction plant and equipment management in order to make these machines more productive, efficient and safer. For the architecture, emerging ICT such as mobile computing, real time tracking systems and Automatic Identification and Data Collection (AIDC) technology with MIS are explored and considered. The integration is presumed to lead to a far-reaching technology platform where information needs of plant operators and safety managers are targeted and addressed.

Figure 6.5 provides a schematic of the system architecture encompassing various aspects of technology application for plant and equipment. The architecture highlights four main layers of the application. The first layer, a ‘data capture layer’, collects data from workers on a construction site. The data collection is performed by various means e.g.:
- data entry by the workforce (via personal computers, handheld computers and PDAs etc.);
- automatic data collection using AIDC technology; and
- access data from other management databases e.g. training, personnel, audit and inspection etc.

Figure 6.5: System Architecture

The second layer is the ‘application layer’ which analyses the data for various management reports, trends and alerts on plant management and safety. To disseminate the information, the application layer uses an ‘access layer’ (third layer) which comprises of wired/wireless network. The access layer provides a means of communication in order to fully integrate the various layers within the technology platform. Finally, the information (generated by the application layer) is communicated (through the access layer) to the ‘client layer’. Here timely and relevant information is delivered to:
management in order to plan and direct organizational operations;
- pedestrians (workers/managers operating in the vicinity of plant and equipment) in the form of safety alerts; and
- plant operators as management notifications and safety alerts.

6.4 SIGHTSAFETY: THE CONCEPTUAL MODEL

The system architecture, user requirements and literature review of emerging technologies were used to propose an ICT application, entitled SightSafety, for improved management and safety of plant and equipment on a construction site. The envisaged application employs MIS which encapsulates existing information systems (e.g. training, maintenance, accident investigation, project information etc.) into one principal hybrid system for managing and sharing plant related information. Figure 6.6 shows an extension of this system that explores emerging ICT (e.g. mobile computing and AIDC technology) more fully to address the safety concerns of plant management, operators and pedestrians working in the vicinity of machines on a construction site. In an attempt to reduce accidents, the system particularly focused on:

- monitoring pedestrians working in close proximity of the machines;
- improving accident investigation process through automatic data collection; and
- improving communication among the workforce engaged with plant and equipment on a construction site.

Moreover, it is proposed that SightSafety uses a technology platform for the purpose of tracking pedestrians, information management and automatic notification to management as and when required. This will facilitate a more holistic and proactive approach to deal with both plant and construction worker safety. The main features of the conceptual model (shown in figure 6.5) are outlined below:
6.4.1 Location Tracking and Zone Detection

*SightSafety* monitors and identifies all workers, machines and objects, that may be at risk of becoming involved in an accident. For the purpose of location tracking and collision detection of equipment, it is extremely important for the safety system to know the ‘real time position’ of vehicles/workers and to be able to ‘identify’ them. A positioning and sensor based system can be used for site monitoring and event detection, such as proximity sensing for vehicles, entry of workers into danger zones and so forth.

For identification purposes, the system can be further extended into an e-tagging subsystem (which includes contact-less data storage and retrieval). The e-tagging system offers numerous other benefits for the *SightSafety* system over and above tracking ability. For example, encoding employee e-tags with personal data (e.g. employee number for unique identification and medical details in case of an emergency etc.). Moreover, vehicle e-tags can be encoded with maintenance information (useful in equipment ‘health’ monitoring) thus generating automatic updates on vehicle maintenance schedules and inspections. Once the real time position and ID of every e-tagged item (plant, object or pedestrian) is determined, it is wirelessly communicated to the plant MIS to capture all positioning information into a database.

Once the location information is captured by the system, *SightSafety* next applies the business logic to the captured data such as position evaluation, collision or danger zone entry detection or alarm status. Virtual danger zones are declared around the machines and/or any other objects on the construction site that impose an accident risk for pedestrians or other machines. At the conceptual stage of *SightSafety* it was envisaged that the danger zone would form a circular area around the vehicle or object and the radius from the circle’s centre to the perimeter would depend upon the machine’s safe operational envelope.
Figure 6.6: The Conceptual Model

Tag
Zone Type:
'R' = Red Zone
'A' = Amber Zone
'G' = Green Zone
P&ID = Position & ID

Operator:
- Alert signals depending on intrusion type (pedestrian/vehicle).
- Update on new positions of danger sources.
- Maintenance notifications.

Employee Notification

Report and Knowledge Management
Management:
Reports on:
- Accident records and dangerous occurring; and
- Training status of employees and operators;
- Machine maintenance; and
- Health & Safety audits and inspections.

Plant MIS

Worker:
- Alert signals depending on zone type.
- Update on new positions of danger sources.
- Hazard and precaution notifications.

Internet
The danger zone itself is further subdivided into three core areas, ranging from imminent danger to minimal risk of harm, depending on the risk and likelihood of harm, and these are colour coded red, amber and green respectively (see Figure 6.6). The boundary information of the danger zones is programmed into the SightSafety system according to the type of vehicle and its operating conditions. For example, in the case of an excavator with a maximum reach capacity of the boom and dipper of 10 meters, the green zone around the machine starts at 12 metres (2 metres for the additional protective envelope). The red and amber zones are demarcated depending on the operation mode of the excavator (such as heavy duty trench extracting, lighter duty finishing work, general excavating or loading).

SightSafety can then determine if any e-tagged object (vehicle or pedestrian) is near or approaching the danger zone by use of the location tracking system. For example, in the amber zone, a pedestrian walking within a machine’s operational envelope is classified as medium risk. Under such circumstances, the system generates alert signals (audio/visual) for any pedestrian and/or plant operator in the specified amber zone. Red zone (high risk) events would result in immediate vehicle immobilisation, to prevent accident occurrence, and management notification so that offending vehicles/pedestrians could be reprimanded for negligence as appropriate. In special cases, the operator through his on-board screen can grant permissions to workers to work in the amber or red zone; such instances may include the appropriate use of banksmen.

6.4.2 Notification

SightSafety delivers content (such as alert signals, updates, notifications etc.) depending on the role of the user (e.g. site worker, manager etc.), task (e.g. plant operator, ordinary worker etc.) and device (e.g. audio, visual, handheld, wearable etc.) (see Figure 6-5). For example, a useful feature of the system is a graduated audio tone which ranges from zero tone and frequency (green zone), to intermittent tone and medium frequency (amber zone) to high pitch constant zone and high frequency (red zone). Due to the high noise levels experienced on many construction sites, it is important to provide accompanying visual signals to operators or pedestrians, for example via mobile phone or on-board screen. In
addition to being a reactive arrangement, *SightSafety* is also a proactive application. Mobile computing technology and wireless systems can streamline processes by determining who and where the users are and what type of device they are using (such as vehicle on-board screens, PDAs, mobile phones, tablet PC etc.). Task specific safety information can then be delivered to the workers and operators, such as hazard and precaution notifications, vehicle maintenance updates etc.

### 6.4.3 Information Management

The proactive design of *SightSafety* is further extended by the ability to ‘learn’ from the captured information. This ability is partly attributable to the fact that all the dangerous occurrences on the construction site are captured and recorded. Whilst not a panacea to site safety problems, the analysis of reports generated from *SightSafety* can provide managers with insight into actual operations and to improve future safety at construction sites.

Additionally, the database system can also be used for the generation of management reports to help managers plan and direct organizational operations. The reporting structure used to provide management and workforce with timely and relevant information is discussed below:

1) **Information for Plant Operators:**

The information shared by the Plant MIS system with the plant operator includes:

- plant and equipment history with information on various tools and parts;
- machine maintenance and service schedules;
- inspection reports and machine ‘health’;
- alert signals and messages on the violation of the restricted-area around the plant by pedestrians or other vehicles;
- information on the location of any buried services or other hazards present on a construction site; and
- training status of pedestrians working in the vicinity of the plant e.g. operators are required to be more careful in case workers with less training are operating in the
area, similarly they can grant permissions to workers with higher level of training to operate near the plant under certain conditions with minimal risk of harm.

ii) **Information for Pedestrians:**
The information shared by the plant MIS with the plant operator includes:

- an alert notification depending on the distance of the pedestrian from the plant and on the risk and likelihood of harm;
- information on safe pedestrian routes around the construction site;
- an update on new positions of danger sources; and
- hazard and precaution notifications.

The pedestrians should also be able to report new hazards and electronically enter witness statements to the MIS.

iii) **Information for Managers and Decision Makers:**
A fundamental component of the plant MIS is the processing of collected data to produce current, accurate and useful reports for the decision makers. The plant MIS generates reports that consist of the following subsections:

*Plant and Equipment History*
The system stores plant information on suppliers, manufacturers, purchase and maintenance details. These records can be employed to generate reports such as:

- life of plant and equipment;
- list of all suppliers/manufacturers with details; and
- maintenance schedules/reminders.

*Vehicle inventory Management and Service Schedules*
The records stored in the plant MIS on tools/parts and inventory of the plant and equipment are useful in generating reports on inventory tracking, total or periodical purchase of
tools/parts. Moreover, service schedules can be entered into the system which can be used for schedule tracing and repair orders.

**Tracking System**

The information regarding the location of plant and equipment, pedestrian and other assets can be captured by location tracking and smart detection techniques on a construction site. In addition to tracking people and vehicles on a site, the system can also verify plant route variance, its speed and provide better theft control. The reports generated by the system for management are:

- asset deployment reports;
- activity report by driver/equipment ID;
- use of vehicle in a given period to determine total engine operating hours (operation time), fuel costing, time costing, working time/idle time; and
- list of collision incidents.

**Accident Management**

The plant MIS presents an all-encompassing system that facilitates health and safety related issues on a construction site. Project managers in general and health and safety managers in particular can benefit from reports such as:

- unauthorised personnel trips (entry to machine’s operational envelope);
- speed record/profile of vehicles;
- health and safety audit and inspection schedules/reports;
- training status of employees working close to the equipment;
- accident records and dangerous occurring; and
- hazard and precaution details.

The information can be disseminated to the end users through various channels e.g. wired network and the Internet. To satisfy the information needs of the mobile workforce, the network is further extended to a wireless network e.g. content is delivered to the managers (on laptop, PDAs etc.), plant operators (screens onboard plant and equipment) and
pedestrians (on mobile phones, PDAs etc.). The perceived benefit is improved communication of health and safety reports to site management.

6.4.4 Industry Feedback

An initial conceptual model was discussed with health and safety managers during site visits for the case studies (i.e. cases A to E). Feedback received was very positive however, some drawbacks within the model were noted, which are presented in Table 6.2. The health and safety experts clearly did not approve of the sensor based immobilisation of plant when the operational envelope is encroached. Moreover, depending on the operation type, banksmen are at times required to work in the operational envelop of the machines. According to the managers, these workers should only be allowed to work in the vicinity of the machines if they are trained and competent for that particular task. Consequently, it was considered extremely important to know the training status of workers operating in close proximity of machines.

The drawbacks identified by the industry experts suggested some additions to the conceptual model which were taken into account when extending the model into scenarios for the future design of the system.
### Table 6.2: Drawbacks to the conceptual model being realised

<table>
<thead>
<tr>
<th>Drawbacks</th>
<th>Example Feedback</th>
<th>Cases</th>
<th></th>
</tr>
</thead>
</table>
| Vehicle immobilisation                          | "I think immobilisation could be quite drastic specially if the machine is used in a lifting operation. The one drawback that I can see is that if you stop a vehicle due to immobilisation and if the boom stops suddenly, the object would still be moving or swinging and that can be a potential hazard."  
"Sometimes the 360 [excavators] are used to lift drainage pipes. Now if the machine stops suddenly then you have got a swinging object which is also a hazard." | N     | N | N | N | Y |
| Banksmen free operational envelope              | "There are people who have to be there working near the machines, for instance in case of a trenching operation."  
"At times the operator needs to have banksmen working in close proximity of the bucket."                                                                 | N     | N | N |   | N |
| Overwriting rights with plant operators (to permit banksmen enter the operational envelope)      | "Once a system is up and running then no one should be able to tamper with it except for supervisors."                                                                                                         | N     | N | N |   |   |
| Permissions for trained banksmen                | "Since it is computer based then it should allow say Joe Black who is trained enough. However, there should be an audible warning if untrained John Smith is in the close proximity."  
"For us [health and safety management] it is extremely significant to position only the trained banksmen in close proximity of the machines. It is therefore important to know their training status and not only their ID." | Y     | Y | Y | Y | Y |
| Fragmented nature of the industry               | "My concern is how is this system going to be enforced when there are different tradesmen and contractors on a site."                                                                                           | Y     | Y | N |   | Y |

**NB:** Y = Yes, N = No.
6.5 SIGHTSAFETY SCENARIOS

This section presents various scenarios, illustrating SightSafety from the perspectives of four different user roles on a typical construction site. These roles are: plant operator (in the case of a scenario an excavator operator); construction worker (operating in the operational envelope of an excavator); plant supervisor (in charge of all mobile plant and equipment related health and safety); and health and safety managers. The aim for scenario generation is to present 'alternate' future construction sites.

6.5.1 A Scenario for the Plant Operator

This scenario illustrates the case of a Plant Operator scanning for all personnel working in the operational envelope of an excavator. The following numbers illustrate the order of occurrence for system interactions and correspond to the numbers in Figure 6.7.

1. Using a tablet PC mounted in an excavator's cabin, the operator logs into the SightSafety application. The application is run before/during any machine operation in order to determine the number of workers operating in the machine’s operational envelope at all times.

2. The operator then requests the system for project details. The system connects to the Project database to retrieve a list of currently running projects, onsite locations and IDs of machines employed at these locations. The operator selects the suitable information by specifying the appropriate location on the site.

3. Once location is specified the operator requests a scan operation. Scanning for tags is a SightSafety functionality that detects multiple tags within a read range. For the prototype application, this feature means that a receiver (i-Card 3, a mobile reader in the Identec Solutions’ RFID system) is connected to a portable device e.g. tablet PC and mounted on an excavator. The scanning process would then detect all the tags carried by the pedestrians working in the vicinity (up to 10m range) of the machine.
4. For the *SightSafety* system it is proposed that a RFID tag is embedded in each Personnel ID card. Each tag has a unique serial number which means that each tag would identify the individual who is carrying the tag. Consequently, it is mandatory for system accuracy that all personnel are carrying their ID cards at all times. As a result of the scanning process all the RFID tags in the read zone are detected and displayed to the operator. Figure 6.7 depicts a scenario where three workers operating close to an excavator are wearing tags: ID:200111127, ID:200096730 and ID:200096742 respectively. The system will list only tags ID:200111127 and ID:200096742 since they are positioned inside the read zone. The operator also has the 'auto-scan' option where the system will scan for tags automatically after every 10 seconds and would detect any changes in the presence of personnel in the read zone.

5. The system displays on the operator screen a list of all tags detected in the read zone. The list also correspond to the ID numbers, names and training status of personnel carrying the tags. Training status is an important attribute for the system as it helps to differentiate the trained workforce from unqualified and inexperienced workers. It is retrieved along with other personnel information from the *Personnel and Training* database of the envisioned MIS. For the prototype the training status is assessed on a five level scale, 'Level V' being highest trained and 'Level I' being least trained worker. According to the business logic of the *SightSafety* system, the operator is notified of any trips by less trained workers i.e. Level I and II via the screen display in the cabin. For example, Figure 6.7 shows a list of personnel operating in the read zone. The operator will be notified about the presence of 'Paul Young' due to a lower training level.

6. Finally, any unauthorised trips in the operational envelope of this excavator are recorded in the database for a review by the managers.
Figure 6.7: SightSafety Scenario for Plant Operator

1. Plant Operator logs into the SightSafety Application through a tablet PC mounted on the excavator. The operator runs the application before/during any machine operation.

2. Operator requests project details. System queries the Project Info database to retrieve a list of current projects, location on site and IDs of machines employed on these locations. Operator selects appropriate information.

3. Operator requests a scan for tags within the operational envelope of the machine.

4. System connects to a tag reader which detects all the RFID tags (embedded in Personnel ID Cards) in the read zone. The reader thus returns a tag list to the system.

5. The operator is displayed a list of all tags detected in the read zone. He is notified on the screen about unauthorised trips by untrained staff in the operational envelope of the machine.

6. System logs all the trips into the local Trip Log database for this particular excavator.
6.5.2 A Scenario for a Construction Worker

This scenario illustrates the case of a Construction Worker operating in the operational envelope of an excavator. The following numbers illustrate the order of occurrence for system interactions and correspond to the numbers in Figure 6.8.

1. A construction worker on a site is given a Personnel ID with an embedded RFID tag. All personal details including medical history and contact information are ‘written’ to the tag. The information can be ‘read’ instantly by a plant operator (via screen in the cabin) or site supervisor (via a handheld e.g. a PDA) in the case of emergency or accident.

2. The presence of the worker in the operational envelope of the excavator is detected by the plant operator through the SightSafety application (installed on a tablet PC mounted in the excavator’s cabin).

3. SightSafety implements a business logic on the ‘read’ training status of the worker. The system identifies if the less trained staff (i.e. Level I or II) is working in the proximity of the machine (ID Ex5239).

4. The application informs the worker at risk through audio (e.g. alarms through headphones) and visual (e.g. beacon set on the vehicle, SMS generated on mobile phones with vibrator settings). The health and safety supervisor is also sent notification through SMS. Figure 6.8 shows that worker with ID: 200111127 is notified of imminent hazard due to a lower training level.

5. The system finally registers the worker details, time and location of incidence into a local database for the excavator. This information is useful for managers to identify workers with less training who tend to stray too close to machine.
Figure 6.8: *SightSafety* Scenario for a Construction Worker

**Construction Worker**

1. Each construction worker on a site is given a Personnel ID with embedded RFID tag. All personal details including medical history of the worker are written to the tag. In case of emergency or accident the details can be read instantly.

2. Plant Operator scans for tags within the operational envelope of the machine. All personnel tags in the read zone are detected.

3. System detects the presence of all workers in the machine's operational envelope and determines if any 'less' trained personnel are working in the vicinity of the machine.

4. If (Training Level < 111) Then

5. The workers at risk and supervisor are notified through audio and visual alerts.

6. System logs the worker details, time and location of the trip into the local Trip Log database.

**Trip Log**
- Personnel ID
- Name
- Training Status
- Date/Time of Trip
- Location

<table>
<thead>
<tr>
<th>Personnel ID</th>
<th>Name</th>
<th>Training Status</th>
<th>Date/Time of Trip</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1234</td>
<td>John</td>
<td>Level I</td>
<td>2023-01-10</td>
<td>Site</td>
</tr>
</tbody>
</table>

**Model**

- **RFID Tag**
- **Personnel Tag**
- **Application**
6.5.3 A Scenario for a Plant Supervisor

This scenario illustrates the case of a Plant Supervisor, in charge of all mobile plant and equipment and related health and safety. The following numbers illustrate the order of occurrence for system interactions and correspond to the numbers in Figure 6.9.

1. Using a mobile handheld device, a plant supervisor retrieves all trip logs from the engaged onsite plant and equipment through a wireless connection.

2. The plant supervisor then views a report for all the trips in the operational envelope of the employed machines. The supervisor can use the SightSafety application to query the database in order to retrieve all the trips, categorising by:
   a. particular time period; and
   b. training status of the worker (Level I – V in case of the prototype).

The report assists the supervisor to determine a consistent trend amongst construction workers who have a tendency of wandering close to the machine. The information will also support supervisors and managers to plan and direct organizational training and generate warnings for workers.

3. In case of any dangerous occurrence or accident taking place due to workers working in close proximity of machines, plant supervisor requests an investigation to the health and safety department through the mobile device.

4. The Accident Investigation Information System (IS) in the health and safety department is updated with latest trip log and investigation request generated by the plant supervisors.
**Figure 6.9: SightSafety Scenario for Plant Supervisor**

1. A plant supervisor retrieves all trip logs from the employed machines.

2. Plant supervisor views a report for all the trips for employed machines. The report generation parameters include time period and training status of workers.

3. Plant supervisor requests an investigation to the health and safety department on any dangerous occurrence or accident taking place on the site due to workers working in close proximity of machines.

4. The Accident Investigation IS in the health and safety department is updated with latest trip log and investigation request.
6.5.4 A Scenario for Health and Safety Management

This scenario illustrates the case of a *health and safety management* in charge of all mobile plant and equipment related health and safety. The following numbers illustrate the order of occurrence for system interactions and correspond to the numbers in Figure 6.10.

1. Health and safety managers must be informed on any dangerous occurrence or accident taking place due to workers working in close proximity of plant and equipment in order to conduct investigations. Consequently, a plant supervisor using *SightSafety* communicate investigation requests electronically to the health and safety department at the site office.

2. The *Accident Investigation IS* (in the health and safety department) is updated with latest trip log and investigation requests.

3. The *Accident Investigation IS* integrates with other applications e.g. *Project Info, Personnel and Training, Machine and Maintenance* etc. in order to retrieve information on: current project; worker details and their training status; and plant and equipment respectively.

4. The health and safety manager, when logged into the *SightSafety* application, is prompted for new investigations to be carried out. For each investigation report the project details, incident date and time, incident type, details of the personnel involved etc are updated electronically.

5. Depending on the incident type, the health and safety manager initiates the investigation process.
6.6 CHAPTER SUMMARY

The chapter has presented the guidelines for the effective use of technologies for improved plant management and safety. These guidelines are derived from the user requirement analysis which focuses on: addressing the shortcomings of the existing plant safety process; information integration among various subsystems; and developing a sustainable technology platform. The chapter also revealed system architecture and conceptual model of the application (entitled SightSafety). It is envisaged that the system will provide practitioners with a useful means to integrate various components of plant management into one comprehensive plant management
system with a particular focus on health and safety. A series of scenarios of a future construction site were produced that used emerging technology to concentrate on the information needs of the workforce. This workforce included plant operators, workers working within the operational envelop of machines, plant supervisors and health and safety managers involved in the construction project.

The scenarios are used to design and develop a prototype system for SightSafety which integrates emerging technologies, RFID in particular, with management tools like MIS to provide a more comprehensive health and safety management solution on a construction project than those currently available.
CHAPTER 7

PROTOTYPE DESIGN AND OPERATION

7.0 INTRODUCTION

The prototype application uses an Automatic Identification and Data Collection (AIDC) mechanism integrated with a plant Management Information System (MIS). The integration is presumed to lead to a far-reaching technology platform where information needs of plant operators and safety managers on a construction site are simultaneously addressed. Based on the technology platform, this chapter first discusses the choice of a RFID based system and its expansion using other software development environments. Subsequently, a pilot study is presented where the suitability of the selected RFID product was put to trial on a small construction site. Finally, system design (using activity diagrams) and operation of the SightSafety application (using screens of the system) are presented. The role of the researcher in system design and development is presented in Appendix H.

7.1 CHOICE OF DEVELOPMENT ENVIRONMENT

The prototype has used software development and database environments, which are discussed below:

IDENTEC Intelligent Long Range (ILR) Technology

The prototype has employed a RFID based system called ILR that was developed by an Austrian company IDENTEC Solutions. This product was selected because of its:

- appropriateness for the realisation of proposed scenarios e.g. memory capability of the RFID tags, mobile readers to be fixed on the vehicles to scan for tags around the machine etc.
- potential for customisation via a Software Development Kit (SDK).
- availability and competitive purchase cost.
Microsoft Visual Studio .NET 2003
Microsoft Visual Studio is a software development product which allows programmers to create bespoke software applications. The prime reason for using the Microsoft Visual Studio .NET 2003, as a programming platform, was the provision of IDENTEC.NET by IDENTEC Solutions. IDENTEC.NET is a RFID component used by software developers to capture and interact with IDENTEC Solution’s RFID tags. This component comes as part of the ILR Software Development Kit (SDK). Hence, Microsoft .Net framework was used to access RFID communication protocols through the SDK and to integrate IDENTEC ILR technology with the prototype application.

Microsoft SQL Server 2005 (Express Edition)
Microsoft SQL Server 2005 was used to provide a database environment for the prototype application. The choice was made because of the edition being a freeware and its easy integration with rest of the Microsoft product family, the .Net platform in particular.

7.2 THE ILR TECHNOLOGY

The main components of RFID based ILR technology, along with their major features, are listed in Table 7.1. The table categorises the system into both hardware and software components.

7.2.1 Hardware

The RFID system consists of hardware that tracks, locates and identifies RFID tags. The IDENTEC Solution ILR Technology uses the following hardware classification:

Readers: The technology comes with two types of readers or interrogators:

- **PC i-CARD III**: a mobile interrogator in a type II PC Card format which can be easily integrated into portable or laptop computers to read and write data to tags (IDENTEC Solutions, 2004).
- **i-PORT III**: a fixed interrogator which can use up to 4 antennas for automated and wireless data collection. The built-in signal strength measurement capability enables the localization of tags using triangulation (IDENTEC Solutions, 2005a).
Table 7.1: Major Components of ILR (adapted from IDENTEC Solutions Userguide for the ILR Technology System, version 2.3, 2005)

<table>
<thead>
<tr>
<th>Main Components of ILR Technology</th>
<th>Type</th>
<th>Features</th>
<th>Common Features</th>
<th>Cost</th>
</tr>
</thead>
</table>
| Tags: identify items (by electronic serial number) and store information regarding the items identification. Used for tracking and localization application. | i-D Active RFID Tags. | - Transmit/Receive data at distances of up to 6 meters (20 feet) from handheld/fixed interrogator.  
- 64 byte data memory.  
- Credit card-style housing. | - 6 year battery lifetime.  
- Non-line-of-sight data transmission.  
- LED indicator.  
- Communication on demand only.  
- 100 tag/sec identification rate provides reliable identification of fast moving-objects. | € 22.2 |
| | i-Q Active RFID Tags. | - Transmit/receive data at distances of up to:  
  o 30m (100 ft) from a handheld device; and  
  o 100m (300 ft) from a fixed interrogator.  
- 8KB or 32KB of data storage capacity.  
- Industrial housing. | | |
| Readers: fixed and/or hand-held Interrogators used to read or write information to the tags. | i-CARD III Interrogator. | - Mobile interrogator.  
- In a PC Card format that makes integration easy into a portable or laptop computers.  
- Computers with a PC i-CARD III can communicate to tags at a distance of up to 10m (33ft). | - 100 tag/s identification rate. | € 1140 |
| | i-PORT III Interrogator. | - Read/Write range is tuneable up to 100m (300 ft) with an i-Q tag.  
- Operates with up to four antennas and provides concurrent antenna processing.  
- Serial interface.  
- Ethernet interface. | | € 3900 |
| Antennas: act as channel between tags and readers. | Single external antenna connected to i-CARD III. | | | |
| | Linearly polarized antennas externally connected to i-PORT III (max. 4 antennas). | Depending on the direction of mounting, the antenna’s field is vertically/horizontally polarized, requiring the tag to have the same orientation. | | € 167 |
| Software: provides extension to other enterprise-wide systems. | Data collection system | Extensible through Microsoft .NET Framework and C++ which provides integration with other information systems and enterprise solutions. | | |
Antennas: The IDENTEC Solution (2005a) ILR Technology comes with two types of antennas, namely:

- fixed linearly polarised antennas that are connected to the i-PORT III (an i-PORT III is a fixed reader that can accommodate four such antennas); and
- a single external antenna for the PC i-CARD III (this is a mobile reader).

Tags (also called transponders): The ILR Technology comes with two types of active tags which are used for the purpose of identification and tracking:

- *i-Q tag*: These tags are available with a memory capability of 8 kByte or 32 kByte and distances of up to 100 metres can be achieved (IDENTEC Solutions, 2005b).
- *i-D tag*: These tags have 64 bytes of memory and distances of up to 6 metres can be achieved (IDENTEC Solutions, 2005c).

7.2.2 Software

The ILR Software Development Kit (SDK) can be used to integrate the ILR hardware into new or existing technology applications. The SDK provides programmers access to code that provides the RFID functionality, without going into the details of RFID communication protocols (IDENTEC Solutions, 2005a). The SDK currently supports the following operating systems: Microsoft Windows, Windows CE and Linux. In addition, libraries are available for C, C++, Java, and the Microsoft .NET Framework. Hence, the SDK supports the integration of the captured data with other applications and enterprise solutions.

7.3 PRODUCT TESTING FOR PROTOTYPE DEVELOPMENT

In order to test the performance of the IDENTEC Solution ILR technology in the harsh construction environment, a pilot study was conducted. In the study, the basic application of the RFID system was investigated on a small construction site at Loughborough University where a mini excavator was employed for an earth-fill operation (see Picture 7.1). A mobile reader (i-CARD III) was connected to a portable device (in this case a laptop) which was positioned in the cabin of the excavator.
Three personnel/pedestrians, including the researcher, were carrying tags in their pockets. Both types of tags i.e. i-Q and i-D2 were tested initially to check the capability and strength of each type. Figure 7.1 illustrates the configuration of a receiver placed in the excavator and the tags carried by pedestrians working around the machine.

**Figure 7.1: University test site**

For the pilot study the basic application of the RFID system was put to a test which aimed to trial robustness, range and performance of the equipment and software. As a result, a laptop was set up as a mobile reader (linking it with an i-CARD III) to
investigate: scanning for tags in the read zone of the mobile reader fixed on a mini excavator; and reading/writing a specific tag in the read zone.

**Reader scanning for e-tags:**

Scanning for tags was a functionality developed to detect multiple tags within a read range. Once the laptop was connected to the receiver, a scan command detected the tags in the read zone attributable to the communication between the tags and the i-CARD III receiver. The scanning process thus resulted in detection of all tags carried by the pedestrians working in the vicinity of up to 10m radius of the machine.

Each tag (carried by the pedestrians) had a unique serial number which meant that once identified, details of the individual carrying the tag could be identified. Figure 7.2 depicts a scenario where three pedestrians working in the read zone of 10 metres, were carrying tags ID:200111127, ID:200096730 and ID:200096742 respectively. Figure 7.3 shows the screen developed for the basic pilot system to implement the connection (with the i-CARD III receiver) and scanning functionality. The figure also shows the response to the 'scan' command as the system detected and displayed the three IDs of the tags carried by the pedestrians for the scenario in Figure 7.2.

*Figure 7.2: Scanning scenario 1 (where tags ID:200111127, ID:200096730 and ID:200096742 are in the read zone).*
The system successfully detected any changes in the read zone when scanned next. For instance, in the next scenario ID:200096742 left the read zone (see Figure 7.4) which is detected by the pilot system and only ID:200096730 and ID:200111127 were displayed (see Figure 7.5).

**Figure 7.4**: Scanning scenario 2 (where tags ID:200111127 and ID:200096730 are in the read zone)
Reader communication with the tags:

The tags had the ability of storing data in textual format which made it easier to inspect data when it was read back. In addition to a worker’s personal information (e.g. name, ID number, age, address etc.), medical history was also stored on the tag which could be read in case of an accident. Figure 7.6 shows a writing scenario where data is written to a tag with ID: 200096742. Figure 7.7 shows a screen where personnel information was written to tag (ID: 200096742) for a worker named ‘John’.

Figure 7.6: Write scenario
Figures 7.8 and 7.9 show the scenario and the resulting screen respectively for the pilot where the system retrieved data (i.e. read) for the selected tag. Figure 7.8 shows a read scenario where data is read from a tag with ID: 200096742. Figure 7.9 shows a screen where personnel information was read from tag (ID: 200096742) for a worker named ‘John’ along with his age, contact details and medical history.
Test results:

Overall, the system functionalities were successfully tested on the university construction site. The reader worked effectively in the presence of noise and vibration generated by the excavator (during its slewing and tracking operation). However, for
7.4 PROTOTYPE DESIGN AND DEVELOPMENT

Once the suitability of the IDENTEC Solution ILR technology was established through the pilot study, the prototype system SightSafety was developed by using the generated scenarios (Section 6.4) as a guideline. This section details:

- the key actors who interact with the system to fulfil their tasks;
- the activity diagrams which describe the system design in terms of business logic flow and events that cause decisions/actions to be undertaken in the code; and
- implementation of the design displayed through screen captures of the system.

Consequently the SightSafety system, depending on functionality and user role, is divided into four activities which are discussed in the following subsections.

7.4.1 Implementation of Activity 1: Tag Read/Write

Given the fact that for SightSafety every construction worker requires a RFID embedded project ID card, tag read/write activity describes the operation in which tags for construction workers are written and read. The major actor of this operation is the...
• the activity diagrams which describe the system design in terms of business logic flow and events that cause decisions/actions to be undertaken in the code; and

• implementation of the design displayed through screen captures of the system.

Consequently the SightSafety system, depending on functionality and user role, is divided into four activities which are discussed in the following subsections.

7.4.1 Implementation of Activity 1: Tag Read/Write

Given the fact that for SightSafety every construction worker requires a RFID embedded project ID card, tag read/write activity describes the operation in which tags for construction workers are written and read. The major actor of this operation is the personnel department since they are typically responsible for managing employee records and issuing the ID cards. Figure 7.10 shows the activity diagram for the operation and describes the actor activities in a sequence.
Using Figure 7.10 a functionality of the prototype was developed to map the tag read/write functionality with the following flow of events:

- The system user (employee of personnel department) places RFID embedded ID cards in the range of the reader (i-CARD III).
The user logs into the system through a log-in screen and the system authenticates username and password.

If the log-in is successful, the user connects to the reader (i-CARD III).

Once a connection is established with the reader, the user sends a scan command to the system to detect the tags in the read zone.

The system displays all the tags detected in the read zone.

The user selects the tag on which data is to be written or read from (see Figure 7.11).

The user selects the 'Tag Write' tab if it is required to write employee data to the tag.

The system retrieves a list of job titles, supervisors and training levels employed in the current project. The prototype training level is defined from 1 to 5, 1 being the least trained operative and 5 being the most.

The user enters the employee data to be written on a tag (see Figure 7.11).

The system validates the data entry and writes it to the tag (through the reader) as well as to the personnel database.

The user selects the 'Tag Read' tab if it is required to read the data from the selected tag.

The system reads the data of the selected tag through the reader (i-CARD III) and displays it for the user (see Figure 7.12).

The user can read/write data to all tags registered in the scanned tag list.

The user logs-out of the system.
Figure 7.11: Screen capture of the SightSafety system for tag write operation

Tag Identification and Communication

Connect
Scan for Tags

<table>
<thead>
<tr>
<th>Tag Read</th>
<th>Tag Write</th>
</tr>
</thead>
<tbody>
<tr>
<td>Employee ID</td>
<td>A736578</td>
</tr>
<tr>
<td>Name</td>
<td>Richard Shmpe</td>
</tr>
<tr>
<td>Date of Birth</td>
<td>20 May 1976</td>
</tr>
<tr>
<td>Address</td>
<td>38 Crescent Drive, Loughborough, LE11 3RU</td>
</tr>
<tr>
<td>Job Title</td>
<td>Foreman</td>
</tr>
<tr>
<td>Supervisor</td>
<td>Robert Gates</td>
</tr>
<tr>
<td>Training Status</td>
<td>Level III</td>
</tr>
<tr>
<td>Emergency No</td>
<td>709356644</td>
</tr>
<tr>
<td>Blood Group</td>
<td>AB</td>
</tr>
<tr>
<td>Medical History</td>
<td>Asthma</td>
</tr>
</tbody>
</table>

Writes data to Tag and Personnel Database

Figure 7.12: Screen capture of the SightSafety system for tag read operation

Tag Identification and Communication

Connect
Scan for Tags

<table>
<thead>
<tr>
<th>Tag Read</th>
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<tr>
<td>Blood Group</td>
<td>AB</td>
</tr>
<tr>
<td>Medical History</td>
<td>Asthma</td>
</tr>
</tbody>
</table>

Read
7.4.2 Implementation of Activity 2: Detect Unauthorised Pedestrian in the Operational Envelope of Plant

This activity describes the operation where the workers working in close proximity of a plant are monitored. The major actor of this operation is the plant operator who is provided with an on-board visual display unit to interact with the system. Figure 7.13 shows the activity diagram for the operation highlighting sequence of actor activities.

**Figure 7.13: Activity diagram for unauthorised pedestrian monitoring operation**

```
Plant Operator                                         SightSafety                                      IDENTEC ILR Technology

User login                                           Authorise                                       Connect to i-CARD III

Select appropriate project info                      Retrieve project info from database              [Success]

Connect to the RFID reader                           [Valid Login]

Scan for Tags                                        Handle exception: Communication not established

[Auto Scan Checked] Set Scan Timer                   Scan for IQ Tags

[Update database] Set database Update Timer          [Failure]

Record pedestrian details                            Display Tag collection                           [Training Status >= 3]

Retrieve and display employee information against the ID

[Training Status <= 2] Generate alert

Record unauthorised 'trips'
```
The developed functionality of the prototype using this sequence is discussed below:

- The system user (plant operator) logs into the system which verifies the username and password.
- If the log-in is successful, the system retrieves current project information i.e. project ID, locations on the project and ID of machines used on the project (see section ‘Project Info’ in Figure 7.14).
- The user connects to the reader (i-CARD III) and commands a scan operation (see section ‘Detect Tags in Range’ in Figure 7.14).
- The system retrieves a list of personnel tags working within a machine’s operational envelope. In addition, the system displays the name, ID and training status of operatives working in the vicinity of the machine (see sections ‘IDs of Scanned Tags’ and ‘Training Status of Employees’ in Figure 7.15).
- If the training status of the worker/pedestrian is less than 3, the system generates visual alert for the plant operator. The business logic applied to the system considers that any worker with a training status less than level 3 is reported to the site health and safety supervisor (see section ‘Logs Trips’ in Figure 7.15). The system is flexible to be customised according to the business logic of any project.
- If the operator checks the ‘Auto Scan’ option on the screen and enters a time (in seconds), the system automatically scans for tags in the read zone after the specified time (see section ‘Detect Tags in Range’ in Figure 7.16). Alerts and database records are generated constantly when untrained (level I and II) workers are detected in the read zone.
- If the operator checks the ‘Update Database’ option on the screen and enters a time (in seconds), the system automatically records into a database the presence of all the workers in the read zone after the specified time period (see section ‘Detect Tags in Range’ in Figure 7.17). The database records generate useful reports for health and safety supervisors to monitor the workers who are present around the machine at various instances (see Figure 7.18 for the records that are stored in a table of a database for this operation).
- Plant operator logs-out of the system at the end of plant operation.
**Figure 7.14:** Screen capture of *SightSafety* for pedestrian monitoring operation – before scan

**Figure 7.15:** Screen capture of *SightSafety* for pedestrian monitoring operation – after scan
Figure 7.16: Screen capture of SightSafety for pedestrian monitoring – the ‘Auto Scan’ operation

![Screen capture of SightSafety for pedestrian monitoring – the ‘Auto Scan’ operation](image)

Figure 7.17: Screen capture of SightSafety for pedestrian monitoring – the ‘Update Database’ function

![Screen capture of SightSafety for pedestrian monitoring – the ‘Update Database’ function](image)
7.4.3 Implementation of Activity 3: Report Generation for Plant Supervisor Responsible for Health and Safety

Activity 3 describes the operation where plant supervisors, responsible for health and safety, can generate reports using the records that were stored in activity 2. The major actor of this operation is the plant supervisor who can access information on the handheld device by synchronising it with the systems on plants through a wireless network. Figure 7.19 shows the activity diagram pointing out the sequence of events for the operation. The developed functionality of the prototype using this sequence is as follows:

- The system user (plant supervisor responsible for health and safety) logs into the system which verifies the entered user name and password.
- If the log-in is successful, the system retrieves current project information i.e. project ID and training status (see section ‘Generate Report’ in Figure 7.20).
The user then provides parameters to generate a report on the workers present in the operational envelope of various machines working at a particular time. Parameters that can be viewed include: the project ID; the start and end date of the work; and the various training levels used in the project. Figure 7.20 shows
one such report generated by a supervisor to observe the presence of workers (of all training levels) working in proximity of machines on May 20, 2007 for the project He-T5-02 (project code). Through the reports supervisor can notice the presence of employees (namely Miss Zainab Riaz with training level I and Mr. Udit Gohil with training level II) operating near machines with ID Th29084 and Ex32313 (see Figure 7.21 and Figure 7.22).

- In case of an accident or dangerous occurrence the supervisor electronically sends an investigation request to the health and safety managers (see Figure 7.23 and Figure 7.24).
- Finally, the user logs out of the system.

Figure 7.20: Screen capture of SightSafety for report generated by supervisor (for all training levels)
**Figure 7.21:** Screen capture of *SightSafety* for report generated by supervisor (for training level I)

![Figure 7.21](image1.png)

<table>
<thead>
<tr>
<th>Log No</th>
<th>Employee ID</th>
<th>Employee Name</th>
<th>Supervisor</th>
<th>Machine ID</th>
<th>Date &amp; Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A4467672</td>
<td>Zarnab Riaz</td>
<td>Robert Gates</td>
<td>TH29084</td>
<td>20/05/2007 17:19:57</td>
<td>Phase 1</td>
</tr>
<tr>
<td>2</td>
<td>A4467672</td>
<td>Zarnab Riaz</td>
<td>Robert Gates</td>
<td>EX32313</td>
<td>20/05/2007 16:52:57</td>
<td>Phase 1</td>
</tr>
<tr>
<td>3</td>
<td>A4467672</td>
<td>Zarnab Riaz</td>
<td>Robert Gates</td>
<td>EX32313</td>
<td>20/05/2007 17:04:34</td>
<td>Phase 1</td>
</tr>
</tbody>
</table>

**Figure 7.22:** Screen capture of *SightSafety* for report generated by supervisor (for training level II)

![Figure 7.22](image2.png)

<table>
<thead>
<tr>
<th>Log No</th>
<th>Employee ID</th>
<th>Employee Name</th>
<th>Supervisor</th>
<th>Machine ID</th>
<th>Date &amp; Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A357485</td>
<td>Udit Gehl</td>
<td>Jimmy Henze</td>
<td>EX32313</td>
<td>20/05/2007 16:51:41</td>
<td>Phase 1</td>
</tr>
<tr>
<td>2</td>
<td>A357485</td>
<td>Udit Gehl</td>
<td>Jimmy Henze</td>
<td>EX32313</td>
<td>20/05/2007 16:52:58</td>
<td>Phase 1</td>
</tr>
<tr>
<td>3</td>
<td>A357485</td>
<td>Udit Gehl</td>
<td>Jimmy Henze</td>
<td>EX32313</td>
<td>20/05/2007 17:04:05</td>
<td>Phase 1</td>
</tr>
<tr>
<td>4</td>
<td>A357485</td>
<td>Udit Gehl</td>
<td>Jimmy Henze</td>
<td>EX32313</td>
<td>20/05/2007 17:04:35</td>
<td>Phase 1</td>
</tr>
<tr>
<td>5</td>
<td>A357485</td>
<td>Udit Gehl</td>
<td>Jimmy Henze</td>
<td>TH29084</td>
<td>20/05/2007 17:19:58</td>
<td>Phase 1</td>
</tr>
</tbody>
</table>
Figure 7.23: Screen capture of SightSafety for generating incident investigation request

Figure 7.24: Screen capture of SightSafety for successful transaction
7.4.4 Implementation of Activity 4: Electronic Accident Reporting and Investigation for Health and Safety Managers

This activity describes the operation where a health and safety department is electronically notified about any accident/dangerous occurrence on a construction site. The major actor of the activity is the health and safety department/manager who logs into the system at the site office. Figure 7.25 shows the activity diagram illustrating the sequence of events for this operation. The flow of these events is discussed below:

- The system user (health and safety managers) logs into the system which verifies the entered user name and password.
- If the log-in is successful, the system retrieves and displays a list of accident investigation requests made by site supervisors (see Figure 7.26).
- The user enters the incidence reference number in the accident investigation form to initiate the investigation (see Figure 7.27 where the user has entered incidence reference no. 4).
- The system automatically retrieves information on: project and location of event; incident type; date and time of incident; date incident investigation was requested; ID of machine involved in the incident; and details of the person involved/injured (see Figure 7.27 and Figure 7.28).
- The user enters the results of the carried out investigation and saves it (see Figure 7.29 and Figure 7.30 for all the fields suggested for accident investigation).
- The system updates the database with the investigation data and removes the investigation request from the request queue (see Figure 7.31).
- The user logs out of the system.
Figure 7.25: Activity diagram for electronic accident reporting and investigation operation.

Health and Safety Manager

- User login
- Authorise
- [Invalid Login]
- [Valid Login]
- Retrieve pending investigation requests
- Select pending investigation
- Retrieve existing investigation info
- Enter investigation results
- Update accident investigation records
- Remove investigation request from pending requests

SightSafety

- Retrieve pending investigation requests
- Select pending investigation
- Retrieve existing investigation info
- Enter investigation results
- Update accident investigation records
- Remove investigation request from pending requests
Figure 7.26: Screen capture of SightSafety showing new and pending investigation requests

Figure 7.27: Screen capture of SightSafety for accident investigation – user enters incident reference number to initiate investigation where accident references are retrieved automatically.
Figure 7.28: Screen capture of SightSafety for accident investigation – details of employee involved/injured in accident are also retrieved.

Figure 7.29: Screen capture of SightSafety – Accident investigation form 1
Figure 7.30: Screen capture of SightSafety – Accident investigation form 2

Figure 7.31: Screen capture of SightSafety – list of new/pending accident investigation is updated
7.5 CHAPTER SUMMARY

In an attempt to record and reduce plant accidents on a construction site, this chapter has reported upon the development of the prototype system, entitled SightSafety, which includes incorporation of AIDC technology and mobile computing with plant MIS. The AIDC technology includes the RFID tagging systems which offer non-contact reading and has proved highly effective in hostile environments (e.g. construction industry) where bar code labels (that require manual scanning) could easily become damaged.

The prototype system includes activities such as communication with RFID tags, monitoring of personnel working within machine’s operational envelope, reports for plant supervisors on authorised presence of workers in the operational envelope, electronic reporting of incidents on site to health and safety department, access to incident details for health and safety managers etc. To implement these activities, the prototype system has employed the IDENTEC ILR technology along with Microsoft software development environment. The technology platform is believed to lead to a proactive solution where information needs of plant operators and safety managers on a construction site are addressed.
CHAPTER 8
PROTOTYPE EVALUATION

8.0 INTRODUCTION

As a generic statement, prototype evaluation consists of jointly reviewing a system or product with end-users in order to learn about any necessary changes required to meet user expectations (Futrell et al., 2002). The design and operation of SightSafety was based on end-user needs identified through requirement analysis and scenario generation. Next, an evaluation of this system was carried out in order to obtain user feedback and to draw conclusions with respect to system performance.

This chapter presents the results of the evaluation process which was augmented with an analysis to determine the level of agreement among the evaluators (managers and plant operators). Using statistical parametric and nonparametric techniques the work sought to determine whether a significant difference in opinion existed between the two user groups. In addition, a qualitative analysis also highlighted system benefits, barriers to implementation and further improvements to the application.

8.1 EVALUATION OBJECTIVES

The validation process focused on identifying any shortcomings of the SightSafety system and user-friendliness of the system interface. It was also considered whether the system actually met the theoretical study goals whilst remaining relevant to pragmatic industry needs. As a result, the following objectives were identified for the evaluation process:

1. to verify and validate that the system complies with user needs and satisfies the original design goals identified from user requirement analysis and scenario generation;
2. to evaluate the usability and acceptability of the prototype;
3. to determine how significant the difference in opinion was between the system users (i.e. plant operators and managers);
4. to obtain user feedback for further improving the system and to highlight any missing functionality; and
5. to obtain user feedback about possible industry specific barriers and facilitators to guide any future development.

8.2 CHARACTERISTICS OF THE PARTICIPANTS

A total of five construction projects were visited to evaluate the prototype. The selection of these projects was based on company size (with an annual turnover of more than £400 million) and to ensure collection of data from the representative user group. Site management (responsible for health and safety of plant related work) and plant operators were identified as relevant system users. Table 8.1 shows the list of participants who completed the evaluation process. The table clearly illustrates that users were divided into two groups namely, managers and plant operatives (drivers and supervisors).

<table>
<thead>
<tr>
<th>Site Code</th>
<th>Serial No.</th>
<th>Job Title (Managers)</th>
<th>Organisation Type</th>
<th>Experience in Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>Site Manager/Senior Engineer</td>
<td>Contractor</td>
<td>19 years</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>Project Manager/Regional Engineering Manager</td>
<td>Contractor</td>
<td>31 years</td>
</tr>
<tr>
<td>B</td>
<td>3</td>
<td>Project Manager</td>
<td>Contractor</td>
<td>9 years</td>
</tr>
<tr>
<td>C</td>
<td>4</td>
<td>Senior Site Manager</td>
<td>Contractor</td>
<td>18 years</td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td>Project Manager</td>
<td>Design Consultants</td>
<td>4 years</td>
</tr>
<tr>
<td>D</td>
<td>6</td>
<td>Contracts Manager</td>
<td>Sub-Contractor</td>
<td>20 years</td>
</tr>
<tr>
<td>D</td>
<td>7</td>
<td>Site Manager/Senior Engineer</td>
<td>Design Consultants</td>
<td>25 years</td>
</tr>
<tr>
<td>E</td>
<td>8</td>
<td>Works Manager</td>
<td>Suppliers of building materials (Quarry)</td>
<td>18 years</td>
</tr>
</tbody>
</table>

(Plant Supervisors and Operators)

<table>
<thead>
<tr>
<th>Site Code</th>
<th>Serial No.</th>
<th>Job Title</th>
<th>Organisation Type</th>
<th>Experience in Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>Plant Supervisor</td>
<td>Contractor</td>
<td>20 years</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>Plant Operator (Excavator 360)</td>
<td>Contractor</td>
<td>15 years</td>
</tr>
<tr>
<td>D</td>
<td>3</td>
<td>Site Agent/Senior Plant Supervisor</td>
<td>Sub-Contractor</td>
<td>16 years</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>Site Agent/Plant Supervisor</td>
<td>Sub-Contractor</td>
<td>14 years</td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td>Plant Operator (Excavator 360)</td>
<td>Sub-Contractor</td>
<td>14 years</td>
</tr>
<tr>
<td>E</td>
<td>6</td>
<td>Plant Operator (Wheeled Loader)</td>
<td>Suppliers of building materials (Quarry)</td>
<td>18 years</td>
</tr>
<tr>
<td>E</td>
<td>7</td>
<td>Plant Supervisor</td>
<td>Suppliers of building materials (Quarry)</td>
<td>12 years</td>
</tr>
</tbody>
</table>
8.3 EVALUATION APPROACH

The format adopted for the evaluation process consisted of the following steps:

a. a short presentation on the research background was given to potential SightSafety users purely to establish the context of the work.

b. a brief introduction about the contact-less Automatic Identification and Data Collection (AIDC) technology was given to ensure that evaluators fully understood the underlying application’s concept.

c. the prototype application was demonstrated to evaluators in the context of developed scenarios. This was followed by semi-structured interviews with evaluators in order to elicit on possible system improvements and determine any implementation issues of the application.

d. finally, to obtain a structured feedback and to generalise user perception of the system, evaluators were asked to complete a questionnaire addressing issues e.g. system effectiveness, practicality, usability etc. Two separate questionnaires were prepared for managers and plant operators (see Appendix A2 for the questionnaires).

The demonstration of the prototype application involved setting up a single server application on a tablet PC. Real time demonstration with the prototype application could be performed only on one site by placing the system on a machine (a wheeled loader in this case) and monitoring four workers in the machine’s operational envelope by providing them with RFID tags. Evaluators expressed concerns about their busy schedules on the construction sites and they could only spare 30-40 minutes for the whole evaluation process. Secondly, it was extremely difficult to gain access to an area where plant and equipment were in operation due to health and safety reasons. Because of time and infrastructure requirements of the system, it was only feasible to show the evaluators a working prototype on a single server tablet PC setting.

8.4 ANALYSIS AND DISCUSSION OF THE EVALUATION PROCESS

A preliminary evaluation was conducted to trial the initial evaluation questionnaire and process. Three practitioners (2 managers, 1 plant operator) from a construction site at
Loughborough University participated in the pilot evaluation. Evaluators complained about the questionnaire being too lengthy and time consuming. A final set of two questionnaires were prepared by taking into account evaluators feedback on questionnaire design (see Appendix A2).

A total of 15 evaluators participated in the evaluation process during which feedback was gathered on the themes given in Table 8.2. The table also highlights how these themes were identified.

**Table 8.2: Identification of themes for the survey questionnaire**

<table>
<thead>
<tr>
<th>Theme</th>
<th>Identified through</th>
</tr>
</thead>
<tbody>
<tr>
<td>System effectiveness</td>
<td>Literature (Grover and Segars, 2005)</td>
</tr>
<tr>
<td>Proactive nature of the system</td>
<td>Benefit highlighted by practitioners during scenario validation</td>
</tr>
<tr>
<td>Practicality of the system</td>
<td>Concerns highlighted by practitioners during scenario validation</td>
</tr>
<tr>
<td>System usability</td>
<td>Literature (Aziz, 2005; Domdouzis, 2007)</td>
</tr>
<tr>
<td>Financial feasibility</td>
<td>Concerns highlighted by practitioners during scenario validation and literature (Bowden, 2005)</td>
</tr>
</tbody>
</table>

Participants were requested to assess these themes on a *level of agreement* on a Likert scale of 1 to 5, where: 1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; and 5 = strongly agree. The responses were quantitatively analysed using a variety of techniques ranging from simple percentage comparison to more complex parametric and nonparametric tests. The tests were carried out to determine whether a significant difference of opinion (at \( p = 0.05 \)) exists between plant operators and managers; this was necessary to see how both managers and operators perceived the system. In addition, participants were requested to answer open ended questions which generated qualitative data. This data was analysed to suggest:

- improvements in the system;
- potential system benefits;
- hard (technical) and soft (social and cultural) issues; and
- barriers to the application.
8.4.1 System Effectiveness

In terms of system effectiveness, it can be seen from Table 8.3 that the managers mostly agree that "the system is useful" and "will contribute towards accident reduction", as both questions having received a combined level of agreement of 62.5%. For the same questions, a more varied trend is observed in the responses of plant operators and supervisors (see Table 8.4), where 14.23% disagreed and a similar number strongly disagreed when asked about "system usefulness" and "contribution towards accident reduction" respectively. With a high level of agreement from management, it may be inferred that management sees the potential of the system whilst plant operators are more reserved. An almost similar trend in agreement levels was noticed among managers and operators when asked if the system "will help monitor the workforce" working in the operational envelope of plant and equipment. Yet again, site management agrees with the system's monitoring capability however operators had mixed opinions about it. It may be argued here that operators view the monitoring ability of the system negatively as a 'spy' instead of considering it as an advantage for improved site safety.

Finally, when asked about the system's relevance for the industry needs, operators again gave a mixed response which was more towards agreement (28.57% agreed and 28.57% strong agreed). However, the majority of management (87.5%) agreed that the system had a relevance for the industry's needs. With a high agreement level, it may be inferred that the industry, in general, recognises the need for more comprehensive measures for improved plant related safety on construction sites.

<table>
<thead>
<tr>
<th>Ref No</th>
<th>System Effectiveness</th>
<th>Level of agreement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>I consider the overall SightSafety system: is a useful application.</td>
<td>37.5 50.0 12.5</td>
</tr>
<tr>
<td>1.2</td>
<td>Will contribute in reducing accident rates on sites</td>
<td>37.5 50.0 12.5</td>
</tr>
<tr>
<td>1.3</td>
<td>will help in monitoring the workforce working in the operational envelope of plant.</td>
<td>12.5 50.0 37.5</td>
</tr>
<tr>
<td>1.4</td>
<td>has a relevance for the industry's needs.</td>
<td>12.5 87.5</td>
</tr>
</tbody>
</table>
Table 8.4: Results of responses from plant supervisors and operators on system effectiveness

<table>
<thead>
<tr>
<th>Ref No</th>
<th>System Effectiveness</th>
<th>Level of agreement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>I consider the overall SightSafety system:</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>Is a useful application.</td>
<td>14.3 28.6 28.6 28.6</td>
</tr>
<tr>
<td>1.2</td>
<td>Will contribute in reducing accident rates on sites</td>
<td>14.3 57.1 14.3 14.3</td>
</tr>
<tr>
<td>1.3</td>
<td>will help in monitoring the workforce working in the operational envelope of plant.</td>
<td>14.3 28.6 28.6 28.6</td>
</tr>
<tr>
<td>1.4</td>
<td>has a relevance for the industry’s needs.</td>
<td>14.3 14.3 14.3 28.6 28.6</td>
</tr>
</tbody>
</table>

8.4.2 A Proactive System

In terms of the proactive nature of the system, it can be observed from Table 8.5 that managers approved of the ability of the system “to improve health and safety practices on a construction site” (75% agreed) and “to help towards a proactive health and safety management system” (75% agreed). Interestingly, an even higher percentage of managers endorsed the view (e.g. 50% agreed and 37.5% strongly agreed) that the system will help managers to retrieve vital information that may subsequently be “used as a training aid for inexperienced workers”. These figures highlight the fact that there is a high level of recognition among managers on the system’s ability to help management ‘learn’ how to improve upon current best practice adopted. It may be inferred here that managers appreciate the use of a tool to provide support in decision making as suggested by O’Brien (1999).

On the other hand, the response of plant operators and supervisors was quite at odds when asked if they considered the system would “improve health and safety practices on a construction site” (see Table 8.6). A high level of disagreement was observed when asked if the system’s information could be used as a training aid for managers (as 57.1% of respondents disagreed). It may be inferred here that plant operators did not consider it useful to transfer the information of workers (working in a machine’s operational envelope) to managers. An apparent explanation could be that operatives want to hold back this information from management in order to avoid any consequences of the unsafe practices in machines’ operational envelope. Another reason cited for the lower level of acceptance of the system among plant operatives is that they have low technical literacy. Although they were given a complete demonstration of the
system, it is apparent that a full appreciation of the system can only be acquired when hands-on experience is gained.

Table 8.5: Evaluation results on the proactive nature of the system by managers

<table>
<thead>
<tr>
<th>Ref No</th>
<th>Proactive System</th>
<th>Level of agreement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>I consider that the SightSafety system:</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>will enable managers to learn how to improve health and safety practices on a construction site.</td>
<td>25.0</td>
</tr>
<tr>
<td>2.2</td>
<td>will help managers to retrieve information that may subsequently be used as a training aid for inexperienced workers.</td>
<td>12.5</td>
</tr>
<tr>
<td>2.3</td>
<td>will help towards a proactive health and safety management system.</td>
<td>25.0</td>
</tr>
</tbody>
</table>

Table 8.6: Evaluation results on the proactive nature of the system by plant operators and supervisors

<table>
<thead>
<tr>
<th>Ref No</th>
<th>Proactive System</th>
<th>Level of agreement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>I consider that the SightSafety system:</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>will enable managers to learn how to improve health and safety management practices on the construction site?</td>
<td>14.3</td>
</tr>
<tr>
<td>2.2</td>
<td>will help managers to retrieve information that may subsequently be used as a training aid for inexperienced workers?</td>
<td>57.1</td>
</tr>
</tbody>
</table>

8.4.2 System Practicality

Participants were also enquired about practicality of the application. Here particular emphasis was given to understanding the ‘soft’ issue i.e. acceptance of personnel tagging by the construction workers. The responses on system practicality from managers, presented in Table 8.7, show that nearly 63% of managers interviewed support the view that “the system is a practical solution”. The response from the managers was fairly diverse when asked if they were “comfortable with the idea of employee tagging”. It was interesting to see a relatively high percentage (as 12.50% agreed and 37.50% strongly agreed) in favour of an idea which has many ‘soft’ (social and cultural) issues associated with it. It may be argued here that the managers have ignored the monitoring concerns of workers. In addition, they may foresee that system training and awareness among the workforce can reduce the tagging implications.
In contrast, plant operators and supervisors were divided on the opinion "system being a practical solution" (see Table 8.8); 42.9% disagreed, 14.3% agreed and 42.9% strongly disagreed. However, a clear majority were not "comfortable with the idea of employee tagging", with 28.6% disagreeing and 42.9% disagreeing strongly. This evidently points out to the implications of technology application in a social domain (construction site) where the management needs to keep a track of all events while the workforce wants to work without any restrictions. This argument was further endorsed when both the groups were asked if in their opinion "the workers will use the system without any fear of being monitored" and a clear majority of both user groups disagreed with the statement.

When the managers were asked if in their opinion "plant operators would use the system", all of the respondents (100%) were not sure if they would use it or not. However, interestingly 42.9% of the plant operators agreed that they will use the system. Finally, both user groups were entirely convinced that a "major system training will be required" for the initial system setup. This will add up to the additional training cost of the system which the managers also need to take into account.

Table 8.7: Evaluation results on system practicality by managers

<table>
<thead>
<tr>
<th>Ref No</th>
<th>System Practicality</th>
<th>Level of agreement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>I consider SightSafety a practical solution.</td>
<td>37.5 62.5</td>
</tr>
<tr>
<td>3.2</td>
<td>I am comfortable with the idea of employee tagging.</td>
<td>12.5 25 12.5 12.5 37.5</td>
</tr>
<tr>
<td>3.3</td>
<td>The workers will use the RFID embedded swipe cards without any fear of being monitored all the time by management.</td>
<td>50.0 25.0 25.0</td>
</tr>
<tr>
<td>3.4</td>
<td>I am convinced that the plant operators will use the system.</td>
<td>100.0</td>
</tr>
<tr>
<td>3.5</td>
<td>major system training will be required for the system setup</td>
<td>25.0 37.5 37.5</td>
</tr>
</tbody>
</table>
Table 8.8: Evaluation results on system practicality by plant operators and supervisors

<table>
<thead>
<tr>
<th>Ref No</th>
<th>System Practicality</th>
<th>Level of agreement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>In my opinion, SightSafety a practical solution.</td>
<td>42.9 14.3 42.9</td>
</tr>
<tr>
<td>3.2</td>
<td>I am comfortable with the idea of employee tagging.</td>
<td>28.6 28.6 42.9</td>
</tr>
<tr>
<td>3.3</td>
<td>The workers will use the RFID embedded swipe cards without any fear of being monitored all the time by management.</td>
<td>28.6 71.4</td>
</tr>
<tr>
<td>3.4</td>
<td>I am convinced that the plant operators will use the system.</td>
<td>14.3 42.9 42.9</td>
</tr>
<tr>
<td>3.5</td>
<td>major system training will be required for the system setup</td>
<td>71.4 28.6</td>
</tr>
</tbody>
</table>

8.4.3 System Usability

Participants were requested to answer questions on usability of the prototype application. The idea behind this investigation was to determine if the users considered the system easy to use. When asked if the prototype system is "a user friendly system", it was noteworthy that plant operators and supervisors regarded the system more user friendly (see Table 8.10) when compared with managers (see Table 8.9). This shows that operators who are commonly less technically literate did not find the system too complicated.

When the managers were inquired about the "information delivery on the screen and interface design of the system", half of them (50%) were uncertain about it (see Table 8.9). It may be inferred here that the managers were not sure how well an average user, generally having low technical literacy, would receive the system. On the contrary, the plant operators and supervisors were reasonably satisfied with the information displayed on the screens and with the system interface (see Table 8.10). The results show a positive feedback about the usability of the prototype system. However, further improvements can be made by addressing user suggestions (discussed in the forthcoming section of the chapter) in order to get a convincing response. Secondly, many user uncertainties can be removed if hands-on experience of the system is acquired over a certain period of time.
Table 8.9: Evaluation results on system usability by managers

<table>
<thead>
<tr>
<th>Ref No</th>
<th>System Usability</th>
<th>Level of agreement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>In my opinion,</strong></td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>SightSafety is a user friendly system.</td>
<td>12.5 50.0 37.5</td>
</tr>
<tr>
<td>4.2</td>
<td>the information is displayed effectively on the screen.</td>
<td>50.0 50.0</td>
</tr>
<tr>
<td>4.3</td>
<td>the system interface is easy enough for an average construction worker (assuming low technical literacy) to learn and use for his daily tasks.</td>
<td>75.0 25.0</td>
</tr>
</tbody>
</table>

Table 8.10: Evaluation results on system usability by plant operators and supervisors

<table>
<thead>
<tr>
<th>Ref No</th>
<th>System Usability</th>
<th>Level of agreement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>In my opinion,</strong></td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>SightSafety is a user friendly system.</td>
<td>14.3 14.3 42.9 28.6</td>
</tr>
<tr>
<td>4.2</td>
<td>the information is displayed effectively on the screen.</td>
<td>14.3 14.3 42.9 28.6</td>
</tr>
<tr>
<td>4.3</td>
<td>the system interface is easy enough for an average construction worker (assuming low technical literacy) to learn and use for his daily tasks.</td>
<td>28.6 57.1 14.3</td>
</tr>
</tbody>
</table>

8.4.4 Financial Feasibility

Cost barriers are identified as a major hurdle in any technology applications. As a result, managers were asked if the industry would be ready to invest in this application. A breakdown of system cost was provided to them (based on the cost of the IDENTEC solution hardware at the time of purchase). The response on a unit cost (a receiver mounted in a vehicle) was very mixed (see Table 8.11) with a low mean value of 2.75 (see Figure 8.1). However, 50% of the managers agreed on the price of personnel tags with a slightly higher mean value of 3 (see Figure 8.2). It is suggested here that the implementation of this system in the construction industry will only be possible if industry experts see advantages of the system out-weighing the cost. With the reducing cost of technology in general (Aziz, 2005) and RFID in particular (Brown, 2007), the system can be envisaged as a very feasible system.
Table 8.11: Evaluation results on financial feasibility by managers

<table>
<thead>
<tr>
<th>Ref No</th>
<th>Financial Feasibility</th>
<th>Level of agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I think the system is financially feasible when,</td>
<td>1</td>
</tr>
<tr>
<td>5.1</td>
<td>One unit (per vehicle) costs approximately £2000.</td>
<td>25.0</td>
</tr>
<tr>
<td>5.2</td>
<td>each personnel tag costing approximately £15 or less.</td>
<td>25.0</td>
</tr>
</tbody>
</table>

Figure 8.1: Histogram for manager response on unit cost

![Histogram for manager response on unit cost](image)

Mean = 2.75
Std. Dev. = 1.282
N = 8

Figure 8.2: Histogram for manager response on tag cost

![Histogram for manager response on tag cost](image)

Mean = 3
Std. Dev. = 1.309
N = 8
8.4.5 Difference of Opinion Between Managers and Plant Operators

In order to determine whether a significant difference in opinion exists between managers and operators, a combination of analytical techniques were carried out on the responses of the two groups. These included comparison of means and medians, mean distribution, parametric (t-test) and non-parametric (Wilcoxon) test.

Summary Statistics

Mean (the average of the data) and Median (the value in the centre of the ordered data) are the most popular measure of central tendency (Kvanli et al., 2000). A median generally provides a more reliable measure of central tendency in the presence of one or more outliers (very high or low values compared to other average values) (ibid). Table 8.12 presents a comparison of mean and median values for responses by managers and plant operators. The mean comparison highlights a trend that the means of the two groups are in close proximity. However, there are some obvious exceptions e.g. "Eff_monitoring" (will help in monitoring the workforce working in operational envelope of plant), "Pro_learn" (will enable managers to learn how to improve health and safety practices on a construction site), "Pro_training_aid" (will help managers to retrieve information that may subsequently be used as a training aid inexperienced workers), "Pra_comfortable" (I am comfortable with the idea of employee tagging) and "Usa_user_friendly" (SightSafety is a user friendly system), where difference in means can be observed.

Table 8.12: Mean for the responses of plant operators and managers.

<table>
<thead>
<tr>
<th>Ref No</th>
<th>Code</th>
<th>Mean (Manager)</th>
<th>Mean (Operator)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Eff_useful</td>
<td>3.75</td>
<td>3.71</td>
</tr>
<tr>
<td>1.2</td>
<td>Eff_reduced_accident</td>
<td>3.75</td>
<td>3.14</td>
</tr>
<tr>
<td>1.3</td>
<td>Eff_monitoring</td>
<td>4.25</td>
<td>3.29</td>
</tr>
<tr>
<td>1.4</td>
<td>Eff_relevance</td>
<td>3.88</td>
<td>3.43</td>
</tr>
<tr>
<td>2.1</td>
<td>Pro_learn</td>
<td>3.75</td>
<td>3.00</td>
</tr>
<tr>
<td>2.2</td>
<td>Pro_training_aid</td>
<td>4.25</td>
<td>3.14</td>
</tr>
<tr>
<td>3.1</td>
<td>Pra_practical</td>
<td>3.63</td>
<td>3.57</td>
</tr>
<tr>
<td>3.2</td>
<td>Pra_comfortable</td>
<td>3.38</td>
<td>2.14</td>
</tr>
<tr>
<td>3.3</td>
<td>Pra_fear</td>
<td>1.75</td>
<td>1.71</td>
</tr>
<tr>
<td>3.4</td>
<td>Pra_operators_use</td>
<td>3.00</td>
<td>3.14</td>
</tr>
<tr>
<td>3.5</td>
<td>Pra_setup_training</td>
<td>4.13</td>
<td>4.29</td>
</tr>
<tr>
<td>4.1</td>
<td>Usa_user_friendly</td>
<td>3.13</td>
<td>3.86</td>
</tr>
<tr>
<td>4.2</td>
<td>Usa_display</td>
<td>3.50</td>
<td>3.86</td>
</tr>
<tr>
<td>4.3</td>
<td>Usa_interface</td>
<td>3.25</td>
<td>3.86</td>
</tr>
</tbody>
</table>
In order to confirm a difference between the population means, a t-test is recommended (Rees, 1995). The statistical test has a general assumption of normality in the population data (i.e. the scores should be normally distributed in the population), which must be met prior to analysis (Coakes and Steed, 2003). The simplest method of testing for symmetric distribution (or normality) is to compare the mean and median, data is symmetric if these two values are equal or near equal (Kvanli et al., 2000). As the mean and median value drift apart, the data is 'skewed' (ibid). The degree of skewness present in the sample data can be measured using 'Pearsonian coefficient of skewness (Sk)'. Its value is given by:

$$ Sk = \frac{3(\bar{x} - Md)}{s} $$

where \( \bar{x} = \) Mean, \( s = \) Standard Deviation and \( Md = \) Median. The value of Sk ranges between -3 to 3. When Sk = 0 (i.e. Mean = Median), data is perfectly symmetric.

A histogram constructed from the sample can help determine whether the sample distribution is normal (Nourušis, 2004). A histogram indicates through a 'normal curve' if the data is symmetric, where the curve is characterised by a symmetric and smooth bell-shaped appearance (ibid). Consequently, histograms for all the variables in Table 8.12 were generated (see Appendix E) together with the values for standard deviation. This value, along with the mean and median values were used to determine the value of Sk. All these summary statistics are listed in Table 8.13 which shows that some level of skewness exists which may affect the reliability of the t-test. Therefore, in some instances the assumption of normality is questionable and the approval of t-test requires the application of 'alternative' non-parametric measures e.g. the Wilcoxon signed-rank test. Consequently, both parametric (t-test) and non-parametric (Wilcoxon signed-rank test) tests were conducted to determine if any significant difference of opinion exists between managers and plant operators. By using both tests the validity of test results could be cross referenced and confirmed.
Table 8.13: Evaluation of mean, median, standard deviation and coefficient of skewness for the responses of managers and operators.

<table>
<thead>
<tr>
<th>Ref No</th>
<th>Code</th>
<th>Manager</th>
<th></th>
<th></th>
<th>Operator</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Eff_useful</td>
<td>3.75</td>
<td>4.00</td>
<td>0.707</td>
<td>-1.061</td>
<td>3.71</td>
<td>4.00</td>
</tr>
<tr>
<td>1.2</td>
<td>Eff_reduced_accident</td>
<td>3.75</td>
<td>4.00</td>
<td>0.707</td>
<td>-1.061</td>
<td>3.14</td>
<td>3.00</td>
</tr>
<tr>
<td>1.3</td>
<td>Eff_monitoring</td>
<td>4.25</td>
<td>4.00</td>
<td>0.707</td>
<td>1.061</td>
<td>3.29</td>
<td>4.00</td>
</tr>
<tr>
<td>1.4</td>
<td>Eff_relevance</td>
<td>3.88</td>
<td>4.00</td>
<td>0.354</td>
<td>-1.059</td>
<td>3.43</td>
<td>4.00</td>
</tr>
<tr>
<td>2.1</td>
<td>Pro_learn</td>
<td>3.75</td>
<td>4.00</td>
<td>0.463</td>
<td>-1.620</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>2.2</td>
<td>Pro_training_aid</td>
<td>4.25</td>
<td>4.00</td>
<td>0.707</td>
<td>1.061</td>
<td>3.14</td>
<td>2.00</td>
</tr>
<tr>
<td>3.1</td>
<td>Pra_practical</td>
<td>3.63</td>
<td>4.00</td>
<td>0.518</td>
<td>-2.172</td>
<td>3.57</td>
<td>4.00</td>
</tr>
<tr>
<td>3.2</td>
<td>Pra_comfortable</td>
<td>3.38</td>
<td>3.50</td>
<td>1.598</td>
<td>-0.235</td>
<td>2.14</td>
<td>2.00</td>
</tr>
<tr>
<td>3.3</td>
<td>Pra_fear</td>
<td>1.75</td>
<td>1.50</td>
<td>0.886</td>
<td>0.847</td>
<td>1.71</td>
<td>2.00</td>
</tr>
<tr>
<td>3.4</td>
<td>Pra_operators_use</td>
<td>3.00</td>
<td>3.00</td>
<td>0.000</td>
<td>0.000</td>
<td>3.14</td>
<td>3.00</td>
</tr>
<tr>
<td>3.5</td>
<td>Pra_setup_training</td>
<td>4.13</td>
<td>4.00</td>
<td>0.835</td>
<td>0.449</td>
<td>4.29</td>
<td>4.00</td>
</tr>
<tr>
<td>4.1</td>
<td>Usa_user_friendly</td>
<td>3.13</td>
<td>3.00</td>
<td>0.991</td>
<td>0.378</td>
<td>3.86</td>
<td>4.00</td>
</tr>
<tr>
<td>4.2</td>
<td>Usa_display</td>
<td>3.50</td>
<td>3.50</td>
<td>0.535</td>
<td>0.000</td>
<td>3.86</td>
<td>4.00</td>
</tr>
<tr>
<td>4.3</td>
<td>Usa_interface</td>
<td>3.25</td>
<td>3.00</td>
<td>0.463</td>
<td>1.620</td>
<td>3.86</td>
<td>4.00</td>
</tr>
</tbody>
</table>

N.B. SD = Standard Deviation, Sk = Pearsonian coefficient of skewness
**Parametric Test - Independent Sample t-test**

The independent sample $t$ test assesses the differences between the means (or averages) of one dependent, test variable (numerical), when it is grouped by a second independent variable called the grouping variable (Kendrick, 2005). In case of the present data, the grouping variable was the 'position' variable which could hold the value '1' for *managers* and '2' for *plant operators*. All the other variables (listed in Table 8.13) are the dependent variables. The following hypothesis was tested in the t-test:

$H_0$: $\mu_{Manager} = \mu_{Operator}$ "The mean difference between opinion of managers and plant operators is zero, hence there is no difference of opinion". $H_1$: $\mu_{Manager} \neq \mu_{Operator}$ "The mean difference between opinion of managers and plant operators is not zero, hence there is significant difference of opinion between managers and plant operators". Where $\mu$ is mean of the sample.

The $t$ test was generated through SPSS at 95% confidence interval of the mean. The output is shown in Table 8.14. The table shows the results of Levene’s test, which is performed to see whether the variances are different enough to cause concern. According to Field (2000) if Levene’s test is significant at $p \leq 0.05$ then it is concluded that the variances are significantly different and the row in Table 8.14 with label *Equal variances not assumed* is read. However, if Levene’s test is non-significant at $p > 0.05$ then the difference between the variances is zero and the test statistics row labelled *Equal variances assumed* should be read. For example, in Table 8.14 for the first variable "Eff useful" (SightSafety is a useful application) $p = 0.182$ which is greater than 0.05, hence the row with *Equal variances assumed* was taken into account.

Having established that the assumptions of Levene’s test are met, SPSS also generates the values for the t-test automatically (see Table 8.14). The value of $t$ is measured against the value of $t$ that can be expected for a certain degree of freedom or df (Field, 2000). For example, $t$ for the first variable "Eff useful" is 0.075 for the degree of freedom of 13. The two tailed probability of 0.941 (i.e. greater than 0.05) shows that there was no significant difference between the means of these two sample and as a result $H_0$ is accepted. Thus, it may be concluded that there is no difference of opinion among managers and plant operators on system usefulness. Similar to the first variable, it is noticed that in all instances $p > 0.05$ (when Table 8.14 is examined for all other variables). Hence, it can be concluded that in all instances there is no significant difference of opinion in responses by managers and plant operators.
Table 8.14: Independent Samples t-Test.

<table>
<thead>
<tr>
<th></th>
<th>Levene’s Test for Equality of Variances</th>
<th>t-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
<td>t</td>
</tr>
<tr>
<td>Eff_useful</td>
<td>1.984</td>
<td>.182</td>
<td>.075</td>
</tr>
<tr>
<td></td>
<td>Equal variances assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eff_reduced_accident</td>
<td>.392</td>
<td>.542</td>
<td>1.203</td>
</tr>
<tr>
<td></td>
<td>Equal variances assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eff_monitoring</td>
<td>11.334</td>
<td>.005</td>
<td>1.544</td>
</tr>
<tr>
<td></td>
<td>Equal variances assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eff_relevance</td>
<td>13.229</td>
<td>.003</td>
<td>.814</td>
</tr>
<tr>
<td></td>
<td>Equal variances assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pro_learn</td>
<td>8.853</td>
<td>.011</td>
<td>1.422</td>
</tr>
<tr>
<td></td>
<td>Equal variances assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equal variances assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prac_practical</td>
<td>33.072</td>
<td>.000</td>
<td>.095</td>
</tr>
<tr>
<td></td>
<td>Equal variances assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Continues...
...Continued

<table>
<thead>
<tr>
<th></th>
<th>Equal variances assumed</th>
<th>Equal variances not assumed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pra_fear</td>
<td>4.492 .054 .095 13 .926 .036 .378 -.781 .852</td>
<td>.098 11.131 .924 .036 .364 -.763 .835</td>
</tr>
<tr>
<td>Pra_operators_use</td>
<td>8.509 .012 -.380 13 .710 -.143 .376 -.955 .669</td>
<td>-.354 6.000 .736 -.143 .404 -1.132 .846</td>
</tr>
<tr>
<td>Pra_setup_training</td>
<td>1.765 .207 -.446 13 .663 -.161 .360 -.939 .618</td>
<td>-.462 11.492 .653 -.161 .348 -.923 .601</td>
</tr>
<tr>
<td>Usa_display</td>
<td>1.392 .259 -.836 13 .418 -.357 .427 -1.280 .566</td>
<td>-.801 8.561 .445 -.357 .446 -1.374 .660</td>
</tr>
</tbody>
</table>
Nonparametric Test – Wilcoxon Signed-Rank Test

Nonparametric tests are most useful for small samples when there are serious divergences from the required assumptions (Nourusis, 2004). The Wilcoxon signed rank test is a nonparametric technique which is used when small samples from suspected non-normal populations are used (Kvanli et al., 2000).

For the given case of responses for managers and plant operators, the Wilcoxon signed-rank test is performed. Table 8.15 lists the test pairs and their corresponding z-score and two tailed p-value. For example, the test pair for response on "system usefulness" by managers and plant operators is based on negative ranks, has a z-score of -0.087 and that this value (of z-score) is significant at p = 0.931. Since the observed significance level is large (0.931 and greater than 0.05) the null hypothesis is accepted and it can be conclude that the mean rank of response by manager does not differ from that of plant of operator. Similarly, this is the case for all the other test variables. Hence it can be concluded here that the results of nonparametric test backs up the results of the parametric test and there are no significance difference of opinion in the responses by plant operators and managers.

Table 8.15: Wilcoxon signed-rank test

<table>
<thead>
<tr>
<th>Test Pairs</th>
<th>Z</th>
<th>Asymp. Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eff_useful_Oper - Eff_useful_Mana</td>
<td>-0.087*</td>
<td>.931</td>
</tr>
<tr>
<td>Eff_reduced_accident_Oper - Eff_reduced_accident_Mana</td>
<td>-0.962b</td>
<td>.336</td>
</tr>
<tr>
<td>Eff_monitoring_Oper - Eff_monitoring_Mana</td>
<td>-1.084b</td>
<td>.279</td>
</tr>
<tr>
<td>Eff_relevance_Oper - Eff_relevance_Mana</td>
<td>-0.680b</td>
<td>.496</td>
</tr>
<tr>
<td>Pro_learn_Oper - Pro_learn_Mana</td>
<td>-1.089b</td>
<td>.276</td>
</tr>
<tr>
<td>Pro_training_aid_Oper - Pro_training_aid_Mana</td>
<td>-1.382b</td>
<td>.167</td>
</tr>
<tr>
<td>Pra_practical_Oper - Pra_practical_Mana</td>
<td>-0.176b</td>
<td>.860</td>
</tr>
<tr>
<td>Pra_comfortable_Oper - Pra_comfortable_Mana</td>
<td>-1.160b</td>
<td>.246</td>
</tr>
<tr>
<td>Pra_fear_Oper - Pra_fear_Mana</td>
<td>-0.447a</td>
<td>.655</td>
</tr>
<tr>
<td>Pra_operators_use_Oper - Pra_operators_use_Mana</td>
<td>-0.378a</td>
<td>.705</td>
</tr>
<tr>
<td>Pra_setup_training_Oper - Pra_setup_training_Mana</td>
<td>-0.378a</td>
<td>.705</td>
</tr>
<tr>
<td>Usa_user_friendly_Oper - Usa_user_friendly_Mana</td>
<td>-1.200a</td>
<td>.230</td>
</tr>
<tr>
<td>Usa_display_Oper - Usa_display_Mana</td>
<td>-0.828a</td>
<td>.408</td>
</tr>
<tr>
<td>Usa_interface_Oper - Usa_interface_Mana</td>
<td>-1.414a</td>
<td>.157</td>
</tr>
</tbody>
</table>

* Based on negative ranks.
  b Based on positive ranks.
8.4.6 Evaluator’s Feedback on System Benefits, Barriers and Improvements

The respondents who took part in the evaluation process identified many benefits of the system implementation (see Table 8.16) which included improved site safety, accident investigation, operator awareness etc. However, practitioners also highlighted certain ‘hard’ (technical) and ‘soft’ (social and cultural) issues (see Table 8.17) and barriers (see Table 8.18) that may influence system implementation. Consequently, they suggested several additions to the prototype system and the discussed scenarios (see Table 8.19); practitioners perceived these additions to be useful for successful implementation of the system in future. These enhancements included mobility, changes to display and tag information etc.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Evaluator’s feedback on benefits</th>
</tr>
</thead>
</table>
| Improved safety           | • “Improved safety around machinery.”  
                           | • “Safer working environment.”  
                           | • “The system is very useful for big construction projects where there are a number of contractors and a huge workforce. It is not easy to manage and communicate with all these people. Such a system would help to find out who is doing what and whether he should be there or not.” |
| Improved accident investigation | • “Accurate accident and near miss accident reporting.”  
                                | • “…accident information can be used as a training aid for inexperienced staff.”  
| Operator awareness        | • “Making the operator more aware of what is around him.”  
                           | • “Provides an extra ‘set of eyes’ for the machine operator.”  
                           | • “Alerts plant driver of all operatives within the zone radius.”  
                           | • “… its normally the backside of 360 [excavator] where people get injured... it will definitely help.” |
| Proactive                 | • “Proactive way of reducing accidents.”  
                           | • “… may point to relocation of operatives to another area of work if there is a repeated movement within a zone.”  
                           | • “… assess and act on near miss occurrences.”  
                           | • “Self help to operatives who work in an inherently dangerous environment.” |
| Identification            | • “Identifies personnel and their movement within the plant zone radius.”  
| User friendly             | • “Simple to use.”  

Table 8.16: Benefits of the suggested system
<table>
<thead>
<tr>
<th>Issues</th>
<th>Evaluator’s feedback on ‘soft’ issues</th>
</tr>
</thead>
</table>
| The ‘Big Brother’ syndrome | “… its very important that it is not seen as a monitoring tool.”  
| &nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&n
Table 8.18: Barriers to system implementation

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Evaluator’s feedback on barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>&quot;Cost of the system can be an issue.&quot;</td>
</tr>
<tr>
<td></td>
<td>&quot;Initial setup and training cost can be an issue.&quot;</td>
</tr>
<tr>
<td>The 'Big Brother' syndrome</td>
<td>&quot;Monitoring of operatives could be an issue initially.&quot;</td>
</tr>
<tr>
<td></td>
<td>&quot;Full-time monitoring of operatives may be an issue with the unions... infringement of civil liberties.&quot;</td>
</tr>
<tr>
<td></td>
<td>&quot;The feeling of being monitored will not work well within the people working on site... any change is not readily accepted by staff whether working in office or site.&quot;</td>
</tr>
<tr>
<td>Administration</td>
<td>&quot;Extra supervision on site would be needed... like for PPE at the moment.&quot;</td>
</tr>
<tr>
<td></td>
<td>&quot;Workers may forget their tags and the system may not be used effectively.&quot;</td>
</tr>
<tr>
<td>Information overload</td>
<td>&quot;Too much data is collected.&quot;</td>
</tr>
<tr>
<td>Fragmented nature of a</td>
<td>&quot;A construction project is a complex business... there are architects, contractors, subcontractors, suppliers etc... I see a collaboration problem for this system. It has to be decided who is going to pay for the system and who is going to use the information.”</td>
</tr>
<tr>
<td>construction project</td>
<td></td>
</tr>
</tbody>
</table>
Table 8.19: Suggested enhancements in the system

<table>
<thead>
<tr>
<th>Evaluator’s feedback on improvements</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Minimal functionality</strong></td>
<td>This option was discussed with interviewees during the initial study of the health and safety process. Many managers were of the opinion that this initiative might not work because workers have a tendency to wear each others visibility vests or hard hats.</td>
</tr>
<tr>
<td>“Keep it a very simple and basic system and it could prove to be a very beneficial system for the industry.”</td>
<td></td>
</tr>
<tr>
<td>“Step at a time... as a safety tool needs to be sold at a level of ground workers/plant operators... there is need to make them realise that it will improve their safety... it is very important that it is taken a step at a time.”</td>
<td></td>
</tr>
<tr>
<td><strong>Tags</strong></td>
<td>Any positioning or tracking system would work on a tagging technology whether GPS, WiFi or RFID tags. In all cases the tag has to be carried. Addressing human sensing without a tag is beyond the scope of this research.</td>
</tr>
<tr>
<td>“Tags should be stuck to hard hats or high visibility vests.”</td>
<td></td>
</tr>
<tr>
<td>“…it will be useful that system would pick up the tags built into worker’s clothing.”</td>
<td></td>
</tr>
<tr>
<td>“The system only works on tags, if it could detect presence as well as tags, it would ensure anyone near the machine is covered.”</td>
<td></td>
</tr>
<tr>
<td>“Information stored on the tag could contain greater detail specially training records, level of training and experience.”</td>
<td>This is a useful suggestion, training levels are already stored in the system. Details on experience should be part of any future and commercial deployment of the system.</td>
</tr>
<tr>
<td><strong>Zone size and entry options</strong></td>
<td></td>
</tr>
<tr>
<td>“Plant driver to input banksman or day key operatives.”</td>
<td>During the requirement analysis stage of the system, it was suggested by the industry practitioners that any display for plant operators should be as simple as possible with minimal data entry. This was due to their commonly low technical literacy. However, the recommendations here are useful and need further investigation for identification of the exact data fields. In addition, it is suggested that site/plant supervisor</td>
</tr>
</tbody>
</table>
...Continued.

| Display | "...display should show banksmen in one colour and all other operatives in another colour. It should cause alarm/flashing lights if other operatives enter the zone."
|         | "A radar system like display to make it simple for the machine operator."
|         | "Tagged movements/locations need to be displayed instantaneously on the plant display."
|         | "...making the display simple enough for the machine operator to operate it." |
| Alarm system | "... adding an alarm system for the operatives will be a better idea."
|         | "Blinkers may distract you, beep will work... also if a system is too noisy we may not use it because its annoying at times."
|         | "...there is no need to put a monitor if bleeper systems are used instead... if there is a screen for operators it would take the attention/awareness away from their job." |
| Detachable device | "...the system should not be fixed on a machine and can be moved to others to reduce the cost." |
| Extension to hazard areas | "The system can be further extended to check for how long the operator is exposed to a certain environment e.g. noisy and dusty zones, chemicals etc... In some areas the operative has to be there for some time only due to health and safety reasons." |

should be entering 'overriding the zone entry rights' and radius option for safety and practicality reasons.

Considering the low technical literacy of a typical plant operator, a radar system like display is a very useful suggestion. However, the drawback of RFID system is that it does not provide with positioning information. If the system is integrated with a positioning system it will make the display and alert mechanism more effective as suggested by the evaluators.

Alarm system is already part of the suggested scenarios.

This is a very useful suggestion as it would make the system more financially feasible. Further investigation has been carried out which is discussed in section 8.4.7.

This is another important suggestion for future development of the system.
8.4.7 Further Investigation Based on the Evaluation

The evaluation process highlighted some areas that were considered significant for the success of the ICT application. As a result some further research was carried out on the following issues:

‘The Big Brother Syndrome’
A persistent theme identified in the evaluation process was concern among workers who feared that they may be constantly monitored through this system by management. One obvious reason for this sceptical view was that they were not using the swipe card system on their sites. A manager (subcontractor) on one of the evaluation sites suggested,

"the best way to move ahead with this system is to involve the big players of the industry first... they have the resources and the will. Many of them already have got the swipe card system in place."

Based upon this recommendation, one of the interviewees (a health and safety manager of case C, see Table 2.8) was contacted again for additional feedback on the issue. His views on the subject matter were:

"I don't particularly see tagging as a problem, we do something similar here... not to this degree because our cards are zone cards. When somebody comes to the site or office we know that who has come in... during the course of the day people will use swipe machines so we can know where they have been and the time they have spent there. We have about 500 people working here, they all have to go through this security check and they must swipe their cards to get an access to the site. However, we use this information only for emergencies e.g. if there is a fire alarm that went off we actually calculate how long it took to evacuate the place, when they came back again and who came back etc. So we already have a system in place. I do not see a problem with the tagging approach as long as it explains what it is for and how it can be effective."
The health and safety manager, however, suggested a few measures in order to get the workers to accept the system, which are:

- making the workforce believe that using the system will improve their health, safety and welfare on the site;
- convincing workers that the information is not used for monitoring purposes; and
- providing them with the right training to use the system so that they can overcome the fear of using this application.

Therefore, it is proposed that initially, big construction companies who are technically ‘literate’ and already have a swipe card system in place, should implement the RFID application. Moreover, they should be willing to invest in any further expansion of the system into a fully developed product thus providing financial support that will aid future modifications.

**Fixed vs. Detachable System**

Two evaluators in their feedback suggested a detachable device (RFID reader along with a display unit) to be mounted inside the vehicle cabin. This proposal was further investigated because it suggested installing the reader device only with the vehicles that are being operated during the construction activity instead of the entire plant fleet, thereby reducing the overall system cost. Secondly, it would make the collaboration process among contractor and subcontractors more practical. The principle contractor is typically responsible for the health and safety process in a construction project. The system can be deployed by the principal contractor who would also own the information generated from the system.

However, prior to making any decision in favour of a detachable system, the future for fitting such a system on plant and equipment was discussed with the manufacturers of these machines. A total of 5 experts from two leading plant manufacturers were interviewed (the list is provided in Table 8.20).

All the interviewees were asked about their views on fixing such a system in the cabin of machines. All respondents suggested that they will only consider such an option if there is a demand from clients for such a product. One product manufacturer pointed out:
Table 8.20: List of manufacturers interviewed

<table>
<thead>
<tr>
<th>Org Code</th>
<th>S/No</th>
<th>Job Title</th>
<th>Organisation Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>Chief Economist</td>
<td>Plant Manufacturer (3rd largest in the world)</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>Product Support Manager</td>
<td>Plant Manufacturer (3rd largest in the world)</td>
</tr>
<tr>
<td>A</td>
<td>3</td>
<td>Principal Development Engineer</td>
<td>Plant Manufacturer (3rd largest in the world)</td>
</tr>
<tr>
<td>B</td>
<td>4</td>
<td>Product Marketing</td>
<td>Plant Manufacturer (largest in the world)</td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td>Engineering Platform Team Leader</td>
<td>Plant Manufacturer (largest in the world)</td>
</tr>
</tbody>
</table>

"...we are very customer driven. So far we have only once been enquired about such a system and that too very recently, our customers normally do not ask for these sort of bolt-on. However, if we add such devices in our products they will become more expensive, which the customers may not like. We don't see a value for money for these products at the moment."

The Chief Economist of one of the manufacturers pointed out a significant barrier to installation of such safety devices in machines by manufacturers for the UK and EU market. According to the expert:

"...major plant manufacturers are only getting half of the market share. According to my estimate 20 – 50% of the plant in the UK are 'grey' plants, mostly second hand equipment which is coming from other parts of the world. All the dealers have to do is to pay £5 to get the certification. Therefore, I see that ultimately 'bad' machines will drive out the 'good' machines. Secondly, in practice only the UK will have certain laws due to HSE but rest of the EU have their own interpretations of their Government Law. Therefore, at the moment we do not have same health and safety legislation or standards across Europe. We provide and manufacture plant for entire international and European market, not only for the UK. We would welcome any legislations and requirements that are standard and all parties agree, only then we can accept and take such a system on board."

The barriers pointed out by the interviewees indicated a detachable device as a potential solution. After a secondary research, RAM Mount Company (RAM, 2007)
was selected that deals with a product line (based on a patented design) consisting of vehicle mounts for electronic equipment (such as laptops, tablet PC, navigation devices etc.). The selection was on the basis of incorporation of non-slip as well as shock and vibration dampening features of the vehicle mount.

The mounting configuration that was used for the prototype is shown in Figure 8.3. This was considering the tubular frame (or caged units) generally available inside the cabin of vehicles. Depending on size of the rail, the configuration used could easily be adjusted. However, a variety of mounting configurations are available to suit various equipment types. Thus, it is proposed that for any future developments of the prototype system, a careful ergonomics study on where and how to mount the SightSafety system inside the plant cabin is required.

Figure 8.3: Mounting configuration used for prototype system (approximate cost £45)
8.5 CHAPTER SUMMARY

This chapter has presented the results of the evaluation process carried to collect user feedback on the prototype system. In general, there was positive feedback from the evaluators regarding the prototype’s relevance to industry needs. Participants took a keen interest in the presented system demonstration and a few illustrative comments were:

- “A study well worth undertaking, which could be of great benefit to the industry.”
- “Health and safety can be improved if this system is introduced with minor amendments throughout the UK.”

For the evaluation process, respondents were divided into two groups namely, managers and plant operators. Evaluators’ feedback on system effectiveness, practicality and usability, proactivity and financial feasibility was collected. During a simple percentage analysis of the collected data, a difference in opinion was observed among the two respondent groups. This was followed by parametric and nonparametric statistical analysis in order to determine if the difference in opinion is significantly different. The analysis showed that for all responses there is no significant difference of opinion between managers and plant operators. The evaluators also identified various benefits that the system can offer to the industry. Moreover, they pointed out various barriers (‘hard’ and ‘soft’ issues) that can influence the system implementation. Finally, the evaluators suggested several improvements for successful future implementation of the ICT application.

A few important concerns that were highlighted during the feedback and were further investigated included: (i) a ‘hard’ issue of having a detachable device in the vehicle cabin instead of a fixed one and (ii) a ‘soft’ issue related to the fear among workers of being monitored by the device. Subsequent interviews were carried out to understand the way forward. It was concluded that detachable units were more appropriate for the situation. Secondly, any future development of the system should be initially implemented with major companies of the construction industry who have a culture which is more receptive to technology.
CHAPTER 9

RESEARCH CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

9.0 INTRODUCTION

Findings emanating from the Health and Safety Executive (HSE) statistics have led to an acknowledgement that accidents involving plant/pedestrian collisions have remained relatively high year on year. This is in spite of many initiatives taken to improve health and safety on construction sites by the HSE. An examination of health and safety processes for plant and equipment on construction sites has highlighted some of the root causes of accidents. To work towards resolving these problems, managers on site must be equipped with fully integrated ICT systems that allow them to manage the risk more efficiently and effectively. Accordingly, a prototype system, entitled SightSafety, was developed in the research undertaken which required RFID tags to be carried by personnel working in machines' operational envelope. The system 'reads' and records the presence of workers in the operational envelope as part of the advanced plant MIS system to inform plant operators and managers of imminent danger. Whilst not a panacea to safety problems, such a system will significantly advance the management of risk imposed whilst operating mobile plant and equipment on construction sites.

This chapter presents a summary of the research conducted and demonstrates how the aim and objectives were achieved. Furthermore, a synopsis of main conclusions is presented. In addition, the main limitations of the research are presented together with recommendations for future study.
9.1 SUMMARY OF RESEARCH

The aim of this research was to investigate and capture the current health and safety process associated with construction plant management and to develop emerging ICT application for the process improvement. This aim was developed to provide answers to the following research questions:

1) What are the most popular plant items and what are the typical operations of these? What are the safety concerns associated with these aforementioned machines on a construction site?
2) What existing ICT solutions are available to improve plant performance, safety and productivity?
3) What are the developments and trends in the field of emerging ICT and what are the applications of these in the construction and other industries?
4) What are the current health and safety practices used for plant and equipment on a construction site and what are the limitations of the process?
5) What are the information needs of plant managers and operatives and how can these be addressed?
6) What should be the features of an ICT application for effective plant and equipment management in the construction industry?
7) How can the implementation of ICT (incorporation of information system with RFIDs and mobile computing in particular) improve health and safety practices for plant operators, safety managers and workers working within close proximity of machines?
8) What are the barriers to the effective implementation of ICT within the plant and equipment sector?

Subsequently, the following specific objectives were identified to achieve the aim:

1) To identify popular plant types; to develop an understanding of standard operations and to determine the existing use of technology to make these machines more productive and effective tools on construction sites;
2) To determine advancements and trends in the use of ICT to identify the application of these technologies for the construction industry;
3) To document and understand the existing ‘standard practice’ health and safety processes adopted for plant and equipment on a construction site;

4) To develop implementation scenarios for improved onsite health and safety process for mobile machinery with respect to plant operators, safety managers and pedestrians operating in vicinity of vehicles; and

5) To design, develop and evaluate a prototype application that demonstrates the use of ICT (IS incorporating RFIDs in particular) to augment current health and safety process provisions within the construction industry.

A summary of the specific tasks carried out in achieving the research activities have been discussed below.

**Objective 1:** To identify popular plant types; to develop an understanding of standard operations and to determine the existing use of technology to make these machines more productive and effective tools on construction sites.

This objective was achieved through the review of past literature from both academic and government sources. The generic construction plant and equipment items were grouped on the basis of typical operations i.e. earthmoving and lifting. The most commonly used attachments that are chosen to maximise machine performance were also indicated.

During the appraisal of plant and equipment, several areas of concern for plant managers were identified. In particular, this included health and safety issues covering pedestrian protection, collision detection, information management etc. A detailed analysis of plant related accidents incurred by the construction workforce was carried out for the period 1994-2004. It was highlighted that the extensive use of plant and equipment has resulted in a consistent trend of workplace transport accidents on construction sites. An appraisal of reasons for accidents on construction sites and relevant safety regulations was also carried out. Finally, the review highlighted the efforts by both academics and plant manufacturers to apply hybrid ICT solutions for improved machine performance and safety. It was noted that a number of applications ranging from operation specific control systems to tracking systems are available for the benefit of vehicle automation, safety management and performance measurement.
Objective 2: To determine advancements and trends in the use of ICT and identify the application of these technologies for the construction industry.

In order to investigate how plant managers and operators can exploit ICT for the benefit of better plant management and safety on construction sites, a review was carried out to explore the advancements and trends in the use of emerging ICT. The reviewed applications included long-established technologies such as MIS and more recent developments such as wireless communication, mobile computing, positioning and electronic tagging technologies.

The appraisal of these technologies showed that there is a need to develop a comprehensive management system that integrates these recent technologies for the benefit of construction industry in general and for plant and equipment management in particular. The review also underlined the significant advancements in RFID technology and how various industries (e.g. retail, manufacturing, transportation, health etc.) have benefited from it. Finally, it was suggested the potential of RFID applications for improved plant management on a construction site should be explored further.

Objective 3: To document and understand the existing 'standard practice' health and safety processes adopted for plant and equipment on a construction site.

This objective was achieved through multiple case studies in which five construction projects across the UK were visited. Semi-structured interviews with practitioners and document analysis on each project were carried out to report upon standard safety practices for plant and equipment. Data Flow Diagrams (DFD) were used as a modelling tool to record the observed safety practices for example: plant specific health and safety process (addressing plant acceptance test, operator training, risk assessment, machine maintenance etc.); accident investigation process; training and safety awareness practices etc. Components of these recorded practices also assisted in establishing appropriate industry guidelines for effective use of ICT for plant and equipment management. In addition, the semi-structured interviews were also used to identify plant related health and safety issues on construction projects particularly,
causal factors for site incidents and practitioner concerns associated with plant operations.

The research highlighted various shortcomings in current safety practices adopted by practitioners. Consequently, these limitations helped in understanding the requirements for any potential process improvements (by using technology in particular). Findings emerging from the investigation of current safety processes for on-site plant and equipment led to developing guidelines for the effective application of technologies for process improvement. The guidelines for the industry included: features for an effective ICT application; an architecture and conceptual model of the application which integrates various components of plant management into one integral hybrid system; and an Entity Relationship Diagram (ERD) which identified the attributes for the (database) schema of such application.

Objective 4: To develop implementation scenarios for improved on-site health and safety process for mobile machinery with respect to plant operators, safety managers and pedestrians operating in vicinity of vehicles.

This objective was achieved using the scenario-planning method. Scenarios are ‘descriptions of possible or probable futures’. Prior to any system implementation, a visual description of technology implementation scenarios in real construction situations were discussed with industry experts. The validated set of scenarios illustrated the envisaged ICT application, entitled SightSafety, from the perspectives of four different user roles on a typical construction site. These roles were:

i. plant operator;
ii. construction worker (operating in the operational envelope of a machine);
iii. plant supervisor (in charge of all mobile plant and equipment related health and safety); and
iv. health and safety manager.

The generated scenarios discussed the interactions of these roles with the SightSafety system. The scenarios were then used as an outline to design and develop the SightSafety prototype system.
Objective 5: To design, develop and evaluate a prototype application that demonstrates the use of ICT (IS incorporating RFIDs in particular) to augment current health and safety process provisions within the construction industry.

The objective was achieved by designing and developing a prototype system which integrated emerging technologies, RFID in particular, with MIS management tools. This resulted in the production of a technology platform which provided a more comprehensive plant health and safety management solution than those currently available in the UK construction industry.

For the prototype development, the hardware and software development environments were selected and tested. Subsequently, activity diagrams were developed to describe the system design in terms of business logic flow and events that cause decisions/actions to be undertaken in the software code. The implemented activities included: the communication (read/write) between RFID reader and tags; detection of unauthorised workers in machine's operational envelope; report for plant supervisors (responsible for health and safety); and electronic accident reporting and investigation for health and safety managers.

Finally, the prototype system was evaluated by jointly reviewing the system with end-users. Site management (responsible for plant related health and safety) and plant operators/drivers were identified as the relevant users of the system. A demonstration of the application was given to the evaluators in the context of developed scenarios. In order to get a more structured evaluators' feedback, a questionnaire addressing fundamental issues (for example, system effectiveness, practicality, usability etc.) was requested to be filled out. The responses were quantitatively analysed using a variety of techniques ranging from simple percentage comparison to more complex parametric and nonparametric tests. In addition, participants were requested to answer some open ended questions which generated a qualitative response on: system improvement, potential system benefits; and barriers (including technical and cultural difficulties) to the application.
9.2 KEY RESEARCH FINDINGS AND CONCLUSIONS

The following conclusions can be drawn from this research:

A positive correlation between plant usage and accidents on construction sites
The demand and investment in the construction plant and equipment sector has increased exponentially over the years in the UK. However, a positive correlation exists between plant and equipment usage on construction sites and accidents involving plant/pedestrian collisions. Two accident categories (out of 20) recorded by the HSE can be directly linked with plant and equipment operations; these are 'contact with moving machinery or material being machined' and 'struck by moving vehicle'. A detailed analysis of plant related accidents incurred by the construction workforce (i.e. employees and self-employed workers) highlighted that these accidents have remained relatively consistent year on year, despite substantial efforts of industry and academia to reduce them. For employees, an average of 3% of all the injuries incurred were caused due to contact with moving machinery and 2% were due to being struck by a moving vehicle. For self-employed persons, the average percentage of all injuries attributable to the two categories was 4% and 2% respectively.

Consequently, it can be concluded that accidents caused due to the involvement of plant and equipment on a construction site are among the main sources of fatalities and injuries in the UK construction industry. This accident trend prevails in spite of government regulations and HSE requirements. As a result, there is a need to review the plant related safety practices on the construction sites.

Safety concerns related to plant operations
A re-examination of the existing safety systems and processes is required as the analysis of practitioners' safety concerns highlighted various shortcomings in the adopted practices. Some of the underlined shortcomings were: inadequate operative training; insufficient machine maintenance; ineffective pedestrian free operational envelope; and inadequate process management etc.
Moreover, research highlighted machine configuration as another safety concern where a driver's vision is impaired in certain type of machines thereby, resulting in inadequate all round visibility. For instance, in the case of excavators, the operator’s vision is impaired on the right-hand side by the mast of the machine and at the back due to machine’s counterweight.

Additionally, the supply chain and operatives within it, influence quality standards in the downstream (contractor/subcontractor) supply chain. Low quality subcontractors and reduced process conformity also effects the health and safety processes on a construction site.

Existing health and safety process employed for plant related operations

The case studies conducted as part of this research were used to develop process models by employing DFD as a modelling tool. These DFD helped to: understand the procedures and processes employed in construction projects for health and safety of plant related operations; identify the opportunities for process improvements by employing ICT as an enabler; and identify information needs of plant related workforce such as managers and plant operators. However, the same procedures and processes documented in this research can be adopted time and again by other developing construction industries around the world where processes are less developed compared to the UK construction industry. Furthermore, there are growing concerns in these industries over construction activities and construction worker safety.

Need for process improvement

Additional measures, controls systems and procedures are required to reduce plant related accident rates to acceptable levels. This provides a business case for the use of ICT as an enabler for improvement in the process of health and safety for plant related activities on a construction site. Emerging ICT systems should not only be explored for superior plant management on construction sites but also for improved operator awareness and site safety. RFID is one such technology which has mostly been utilised so far for material tracking and automatic data collection purpose. There is a need to investigate the potential of RFID application (which offers non-contact reading and has proved highly effective in hostile environments such as construction
sites) for plant management, health and safety on construction sites and accident management. In particular, the technology, along with mobile computing and real time tracking systems, when integrated with MIS is presumed to lead to a far-reaching technology platform where information needs of plant operators and safety managers are targeted and addressed.

Need for information integration

In order to develop a sustainable technology platform that lends itself to improved plant management and safety, practitioners indicated that certain features should be incorporated for an effective ICT application. These features include: enhanced all-round awareness for plant operators; detection of operatives entering the machine’s operational envelope; availability of employee training levels to site managers on all instances; alerts for management on plant maintenance schedules; accident information management; and accident trend generation. As a result, there is a need to develop a more comprehensive management system for construction plant. Practitioners identified that such a system should share information among different software applications (such as project plans, personnel and training, audit and inspections, plant management and accident management) rather than each application maintaining its own subset of information.

*Sightsafety*: Application of ICT to address safety needs of plant operators and managers

The prototype application (i.e. *Sightsafety*), which incorporated RFID technology and mobile computing with plant MIS, demonstrated how the technology could be employed to deliver a range of safety information for health and safety management. This included: monitoring of personnel working within machine’s operational envelope; report generation for plant supervisors on authorised presence of workers in the operational envelope; electronic reporting of incidents on site to health and safety department; and access to incident details for health and safety managers.

The feedback gathered during the scenario validation and the evaluation process demonstrated that practitioners were very interested in the application of *Sightsafety*. Importantly, practitioners considered that *Sightsafety* offers the industry a proactive
system with improved safety, operator awareness and accident investigation capabilities.

**Barriers to the ICT application for plant management and safety**

Prototype evaluation highlighted many barriers associated with ICT application. These barriers to system implementation can be categorised as financial (e.g. application cost), cultural (e.g. worker monitoring, reluctance to change, lower technical literacy etc.), procedural (e.g. system ownership, collaboration issues etc.) and technical (e.g. system integration with existing infrastructure, hardware constraints etc.) barriers.

However, it can be concluded that with: the decreasing costs and fast pace advancements of ICT related technology; successful adoption of technology in other industries; and readiness of construction management to take up technology for improved and speedy processes, it has become possible to address many of the technology related barriers of ICT deployment in the construction industry. There is a need for the construction companies to engage in further case studies employing ICT in order to identify the overall cost of these applications in a typical construction project and to estimate the return on investment.

Moreover, in order to achieve successful implementation of ICT it is important to: involve users early during system analysis and design process; understand user needs and their attitudes towards technology application; provide them with sufficient training to overcome the fear of technology use and cultural impediments, particularly in case of less technology literate workers; and select the most suitable and userfriendly interface.

**Benefits of the uptake of ICT application for process improvement**

In spite of the barriers to the uptake of ICT, *SightSafety* evaluation showed that there was generally a good level of interest for its future use for process improvement. The evaluators identified many benefits of system implementation. These benefits included: improved safety around plant and equipment; improved accident, including near miss incidents, investigation; improved operator awareness of the presence of
untrained workers; availability of data (of workers in the operational envelope of machines) to be searched for future accident investigations and knowledge management applications; and in general a proactive approach to reduce accidents on site.

The conclusions drawn here relate back to the initial research proposition: *the employment of emerging ICT by the health and safety managers can improve the current health and safety process associated with construction plant management.* The benefits highlight that process improvement can be achieved by: capturing safety related information only at the source; automation of activities related to the health and safety process and getting rid of non-value adding activities; paper free work environment where data (workers in the operational envelope of machines, accident records, investigation outcomes etc.) is readily available.

### 9.3 LIMITATIONS OF THIS RESEARCH

The research undertaken has certain limitations and these are briefly outlined below:

- An issue faced during the data collection process was related to the fact that health and safety issues are regarded as strictly confidential and in some instances controversial by many companies. Because of this, it was noted that interviewees often talked about their experiences in general or those of other construction projects rather than being explicit about any health and safety problems/incidents that had occurred on their current site; this despite assurances of total and complete anonymity for all interviewees.
- The research was limited to the perspective of the principal contractor when studying the current process for health and safety on a construction site related to plant and equipment. Therefore, the viewpoints of subcontractors and other contractors will need to be considered in future work.
- Typically there is a reluctance among construction workers to give time to the design and development of a technology application for which they have difficulty envisioning any benefits in the early stage of design. This was particularly evident in case of plant operators who have strict production
targets to meet and any time spared for an interview meant machine downtime and idle banksmen.

- Safety regulations place impediments in the way of the researcher gaining access to building sites to test the prototype on workers. Induction training was given to the researcher on all sites visited however, in many instances it was against the companies safety strategy to test the prototype system on any machine operating on a site. This gives rise to the need for industry case-studies of SightSafety deployments on real life projects. However, it is recognised that any real-life implementation of such concepts may face a long list of technical and organisational challenges.

- The prototype development was essentially a proof-of-concept application. It was developed to demonstrate the potential of the technology application rather than to cover the complete domain, as would normally be the case with commercial software applications. As a result, the prototype application has looked at the SightSafety dimension of the envisaged plant MIS. Therefore, there is a need to explore other aspects of plant management in future study e.g. incorporation of audit and inspections, maintenance, plant history and inventory etc.

- The respondents in the evaluation process were highly representative of the sample in terms of their role/position (i.e. managers and plant operators) and size of company. However, the number of respondents to the questionnaire survey for prototype evaluation was relatively small (i.e. 15 respondents in all), which calls for cautious interpretation of the statistical analysis.

- The management considered plant operators as relatively less technology literate. As a result, during the primary research and evaluation process the plant operators were not randomly selected rather they were identified by managers whom they considered could show a level of understanding for the technology application. Therefore, results may not be wholly representative of the target population.
9.4 RECOMMENDATIONS AND FUTURE WORK

Based on research limitations and barriers identified from the system evaluation, some of the key pertinent issues that require further research are recommended below.

Need to investigate a mechanism for defining a machine's operational envelope depending on machine type

To avoid vehicle/pedestrian collisions, a mechanism to calculate and define the safe operational envelope around the machine by using machine's configuration and mode of operation is required. For example, in case of an excavator, the machine's maximum reach capacity (including boom, dipper and attachment) must be calculated (JCB 2005). Another important factor that requires consideration is the make, model and type of excavator being used. As an illustrative example, Appendix F lists some typical models of Caterpillar excavators (Caterpillar Inc. 2003) and states the parameters of the maximum digging envelope which should be considered when defining the size of the operational envelope. These parameters include maximum height a bucket can reach and maximum digging depth of the machine arm (boom stick and bucket). In addition, various booms and other auxiliary attachments should also be taken into account, for instance: a reach boom maximises digging envelopes with various stick combinations; a mass boom maximises productivity due to higher digging force; and Variable Angle (VA) boom enhances visibility on the right side of the machine and maximises flexibility when lifting heavy loads or working in tight quarters (Caterpillar Inc. 2005). Using a combination of these factors, the safe operational envelope around a machine should be determined. Ideally this data should be entered into an ICT system (database) to calculate the radius of the operational envelop and in order for it to be useful.

SightSafety can be further extended to incorporate such an 'envelope definition mechanism'. For this expansion of SightSafety an interface is suggested which is provided in Figure 9.1. In such a case, some parameters to be entered by the operator into SightSafety are suggested as follows:
1. Operator would enter machine ID (used on the construction project) and *SightSafety* would retrieve machine type and maximum reach for this model from the database. See Figure 9.1 where the operator has entered machine ID as ‘MHE307’ and the system has retrieved the type as ‘Hydraulic Excavator 360’ and maximum reach as ‘10 metres’ from the database (assuming that data for all the models are entered into the database).

2. The operator should also be able to select a mode of operation that would select a predetermined (suitable for the particular operation) ‘Machine Reach’.

3. The operator should next specify if the machine (during its operation) will be static or mobile. Since for a mobile machine there may be less time for the pedestrian to react therefore, it is proposed to carry out further research on determining the radius of the envelope e.g. for every ‘x’ m/h the radius is increased by 1m.

Figure 9.1: Suggested screen to define radius of machine's operational envelope

![Figure 9.1: Suggested screen to define radius of machine's operational envelope](image)

**Need to address the ergonomics issues**

During the prototype evaluation process, evaluators identified various technical limitations of the employed hardware such as the tablet PC monitor was too big in size to be fitted inside machine’s cabin; and it was difficult to see the display in bright sunlight etc. Thus, future research should also address the hardware related issues of *SightSafety* application that may constitute a barrier to its implementation. In
particular, future investigation should look into the location of the display unit inside
the cabin and the smaller display size. It is important that the display is located in
such a way that it does not take away the operator's awareness or obstruct the line of
sight.

**Need to embed RFID in a swipe card**

For the generated scenarios in the research it was suggested that each personnel ID
card (or swipe card) is embedded with an RFID tag that stores all personal details
including medical history and contact information of the employee. However, during
the prototype development IDENTEC Solution i-Q tags were used which are bulky in
size compared to the small tags currently available in the market. It is therefore
suggested that future work should produce personnel ID cards (or swipe card) that are
embedded with RFID tags for the *SightSafety* system.

**Need to work on the Graphical User Interface (GUI) for the operator screen**

During the prototype evaluation process, evaluators suggested that the display should
be very simple to use for machine operators because of their perceived low technical
literacy. Some plant operators suggested a simple 'radar system' like (graphical)
display. In order to improve the acceptance of the system among operators, future
work should seek to look into ways of improving the visual display that shows tag
movements on the screen. The aforementioned addition asks for investigation into a
simplistic GUI however, the fundamental design of *SightSafety* would remain the
same. For the suggested interface for the plant operator display unit (see Figure 9.2)
the personnel movements are displayed instantaneously on the screen. The untrained
pedestrians in machine's operational envelope are marked *red* (with their tag id
displayed) and the trained workers are shown with *green* mark (see Figure 9.2). With
such a screen in place operators will be made more aware of pedestrians' location at
all times.

However, the drawback of the RFID system is that it does not provide positioning
information. For the GUI presented in Figure 9.2, integration with a high-accuracy
pedestrian positioning system would be required. It is therefore suggested to explore
various positioning systems to be integrated with *SightSafety*. One possible way
forward would be exploring the emerging tags which uses a combination of positioning and tagging technology (IDENTEC Solution, 2007).

**Figure 9.2:** Suggested GUI for the operator screen.

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**Need to expand the scope of implementation**

As highlighted in research limitations that the prototype development was essentially a proof-of-concept application and as a result has looked at the *SightSafety* dimension of the envisaged plant MIS. However, there is a need to explore other aspects of plant management in future study e.g. incorporation of audit and inspections, maintenance, project information, plant history and inventory etc.

**Need to ensure user acceptance**

The ‘big brother syndrome’ was identified as a major concern among workers who feared that they may be constantly monitored through the tagging system by
management. Since user acceptance is a critical factor in the success of any ICT deployment, it is extremely important for the industry in general and project management in particular to make users of SightSafety realise the benefits of the application. As a result, there is a need to invest in the user training in order to make them at ease with the use of technology.

9.5 CLOSING REMARKS

The research highlighted that plant and equipment operation is one of the leading causes of accidents and injuries on construction sites. Through the research findings process maps were created for standard safety practices employed for onsite plant operation. Furthermore, practitioner concerns regarding these existing practices were highlighted to determine the major causes for failed plant/pedestrian safety. In order to address the raised concerns, an ICT solution was recommended to produce a proactive health and safety management system. The developed application investigated incorporation of plant MIS with mobile computing and RFID tagging technology. The integration of aforementioned technologies has led to the development of a primary technology platform where information requirements of safety managers and plant operators could be addressed. In addition, improved management of machines’ operational envelope could result in reduced accident rates.
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APPENDIX A1: GUIDE FOR SEMI STRUCTURED INTERVIEWS

These questions seek to determine the opinions of health and safety managers and plant operators on the currently practiced health and safety processes for construction plant. In addition, the questions enquire about any technology application to improve plant safety and performance. Note that all individual responses will be treated in strict confidence and we would be willing to share any research findings with you. Thank you in advance for your valuable input.

Section 1 – Personal and Company Details
*Other than your job title/position and experience in the industry, answers to these questions may be considered optional

(1.1) Name: ____________________________

(1.2) Job Title/Position: ____________________________

(1.3) Company Name: ____________________________

(1.4) Company Address: ____________________________

(1.5) Experience in Construction Industry: ____________________________

(1.6) Telephone Number: ____________________________

Section 2 – Health and Safety

➢ What existing processes do you follow to ensure the health and safety of plant, their operators and workers operating in the vicinity of these machines?

➢ What plant and equipment related issues are addressed in the H&S plan

➢ What safety precautions are taken by pedestrian (workers) working within a machine’s operational envelope?

⇒ Are any prohibited zones established around these machines?

○ If YES, what are advantages and is it practical?

○ If NO, why not?

➢ Do you agree that the operator’s vision is impaired on the right-hand side by the mast on the telescopic handler/excavators (wheeled and track type)?
Do you use any visibility aids where the driver's (of excavators and telehandlers) direct field of vision is inadequate? If Yes what kind of aids? If NO, why not?

What happens in case a plant hazard is reported? Also when plant is involved in an accident?

What kind of accident records are stored and are they available online?
  ⇒ What kind of reports on accidents are available to managers?
  ⇒ What improvements would you like to see developed? Is it easy to spot health and safety trends from these existing reports?

Section 3 – Technology

What information on plant is communicated to plant operators and how?
  ⇒ What health and safety information is communicated to them?

What on-board computers, software and information systems are currently in general use in construction plants (specifically excavators and telehandlers) and by plant operators.

Is there any software or computer based system used by managers for planning, organizing and controlling plant operations? What information is maintained?
  ⇒ More specifically are you using any technological solutions for
    - Vehicle tracking
    - Collision detection and vehicle path planning
    - Equipment health monitoring
  ⇒ If yes what kind of advantages do they offer?
  ⇒ If not what are the barriers?

Are you using any management information systems for
  - Maintaining Plant history (purchase details, supplier/manufacturer details etc.)
  - Vehicle inventory management (Tools/parts inventory)
  - Fleet management systems
  - Accident management
  - Service schedules
  ⇒ If YES then does this system manage both owned and hired plant types?

Date: ________________________________
Loughborough University

Evaluation Questionnaire

A prototype system for unauthorised trip monitoring for improved plant and equipment related health and safety

This questionnaire seeks to determine the opinions of Health and Safety managers and construction plant (in particular: excavators, telehandlers and dump trucks) supervisors. The completion of this questionnaire should be followed by a demonstration of the prototype system and/or scenarios. We would therefore very much welcome ten minutes of your time to complete this questionnaire. Note that all individual responses will be treated in strict confidence and we would be willing to share any research findings with you. Thank you in advance for your valuable input.

How to complete this questionnaire:

- Where a scale is provided like this: 1 2 3 4 5, please fill the circle that best indicates your opinion to a question.
- Where a line is provided i.e., ______ you can write any response you perceived as being appropriate.

*******************************************************************************

Section 1 – Personal and Company Details
*Other than your job title/position and experience in the industry, answers to these questions may be considered optional

(1.7) Name: _____________________________________________________________
(1.8) Job Title/Position: _________________________________________________
(1.9) Company Name: ___________________________________________________
(1.10) Company Address: ________________________________________________
(1.11) Experience in Construction Industry: _________________________________
(1.12) Telephone Number: ______________________________________________

Section 2 – System Effectiveness

Please fill the circle that best indicates your opinion to a question, where:
1: Strongly agree  2: Agree  3: Neither agree or disagree  4: Disagree  5: Strongly disagree

I consider the overall SightSafety system

1 2 3 4 5
2.1 is a useful application.  
2.2 will contribute in reducing accident rates on sites.  
2.3 will help in monitoring the workforce working in the operational envelope of plant and equipment.  
2.4 has a relevance for the industry’s needs.

Section 3 – A Proactive System

Please fill the circle that best indicates your opinion to a question, where:
1: Strongly agree 2: Agree 3: Neither agree or disagree 4: Disagree 5: Strongly disagree

* I consider that the SightSafety system
  
3.1 will enable managers to learn how to improve health and safety management practices on the construction site?  
3.2 will help towards a proactive Health and Safety management system?  
3.3 will help managers to retrieve information that may subsequently be used as a training aid for inexperienced workers?

Section 4 – A Practical System

Please fill the circle that best indicates your opinion to a question, where:
1: Strongly agree 2: Agree 3: Neither agree or disagree 4: Disagree 5: Strongly disagree

* In my opinion,
  
4.1 I consider SightSafety a practical solution.  
4.2 I am comfortable with the idea of employee tagging.  
4.3 The workers will use the tagged swipe cards without any fear of being monitored all the time by management.  
4.4 I am convinced that the plant operators will use the system.  
4.5 major system training will be required for the system setup

Section 5 – System Usability

Please fill the circle that best indicates your opinion to a question, where:
1: Strongly agree 2: Agree 3: Neither agree or disagree 4: Disagree 5: Strongly disagree

* In my opinion,
  
5.1 SightSafety is a user friendly system  
5.2 the information is displayed effectively on the screen.  
5.3 the system interface is easy enough for an average construction worker (assuming low technical literacy) to learn and use for his daily tasks

Section 6 – Financial Feasibility

Please fill the circle that best indicates your opinion to a question, where:
I think the system is financially feasible when
7.1 one unit (per vehicle) costs approximately £2000.
7.2 each personnel tag costing approximately £15 or less.

Section 7 – General Comments:

What improvements can be made to the overall system?

What do you think are the main benefits of the SightSafety application?

Do you think there are any 'Soft' issues (cultural) associated to the system?

Do you think there are any technical issues associated with the system application?

What in your opinion are the barriers/issues regarding the application of such a system in the industry?

Further Comments (if any)

Date: ____________________________
Evaluation Questionnaire

A prototype system for unauthorised trip monitoring for improved plant and equipment related health and safety

This questionnaire seeks to determine the opinions of mobile plant (in particular: excavators, telehandlers and dump trucks) operators. The completion of this questionnaire should be followed by a demonstration of the prototype system and/or scenarios. We would therefore very much welcome ten minutes of your time to complete this questionnaire. Note that all individual responses will be treated in strict confidence and we would be willing to share any research findings with you. Thank you in advance for your valuable input.

How to complete this questionnaire:

- Where a scale is provided like this: 1 2 3 4 5, please fill the circle that best indicates your opinion to a question.
- Where a line is provided i.e., __________ you can write any response you perceived as being appropriate.

Section 1 – Personal and Company Details
*Other than your job title/position and experience in the industry, answers to these questions may be considered optional

(1.1) Name: ____________________________________________
(1.2) Job Title/Position: ____________________________________
(1.3) Company Name: _____________________________________
(1.4) Company Address: ____________________________________
(1.5) Experience in Construction Industry: ________________
(1.6) Telephone Number: _________________________________

Section 2 – System Effectiveness

Please fill the circle that best indicates your opinion to a question, where:
1: Strongly agree  2: Agree  3: Neither agree or disagree  4: Disagree  5: Strongly disagree

I consider the overall SightSafety system

2.1 is a useful application. 1 2 3 4 5
2.2 will contribute in reducing accident rates on sites. 1 2 3 4 5
2.3 will help in monitoring the workforce working in the operational envelope of plant and equipment. 1 2 3 4 5
2.4 has a reliance for the industry’s needs.

Section 3 – A Proactive System

Please fill the circle that best indicates your opinion to a question, where:

<table>
<thead>
<tr>
<th>Circle</th>
<th>1: Strongly agree</th>
<th>2: Agree</th>
<th>3: Neither agree or disagree</th>
<th>4: Disagree</th>
<th>5: Strongly disagree</th>
</tr>
</thead>
</table>

I consider that the SightSafety system

3.1 will enable managers to learn how to improve health and safety management practices on the construction site?

3.2 will help managers to retrieve information that may subsequently be used as a training aid for inexperienced workers?

Section 4 – A Practical System

Please fill the circle that best indicates your opinion to a question, where:

<table>
<thead>
<tr>
<th>Circle</th>
<th>1: Strongly agree</th>
<th>2: Agree</th>
<th>3: Neither agree or disagree</th>
<th>4: Disagree</th>
<th>5: Strongly disagree</th>
</tr>
</thead>
</table>

In my opinion,

4.1 I consider SightSafety a practical solution.

4.2 I am comfortable with the idea of employee tagging.

4.3 The workers will use the tagged swipe cards without any fear of being monitored all the time by management.

4.4 I am convinced that the plant operators will use the system.

4.5 major system training will be required for the system setup

Section 5 – System Usability

Please fill the circle that best indicates your opinion to a question, where:

<table>
<thead>
<tr>
<th>Circle</th>
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<th>2: Agree</th>
<th>3: Neither agree or disagree</th>
<th>4: Disagree</th>
<th>5: Strongly disagree</th>
</tr>
</thead>
</table>

In my opinion,

5.1 SightSafety is a user friendly system

5.2 the information is displayed effectively on the screen.

5.3 the system interface is easy enough for an average construction worker (assuming low technical literacy) to learn and use for his daily tasks

Section 6 – General Comments:

What improvements can be made to the overall system?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
What do you think are the main benefits of the SightSafety application?


Do you think that plant operators will use the system? Yes/No
If no, why not?


What in your opinion are the barriers/issues regarding the application of such a system in the industry?


Further Comments (if any)


Date: _____________________________
# APPENDIX B: GUIDE FOR OPERATING FREQUENCY OF RFIDS

<table>
<thead>
<tr>
<th>Frequency Range</th>
<th>LF 125 KHz</th>
<th>HF 13.56 MHz</th>
<th>UHF 868 - 915 MHz</th>
<th>Microwave 2.45 GHz &amp; 5.8 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Max Read Range (Passive Tags)</td>
<td>&lt; 0.5 m</td>
<td>approx 1 m</td>
<td>2 - 10 m</td>
<td>1 - 2m</td>
</tr>
<tr>
<td>General Characteristics</td>
<td>• Relatively expensive.</td>
<td>• Less expensive than LF tags.</td>
<td>• Potentially lower cost than HF and much lower than LF tags.</td>
<td>• Similar characteristics to UHF.</td>
</tr>
<tr>
<td></td>
<td>• Least susceptible to performance degradations from metal and liquids.</td>
<td>• Relatively short read range and slower data rates when compared to higher frequencies.</td>
<td>• Offers good balance between range and performance.</td>
<td>• A drawback to this band is that microwave transmissions are the most susceptible to performance degradations due to metal and liquids, among other materials.</td>
</tr>
<tr>
<td></td>
<td>• Read range is very short.</td>
<td>• Best suited for application that do not require long read ranges.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical Applications Today</td>
<td>• Access control,</td>
<td>• &quot;Smart Cards&quot;.</td>
<td>• Pallet tracking.</td>
<td>• SCM.</td>
</tr>
<tr>
<td></td>
<td>• Animal tracking.</td>
<td>• Item-level tracking (including baggage handling, libraries and perishable foodstuffs)</td>
<td>• Electronic toll collection.</td>
<td>• Electronic toll collection</td>
</tr>
<tr>
<td></td>
<td>• Vehicle immobilizers.</td>
<td></td>
<td>• Asset management and high value item tagging</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• POS application including SpeedPass.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Notes</td>
<td>• Largest installed base due to the mature nature of low frequency, inductive transponders.</td>
<td>• Currently the most widely available frequency worldwide as it is globally allocated to ISM.</td>
<td>• The USA has the most radio spectrum available.</td>
<td>• This band is shared with Bluetooth, wireless LANs and many other devices.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Used for contactless smart cards.</td>
<td>• Europe, Japan and the Far East have limited spectrum resulting in slower data rates and the need for smarter system design for dense reader environments.</td>
<td>• Power is limited in most regulatory environments which means reduced read ranges.</td>
</tr>
<tr>
<td>Data Rate</td>
<td>Slower</td>
<td></td>
<td></td>
<td>Faster</td>
</tr>
<tr>
<td>Ability to read near metal or wet surfaces</td>
<td>Better</td>
<td></td>
<td></td>
<td>Worse</td>
</tr>
</tbody>
</table>

Source: RFIP (2007)
APPENDIX C: DFDS FOR INDIVIDUAL CASES
Case A and C: On-Site Plant Health and Safety
ID 1: Training
ID 2: Accident Investigation

Case A and C
Case B: On-Site Plant Health and Safety

KPI = Key Point Indicators
ID1: Plant Specific Health and Safety

Case B
ID 2: Accident Investigation

- Accident/Incident
  - Plant Inspection Report
  - Incident Report, Photograph and Witness Statement
  - PAIR*
- Accident Investigation
  - Report a Near Miss
  - Further Investigation
  - Other Projects
    - IIF 1 & IIF 2
    - IMPACT (Accident Reporting)
      - IIF 1**
      - IIF 2**
      - Monthly Reports
- PAIR* Preliminary Accident Investigation Report
  - IIF 1 = Incident Investigation Form 1 (3 Pages)
  - IIF 2 = Incident Investigation Form 2 (5 Pages)
- IIF 1**
  - Culture Identification
    - Safety Alerts/Preventive Measures
      - Company and T5 wide Safety Alerts
ID1: Plant Specific Health and Safety

- Subcontractors
  - CPCG/CSS Cards for Plant Operators
- 6/12 Monthly Plant Certificate
  - Subcontractor Acceptance Check
    - Approved Portfolio
      - Perform Risk Assessment
        - Traffic Management Method Statement
          - Traffic and Pedestrians Plan
            - Fire Plan and Drawings
          - Site Access Plan
            - Lifting Assessment Form and Lifting Method Statement
              - Safety Inspection Plan
                - H&S Plan for Plant Operations
                  - Control Checklist
                    - Checklist and Inspection Report
                      - 12 Monthly Maintenance Report
                        - Perform Safety Inspections and Audit
                          - Updated Inspection Reports
                            - Inspection Report
                              - Inspection Request
                                - Maintenance Request
                                  - Subcontractors
            - Weekly Inspection Matrix
              - Weekly Inspection Logs
                - Inspection Reports
                  - Request Plant Maintenance
                    - Subcontractors
ID 2: Accident Investigation

Case D
Case D: On-Site Plant Health and Safety

Inspection and Audit Reports* are:
Weekly Audit Report
Environmental/Quality Audits
Scaffold Inspections
Excavation Inspections
Welfare Inspections
Fire Inspections
Toolbox Talks Detail

Company wide Projects
Safety Alerts/ Statistics
Monthly and Quarterly Safety Meetings

Company Policy
Audit Report
Integrated Policy Plan

Weekly Inspection Report

Accident Investigation
ID 2
Accident Reports

Accident Reports at Head Office

Plant Specific H&S
ID 1
Weekly Inspection Logs

Site Induction

Training Matrix
Acquire External Training, CITB Courses etc.

External Training
Management Training

Perform Inspection and Audit (Internal/ Environment/ External)

New Inspection Schedule

New Project H&S Plan

H&S Plan

Induction Plan

New Training Plan

Training Matrix

Deliver Daily Toolbox Talk

Case D
APPENDIX D: AS-IS-PROCESS FOR ACCIDENT INVESTIGATION
APPENDIX E: HISTOGRAM CONSTRUCTED FROM THE EVALUATION SAMPLE TO DETERMINE SAMPLE DISTRIBUTION AND STANDARD DEVIATION
'Eff_useful' rated by Managers

Mean = 3.75
Std. Dev. = 0.707
N = 8

'Eff_useful' rated by Operators

Mean = 3.71
Std. Dev. = 1.113
N = 7

NB: 'Eff_useful' = SightSafety system is a useful application
'Eff_reduced_accident' rated by Managers

Mean = 3.75"
Std. Dev. = 0.707"
N = 8

'Eff_reduced_accident' rated by Operators

Mean = 3.14"
Std. Dev. = 1.215"
N = 7

NB: 'Eff_reduced_accident' = SightSafety will contribute in reducing accident rates on sites
NB: ‘Eff_monitoring’ = SightSafety will help in monitoring the workforce working in the operational envelope of plant
'Eff_relevance' rated by Managers

'Eff_relevance' rated by Operators

NB: 'Eff_relevance' = SightSafety has a relevance for the industry's needs
'Pro_learn' rated by Managers

Mean = 3.75
Std. Dev. = 0.463
N = 8

'Pro_learn' rated by Operators

Mean = 3
Std. Dev. = 1.414
N = 7

NB: 'Pro_learn' = SightSafety will enable managers to learn how to improve health and safety practices on a construction site
'Pro_training_aid' rated by Managers

<table>
<thead>
<tr>
<th>Pro_training_aid</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>3.5</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>4.5</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>5.5</td>
<td>1</td>
</tr>
</tbody>
</table>

Mean = 4.25
Std. Dev. = 0.707
N = 8

'Pro_training_aid' rated by Operators

<table>
<thead>
<tr>
<th>Pro_training_aid</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

Mean = 3.14
Std. Dev. = 1.464
N = 7

NB: 'Pro training aid' = SightSafety will help managers to retrieve information that may subsequently be used as a training aid for inexperienced workers
'Pra_practical' rated by Managers

Mean = 3.62
Std. Dev. = 0.518
N = 8

'Pra_practical' rated by Operators

Mean = 3.57
Std. Dev. = 1.512
N = 7

NB: 'Pra_practical' = SightSafety is a practical solution
'Pra_comfortable' rated by Managers

Mean = 3.38"
Std. Dev. = 1.598"
N = 8

'Pra_comfortable' rated by Operators

Mean = 2.14"
Std. Dev. = 0.9"
N = 7

NB: 'Pra_comfortable' = In SightSafety, I am comfortable with the idea of employee tagging
'Pra_fear' rated by Managers

Mean = 1.75"
Std. Dev. = 0.886"
N = 8

'Pra_fear' rated by Operators

Mean = 1.71"
Std. Dev. = 0.488"
N = 7

NB: 'Pra_fear' = The workers will use the RFID embedded swipe cards without any fear of being monitored all the time by management
'Pra_operators_use' rated by Managers

Mean = 3
Std. Dev. = 0
N = 8

'Pra_operators_use' rated by Operators

Mean = 3.14
Std. Dev. = 1.069
N = 7

NB: 'Pra_operators_use' = The plant operators will use the system
'Pra_setup_training' rated by Managers

Mean = 4.12"
Std. Dev. = 0.835"
N = 8

'Pra_setup_training' rated by Operators

Mean = 4.29"
Std. Dev. = 0.488"
N = 7

**NB:** 'Pra_setup_training' = Major system training will be required for the system setup
'Usa_user_friendly' rated by Managers

![Bar chart showing frequency distribution for 'Usa_user_friendly' rated by Managers.]

Mean = 3.12"
Std. Dev. = 0.991"
N = 8

'Usa_user_friendly' rated by Operators

![Bar chart showing frequency distribution for 'Usa_user_friendly' rated by Operators.]

Mean = 3.86"
Std. Dev. = 1.069"
N = 7

**NB:** 'Usa_user_friendly' = *SightSafety* is a user friendly system
NB: ‘Usa_display’ = In SightSafety the information is displayed effectively on the screen
7. **Usa_interface** rated by Managers

![Histogram for 'Usa_interface' rated by Managers]

- **Mean** = 3.25"
- **Std. Dev.** = 0.463"
- **N** = 8

**Usa_interface** rated by Operators

![Histogram for 'Usa_interface' rated by Operators]

- **Mean** = 3.86"
- **Std. Dev.** = 0.69"
- **N** = 7

**NB**: ‘**Usa_interface**’ = The system interface is easy enough for an average construction worker (assuming low technical literacy) to learn and use for his daily tasks.
### APPENDIX F: SOME TYPICAL MODELS OF CATERPILLAR EXCAVATORS AND THEIR SPECIFICATIONS

<table>
<thead>
<tr>
<th>Model</th>
<th>Maximum Digging Envelope</th>
<th>Counterweight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A metres</td>
<td>B m</td>
</tr>
<tr>
<td>307C</td>
<td>5.56</td>
<td>6.72</td>
</tr>
<tr>
<td>307B</td>
<td>5.56</td>
<td>6.72</td>
</tr>
<tr>
<td>307C SB</td>
<td>4.48</td>
<td>7.50</td>
</tr>
<tr>
<td>307B SB</td>
<td>4.45</td>
<td>7.42</td>
</tr>
<tr>
<td>308C SR</td>
<td>5.09</td>
<td>6.22</td>
</tr>
<tr>
<td>308C CR</td>
<td>5.67</td>
<td>6.77</td>
</tr>
<tr>
<td>311C U*</td>
<td>5.77</td>
<td>8.81</td>
</tr>
<tr>
<td>312C, 312C L</td>
<td>6.34</td>
<td>8.62</td>
</tr>
<tr>
<td>313C SR</td>
<td>6.06</td>
<td>7.23</td>
</tr>
<tr>
<td>313C CR, 314C CR, 314C LCR</td>
<td>7.19</td>
<td>8.63</td>
</tr>
<tr>
<td>315C</td>
<td>6.41</td>
<td>9.14</td>
</tr>
<tr>
<td>315C L</td>
<td>6.44</td>
<td>9.11</td>
</tr>
<tr>
<td>317B L, 317B LN</td>
<td>6.44</td>
<td>9.10</td>
</tr>
<tr>
<td>318C</td>
<td>6.9</td>
<td>9.66</td>
</tr>
<tr>
<td>318C L, 318C N</td>
<td>6.9</td>
<td>9.66</td>
</tr>
<tr>
<td>320CS</td>
<td>6.74(rb), 5.93(mb), 8.18(vb)</td>
<td>9.70(rb), 8.83(mb), 9.55(vb)</td>
</tr>
<tr>
<td>321C LCR</td>
<td>7.98</td>
<td>9.69</td>
</tr>
<tr>
<td>322C</td>
<td>7.15(rb), 5.98(mb)</td>
<td>10.47(rb), 9.12(mb)</td>
</tr>
<tr>
<td>322C L</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>322C LN</td>
<td>6.75(rb), 7.82(vb), 6(mb)</td>
<td>10.00(rb), 9.11(mb), 9.61(vb)</td>
</tr>
<tr>
<td>325C</td>
<td>7.11(rb), 2.03(mb)</td>
<td>10.51(rb), 9.88(mb)</td>
</tr>
<tr>
<td>325C L</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>325C LN</td>
<td>7.07(rb), 7.96(vb), 6.12(mb)</td>
<td>10.58(rb), 9.34(mb), 9.8(vb)</td>
</tr>
<tr>
<td>330C</td>
<td>7.64(rb), 6.67(mb)</td>
<td>11.64(rb), 10.21(mb)</td>
</tr>
<tr>
<td>330C L</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>330C LN</td>
<td>7.67(rb), 6.74(mb)</td>
<td>11.64(rb), 10.16(mb)</td>
</tr>
<tr>
<td>Model</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>---------------</td>
<td>--------------</td>
<td>--------------</td>
</tr>
<tr>
<td>345B Series II</td>
<td>7.32(rb), 6.94(mb)</td>
<td>12.23(rb), 11.03(mb)</td>
</tr>
<tr>
<td>345B L - FIX</td>
<td>7.54(rb), 6.95(mb)</td>
<td>13.00(rb), 11.12(mb)</td>
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<tr>
<td>345B L - VG</td>
<td>7.56(rb), 6.92(mb)</td>
<td>11.69(rb), 11.12(mb)</td>
</tr>
<tr>
<td>365B L -</td>
<td>9.19(rb), 7(mb)</td>
<td>14.09(rb), 11.83(mb)</td>
</tr>
<tr>
<td>Series II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>385B</td>
<td>10.45(rb), 8.39(mb)</td>
<td>15.61(rb), 11.83(mb)</td>
</tr>
</tbody>
</table>

N.B.
A= Maximum loading height of bucket with teeth; B= Maximum reach at ground level;
C= Maximum digging depth; (rb) = Reach Boom; (mb) = Mass Boom; (vb) = VA Boom;
APPENDIX G: KEY FACTS ON HEALTH AND SAFETY IN GLOBAL CONSTRUCTION SECTOR

Construction Health and Safety in the EU (Source: OSHA 2008; OSHA 2004; FIEC, 2008)

- The construction industry is the biggest employer in Europe where nearly 26 million workers depend, directly or indirectly, on the sector and there is an estimated construction investment of €1.196 billion which is 10.4% of GDP. However, the construction sector has one of the worst occupational health and safety records in Europe with around 1,300 workers killed each year; this figure being equivalent to 13 employees out of every 100,000 which is more than twice the average of other sectors.

- The incidence rate of non-fatal accidents in construction is nearly twice the average of the other work sectors.

- Nearly 850,000 construction workers suffered accidents that entailed over three days’ loss of work in 1999.

- In the 10 new member states, it is estimated that construction accounts for 20% of all work-related accidents.

- Falling from heights is one of the biggest problems, along with accidents involving transport, both on and off site.

- Each year, 600 000 construction workers are exposed to asbestos, a potent carcinogen that causes fatal diseases such as mesothelioma and asbestosis, Frequent contact with liquid-based substances and dust that can cause skin problems and respiratory disease respectively.

- Many construction workers who use machines, such as hand-operated power tools, drills and mechanised hammers, are exposed to high noise and vibration levels. High noise levels increase the risk of hearing difficulties and hand–arm vibration syndrome (HAVS) is a serious disease caused by using vibrating tools.

- The costs of occupational accidents and ill-health in the construction sector (including the costs of delays, absenteeism, and health and insurance charges) accounted for 8.5% of project costs which could cost the EU and its taxpayers over €75 billion each year.

Construction Health and Safety in the US (Source: DOL, 2008; BLS, 2006; McCann, 2006)

- The construction sector had the highest number of fatal injuries in 2006.

- Fatal work injuries involving construction labourers accounted for more than one out of every four private construction fatalities in both 2005 and 2006.

- The private construction industry accounted for 1,186 fatal work injuries, the most of
any industry sector and about one out of every five fatal work injuries recorded in 2005.

- Fatal work injury counts were higher by 4% in construction and extraction occupations in 2005 (from 1,138 fatalities in 2004 to 1,180 in 2005).

- Fatal work injuries were higher for construction labourers, carpenters, and construction equipment operators.

- In 2004, construction workers were 7.7% of the U.S. workforce but suffered 22.2% (1278) of the nation's 5764 reported work-related deaths. In addition, there were more than 150,000 nonfatal injuries and illnesses with days away in construction in 2007. The rate was 71% higher than that for all industry as a whole.

- For 1992–1999 identified 54 deaths per year from trenching for all industries, 80% of which were in construction. Excavation-related heavy equipment, such as backhoes, and vehicles accounted for 11% of trench-related deaths; about 6 deaths per year.

- About 45 workers are killed each year in the excavation work industry, 23 of them in heavy equipment-related incidents on construction sites.

- For workers on foot, being struck by vehicles, especially backing vehicles, and being struck by vehicle loads and vehicle parts were the major causes of death. For workers in trenches, being struck by backhoe loads and backhoe parts or falling backhoes caused three-quarters of the deaths.

**Construction Health and Safety in China** (Source: Fang et al., 2004; Tam et al., 2004)

- With the rapid growth of the Chinese construction activities, construction worker safety has become a major concern.

- In 2000, the number of workers in the Chinese construction industry was 35.52 million where it is estimated that 3,000 construction workers were killed in work related accidents each year.

- Construction sites exhibit unique hazardous characteristics; for example, workers are crowded together on sites, operating at height and outdoors, with the use of heavy machine and equipment.

- In 1999, 95 fatalities (8.66%) resulted from the problems of construction equipment.

- In 1999, 7% (63) out of all (923) accident cases were due to use of heavy equipment. There were total 1097 fatalities and 299 severe injuries recorded in the industry, out of which 71 and 38 were due to the use of heavy equipment respectively.
APPENDIX H: THE RESEARCHER'S ROLE IN THE DEVELOPMENT OF SIGHTSAFETY

<table>
<thead>
<tr>
<th>SightSafety Development</th>
<th>Role of the Researcher</th>
<th>Off-shelf Applications (Softwares)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Literature review (Chapter 3 and 4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>User requirement analysis (Section 6.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Practitioners validation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Role of the Researcher</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Development of system architecture and conceptual model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario generation for SightSafety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SightSafety system design (creation of activity diagrams)</td>
<td></td>
<td>IDENTEC ILR Technology (RFID solution)</td>
</tr>
<tr>
<td>Testing Suitability of the Technology for SightSafety. This included: • hardware testing, and • integration of software with .Net Framework.</td>
<td></td>
<td>MS Visual Studio .Net 2003 (development platform)</td>
</tr>
<tr>
<td>SightSafety programming (coding) and integration of ILR technology with database application</td>
<td></td>
<td>SQL Server Express edition</td>
</tr>
<tr>
<td>Practitioners Feedback</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SightSafety evaluation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>