Fundamental Understanding and Future Guidance for Handheld Computers in the Rail Industry

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Abstract

Advances in mobile computing technology and software applications have led to an expansion in potential uses for handheld computers for various tasks. One strong application area is in maintenance and inspection. Network Rail has been progressively developing and applying handheld computers to field-based maintenance and inspection operations, with the aims of improving work productivity and quality, and personal and system safety. However, it is clear that these aims so far have been achieved with varying degrees of success.

Handheld computer devices have the potential to enhance the procedure of performing the tasks in many different ways. However, the current handheld computers introduced to maintenance and inspection tasks in Network Rail have principally been designed as data entry tools and in most cases the primary objective is to reduce the amount of paper work and the associated costs and errors. This highlights the need for fundamental research into the ways in which handheld computer technologies should be specified, designed and implemented for effective use in a complex distributed environment such as the rail industry.

The main purpose of this research was to study the applications of handheld computers in the rail industry and to generate a set of design principles for development of future systems within Network Rail. The findings of this research have contributed to the identification of human factors principles that need to be considered for design and implementation of successful handheld computer applications. A framework was also developed to summarise and organise information and functional requirements of maintenance workers.

Investigating maintenance workers' requirements through interviews and observations emphasised the importance of rail specific spatial information and the benefits of providing this knowledge to maintenance workers through a mobile computing device which is portable and easy to use. However, displaying rail specific spatial information on the small screen of a handheld computer introduces various HCI issues and

challenges. These were addressed in part through a programme of experiments, and therefore the final section of this research focused on examining fundamental aspects of presenting rail specific spatial information on handheld computer screens.

The main findings from different stages of this research have been collated into a set of recommendations for design and development of usable and useful applications for handheld computer devices in the rail industry.

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1. Chapter 1 - Introduction

1.1. Background

Advances in mobile computing technology and software applications have led to an expansion in potential uses for handheld computers. The addition of location aware systems and wireless networks has expanded the potential for using handheld and mobile computing devices for innovative and pioneering applications.

Handheld and mobile computers have proved to be useful devices for various applications in different industries. In particular, there is evidence in the literature of successful deployment of handheld and mobile computers for inspection and maintenance tasks (Hajdukiewicz and Reising, 2004; Hammad et al., 2004; Legner and Thiesse, 2006; Sato et al., 2007).

The rail infrastructure in the UK is maintained by Network Rail. Handheld computers have been introduced to maintenance and inspection operations for over ten years and the company is aiming to introduce and implement better and more comprehensive systems to enhance productivity, quality and personal and system safety. A recent project in Network Rail has set the roadmap for adopting mobile computing technology for maintenance applications in the next five years (AMTSybex, 2009).

The current handheld computers introduced to maintenance and inspection tasks in Network Rail have principally been designed as data entry tools and in most cases the primary objective is to reduce the amount of paper work and the associated costs and errors (Fell, 2005). Nevertheless, talking to track workers and studying the applications shows that not all of these objectives have been met successfully. Furthermore, these devices have the potential to enhance procedures for performing the tasks in many other ways. This highlights the need for fundamental research into the ways in which handheld computer technologies should be designed and implemented for effective use in a complex context such as the rail industry.

This research studies applications of handheld computers in the UK rail industry. This PhD project was conducted in conjunction with and funded by Network Rail and University of Nottingham. In conducting this research, the researcher was based in the Ergonomics National Specialist Team in Network Rail. This engagement in the organisation provided her with access to various departments of the organisation which helped her establish a network of contacts within the organisation. Furthermore, by getting involved in other projects, the researcher obtained a thorough understanding of the organisation, the management structure, structure of various departments, and the culture of the railway industry.

1.2. Aims of the Research

Wilson (2000) identifies two roles for human factors and ergonomics which should be integrated into a "seamless whole". The first is to "fundamentally understand purposive interactions between people and artefacts and especially to consider the capabilities, needs, desires and limitations of people in such interactions" and the second role involves "contribution to the design of interacting systems, maximising the capabilities, minimising the limitations, and trying to satisfy the needs and desires of the human race" (Wilson, 2000, P. 10). These roles have shaped the formation of research questions and objectives in this thesis.

The main objective of this research was to demonstrate how an understanding of rail operations can facilitate a detailed appreciation of the potential impact of mobile devices on these operations, with a view to developing requirements and guidelines for real world practice. The following are the specific objectives of the research:

Research Aim I: Integrate relevant background, theory and models to develop a theoretical framework for human factors of handheld computer usage.

It was important, as a first step, to identify the relationship of this thesis with current research trends. A theoretical framework was considered necessary for providing the researcher with an understanding of the interaction between the users and the handheld device in the context of their work. The theoretical framework also provided the grounds for merging this understanding with the current mobile HCI theories and models.

Research Aim II: Identify personal, organisational, and interaction needs for successful handheld computer use in a rail industry.

The research in this thesis has been based on the assumption that in order to provide useful guidance, it is necessary to understand how current handheld computer systems are being used within the rail industry. As a result, it was extremely important to obtain a thorough understanding of the current use culture and interaction issues. The information gathered at this stage was then used to form a framework for summarising the personal, organisational, and interaction needs of users.

Research Aim III: Explore the factors relevant to presentation of spatial and spatially orienting information on handheld computer screen.

While addressing the previous objectives, it became apparent that spatial information is the most important aspect of information for rail maintenance workers. Hence it was decided to investigate different ways of presenting spatial and spatially orienting information on handheld computer screens and the features that have an impact on interacting with these displays.

Research Aim IV: Establish principles for design and implementation of handheld and mobile computing devices in the future railway.

One of the main objectives of this research was to generate a set of guidelines for Network Rail to assist the company with developing successful handheld computer systems. These guidelines are important for the industry since they provide useful and practical means for addressing the issues associated with development of handheld computer systems.

1.3. Methodological Considerations

The rail industry is considered to be a large and complex socio-technical real world system (Farrington-Darby, 2007). Handheld and mobile computers have special characteristics and attributes that distinguish them from conventional computing systems. Therefore, it is important to ensure that the methods chosen take into account all the different aspects and issues of studying handheld and mobile computers in the context of rail. In deciding upon the appropriate methodological strategies for this research two important questions had to be addressed:

1. How should a complex real world environment be studied?

2. How should a handheld and mobile computing device within this environment be studied?

The research methods chosen for this study had to support systematic and thorough data collection, analysis and interpretation. However, the nature of this PhD meant that the methods had to be adapted to meet the requirements of the research. For instance, the safety critical nature of the rail industry meant that field studies were limited to some extent. Moreover, it was felt that obtaining a more realistic insight about the tasks and the context requires input from participants who understand the rail context and have domain knowledge. Therefore, all of the participants in this research are Network Rail staff and all of the studies and experiments were conducted at various maintenance depots. These considerations are some of the reasons for adopting flexible, pragmatic and mixed research approaches.

Adopting a flexible approach was in particular necessary during the early stages of the research. This was mainly due to the fact that it would have been very difficult to conduct this research unless the researcher had an understanding of the rail industry and its different operations and systems. This understanding could not have been obtained thorough a fixed research approach where the research programme determines what should happen at each stage of the research in detail. One reason is the issues and considerations mentioned above and the other reason is that the research questions and consequently the methods changed and evolved as the researcher obtained more information about the rail context. Therefore, it was assumed that an "open system" research approach which concentrates on making sense of "a complex, relatively poorly controlled and generally messy situation" (Robson, 2002, P. 4) is inevitable. In other words, the research methods have been administered with a "real world research approach" perspective as defined by Robson (2002) where the focus is on real systems and real people and where the research questions can not be addressed solely by conducting experiments in laboratories.

Much of the information gathered in this thesis is the result of the research approach referred to in the literature as the "mixed research method". The versatile nature of this research meant that for most of the studies the methodological strategy had to be a combination of qualitative and quantitative techniques. There are various reasons for adopting a mixed method approach. Robson (2002) has listed the following reasons for combining qualitative and quantitative approaches: 1 - Checking the results of the qualitative studies, 2 - complementing the information gathered through experiments, 3 - adding statistical generalisability, and 4 - integrating the information gathered about the small scales of the system with a more large scale perspective.

The main methods used in this research have been explained in the following sections:

1.3.1. Literature Review

Exploring the applications of handheld and mobile computers and investigating the issues of interacting with these devices within the context of the rail industry is multifaceted. In order to address the objectives of this research, it was necessary to have an understanding of different aspects of mobile Human Computer Interaction literature. This understanding was essential for integrating the existing theories and models with the findings of the qualitative studies about different features of interacting with handheld computers in the rail industry. The main outcome of this integration has been the development of a theoretical framework for descriptive illustration of the interaction with handheld and mobile computers in the rail industry. This framework is explained in detail in chapter four.

In addition to a complete study of the published work in relation to applications of handheld and mobile computing devices in various industries, it was necessary to consider other factors that affect research in the field of mobile HCI. Therefore, the literature related to mobile HCI models and theories were also reviewed. Moreover, in order to obtain an understanding of various evaluation techniques and methods, the published work in this field was also thoroughly considered.

1.3.2. Qualitative Research Approach

Despite the ongoing debate about the usefulness and validity of qualitative research methods, in recent years there has been a greater emphasis on deploying these methods for human factors and ergonomics research (Wilson, 2005a). Many researchers in the field of HCI have praised the advantages of a qualitative approach for studying and evaluating computer mediated systems (Monk et al., 1993a; Preece et al., 1994).

A qualitative approach, according to Hayes (1997), means that the researcher is concerned with "meanings, context, and a holistic approach to the material" (Hayes, 1997, P. 4). On a technical level, i.e., in terms of pragmatic considerations such as availability of time and resources or sampling decisions, the qualitative approach is considered to be a "non-numerical" method (Henwood, 1997). In other words, qualitative data is data that can be categorised in some way, but can not be reduced to numbers (Preece et al., 1994). Qualitative methods enable the researcher to obtain a deeper and richer understanding of the system.

According to Robson (2002), "flexible" research approaches make considerable use of qualitative techniques. In this thesis, qualitative data gathering methods during the early stages of the research have had an important role by shaping the researcher's understanding of the users, the context of study and the tasks.

The approach deployed in this research can not be strictly defined as ethnographic. However, the characteristics of the research conducted in this study match the key aspects of an ethnographic research (Hayes, 2000). An ethnographer attempts to gather any data that is available in order “to throw light on issues that are the focus of the research” (Hammersley and Atkinson, 1995) and to describe and interpret the social group and the system which is being studied (Hignett, 2005). In other words, an ethnographer is an “uninformed outsider” who is trying to understand the system from the point of view of the “natives” (Monk et al., 1993b).

Working in Network Rail as a researcher and getting involved in some of the projects have provided the investigator with invaluable knowledge about the rail industry and in particular about operations within Network Rail. Some of the data reported in this thesis are the result of informal interviews and discussions with different members of staff. Despite the importance of these informal methods for gaining a more realistic insight into the use of handheld and mobile computing devices in Network Rail, in some cases it has become difficult to precisely identify the source of information, as it was absorbed by the researcher over time. Nevertheless, every effort has been made to ensure that the data was recorded systematically and in many cases the information has been verified by the help of two Subject Matter Experts (SMEs) who are part of the Ergonomics National Specialist team.

1.3.2.1. *Interviews*

Interviews shape an important part of the methodological strategy in this research. Interviews are the most common “knowledge elicitation” technique and can take many forms (Shadbolt, 2005). A very common classification distinguishes structured from semi structured and unstructured interviewing (Robson, 2002; Stanton et al., 2005). Some of the most important and valuable conclusions in this research have been derived from the results of semi structured interviews. These were applied with the aim of gathering complementary information during most stages of the research and in particular when the focus of the study was on understanding users' feelings and experiences when interacting with handheld computers. This was mainly due to the flexibility and adaptability offered by semi structured interviewing technique as well as the potential for gathering in depth information.

1.3.2.2. *Observations*

Observational Methods have been widely used in various disciplines including HCI and mobile HCI research (Jones and Marsden, 2006; Preece et al., 1994). When applied in field settings, observational methods usually do not tend to find specific research hypotheses. This is because controlled interventions and comparisons are not performed. Instead, these methods are used as information seeking techniques (Bisantz and Drury, 2005). In this research, observational techniques were mainly used to provide the researcher with an understanding of the tasks and context of work.

1.3.2.3. *Video data*

Video data has been used in this research to provide more comprehensive and insightful information about maintenance workers' experience with the prototype applications developed for Experiment I. Bisantz and Drury (2005) list several advantages of collecting video data and making the observations from the recordings. Perhaps the most important of all the benefits is the fact that, unlike real time observation, the researcher can refer to the recorded data as many times as necessary and this way, video data provides a means for understanding better complex or fast actions (Bisantz and Drury, 2005).

1.4. Research Conceptual Framework

Conceptual frameworks provide an illustrative tool for rationalising and describing the empirical research. In this research it was assumed that it would be impossible and impractical to generate guidelines for development of handheld computer interfaces unless there is a clear and thorough understanding of current applications and tasks. Therefore, during this study the outcome of one aim often led to generation of the other.

A research conceptual framework was developed with the aim of outlining and connecting different aspects of this research. This framework, as can be seen in Figure 3 -1, contains the objectives of the research as well as the high level methods adopted for addressing these aims.

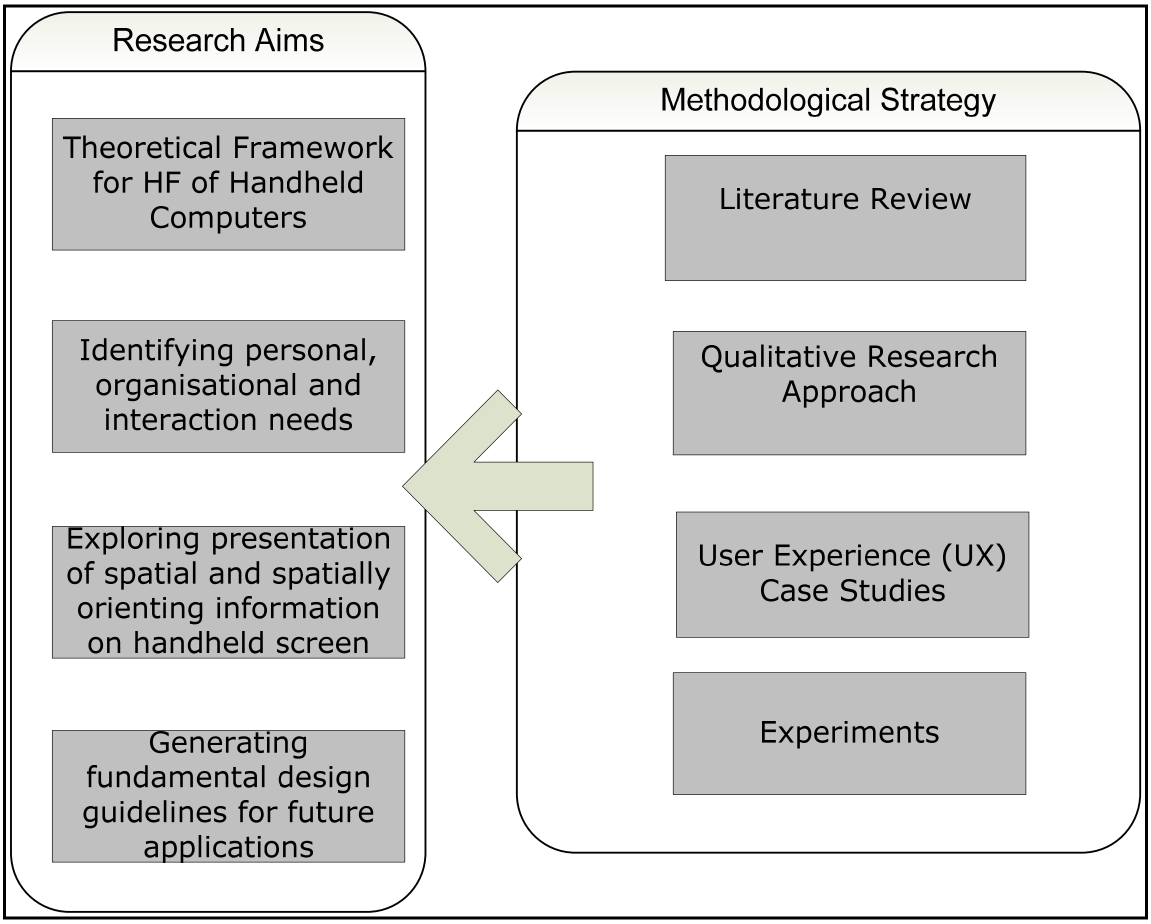

Figure 1-1 - Research Conceptual Framework

1.5. Thesis Structure

This thesis describes the process of work and the research methods deployed, as well as the results obtained during the course of the research.

Chapter two reviews the literature and research into three main topics: 1- Applications of handheld computers in various industries, 2- Interaction with handheld and mobile computing devices, and 3- Mobile HCI research methods.

Chapter three explains, very briefly, the structure of Network Rail and in particular the structure and history of the Infrastructure Maintenance department. The roles and tasks that were the focus of this research have also been explained. Also, in order to structure and gather information requirements of track workers, an applications framework was developed which can potentially be used as a reference to provide data about the information requirements of mobile workers and potential handheld computer applications for designers and system developers. The development of this framework, referred to as the Electronic Device Applications in Rail Engineering (EDARE) Framework, has also been explained in detail in this chapter.

Chapter four reports on the User Experience (UX) case studies on two handheld computer systems which were implemented within Network Rail. These were the Signalling and Telecommunication (S&T) and the Level Crossing (LX) handheld computer systems. These systems were studied in order to understand the interaction issues that the users experience with these devices and find out the factors that affect the interaction with the handheld computer in the rail industry.

The information gathered from the User Experience Case Studies and the EDARE framework together with a literature review on human computer interaction models provided the necessary grounds for developing a theoretical framework for understanding users' interaction with a mobile computer in the rail industry. Development of this theoretical framework has also been explained in chapter four.

The findings of the EDARE framework and UX case studies revealed the importance of spatial information and local knowledge for track workers. In the next part of this research a series of experiments were designed and conducted to investigate different aspects of presenting rail specific spatial information on mobile computing devices. Chapters five, six and seven describe these experiments. Chapter five describes the first experiment in this research. The objective of this experiment was to investigate the differences between presenting spatial information on handheld computer screens compared with the current paper-based documents. The overall experimental programme of the research has also been explained in this chapter. Chapter six explains the methods, data collection procedure, and the findings of the second experiment. This experiment attempted to find the most effective interaction style for interacting with spatial information on handheld computer screen in a rail context.

The last two experiments in this research focused on optimum amount and type of information that should be displayed on the handheld computer screen. These experiments have been reported in chapter seven. The first experiment investigates the effect of scale of the track diagrams and screen clutter on track workers' performance and the next experiment attempts to study the impact of type of information on performance.

Chapter eight brings together and discusses the findings from all the different studies in this research and attempts to explain how aims of the research were met throughout the course of this study. Finally, chapter nine concludes the thesis. Some areas identified for future research have also been explained in this chapter.

2. Chapter 2 – Mobile Computing: Opportunities and Challenges

2.1. Introduction

This chapter summarises the research and literature related to handheld and mobile computers and mobile Human Computer Interaction (HCI).

In the first part of this chapter, the research on applications of handheld computers will be studied. These studies have mainly been conducted in other industries rather than the rail industry, however in many cases the context of use, tasks and the applications are similar to those in the rail industry. The objective of this part of the literature review is to understand the rationale for using handheld computers for different applications.

Once a clear understanding of applications of handheld computers is established, the research conducted in relation to interaction issues with mobile computing devices will be reviewed. This section will focus on interaction methods and explores challenges faced by designers and users in interacting with handheld computers. The third part of this chapter looks at the published work relevant to the research methods used in the field of Mobile Human Computer Interaction and in particular research on techniques used for evaluating handheld computers.

2.1.1. Characteristics of Mobile Computing Devices

Weiss (2002) defines a handheld computer as (Weiss, 2002, P. 2):

> *"extremely portable, self contained information management and communication devices."*

The rapid technological growth of mobile computing devices and technologies paired with advances in implementing wireless connections and location aware systems such as the Global Positioning System (GPS) or the more recent European positioning system Galileo has led to a widespread use of handheld computers for work as well as for leisure.

Mobile computing is fundamentally different from desktop computing. Low computational power, small memory and in most cases lack of mass storage are some of the differences between mobile and desktop computer devices (Roth, 2002).

In his book "Handheld Usability", Weiss (2002) identifies eight characteristics that separate handheld computing devices from desktop devices: 1- reasons for use, 2- form factor, 3- mobility, 4- connectivity, 5- input, 6- display size, 7- memory, and 8- storage.

The following are also some of the physical attributes of handheld computers that distinguish them from desktop computers (Kajewski, 2001; Zimmerman, 1999): 1- size and form factor, 2- weight, 3- microprocessor, 4- primary storage, 5- secondary storage, 6- screen size and type, 7- means of input, 8- battery life, 9- communication capabilities, 10- expandability, and 11- durability of the device.

Table 2-1 summarises some of the differences between various types of personal computing devices ranging from desktop to wearable computers.

Table 2-1 - Characteristics of personal computing devices (Gorienko and Merrick, 2003)

Device Type	Form Factor	Highest Degree of Mobility	Mode of Interaction	Modularity
Desktops	Large	Fixed	Stationary only	Fully modular input/output mechanisms
Laptops	Medium	Transportable	Stationary only	Single unit device with optional external output mechanisms
Palmtops	Small	Transportable	Stationary with minor exceptions	Single unit device with optional external output mechanisms

Handhelds	Medium to small	Fully mobile	Mobile interaction enabled	Single unit device with optional external input/output mechanisms
Wearables	Small	Fully mobile	Mobile interaction enabled	Fully modular input/output mechanisms

Although the main differences between mobile computing devices and their desktop counterparts seem to be in their physical qualities, there is more to the division between mobile and desktop computing. Pownell and Bailey have identified four characteristics of handheld computers and their users (Pownell and Bailey, 2000): 1- portability refers to the physical device, 2- Accessibility refers to the ability for users to get the information they need instantly (which is different to the traditional definition of accessibility), 3- Mobility refers to the user who has the ability for greater movement and is not tied to one place, and 4- Adaptability refers to the ability of the user to change his or her behaviour because of this highly mobile technology. Figure 2-1 summarises the characteristics of mobile computing devices.

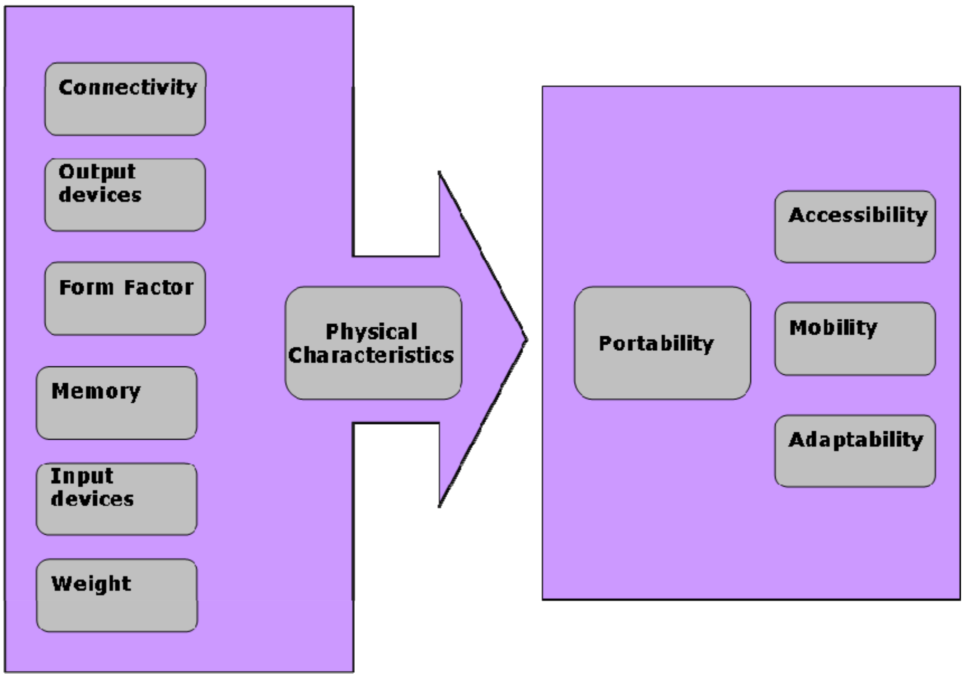

Figure 2-1 - Characteristics of mobile computing devices

As Figure 2-1 suggests, the most important consequence of the physical attributes of mobile computing devices is the portability of these devices and it is their portability that lead to attributes such as accessibility and mobility.

These characteristics have enabled new interaction techniques and ways of working. However, they have imposed new challenges and opportunities on development of mobile systems. In response to the rapid growth in handheld computer usage, researchers have attempted to address various human computer interaction issues associated with using mobile computing devices.

2.1.2. Ubiquitous, Mobile or Wearable Computing?

As with any new technology and discipline, the terminology and definitions in the field of mobile computing is unsettled. It is important to make clear what the meaning of each of these terms is in this research and adapt working definitions for the purposes of this thesis.

The concept of ubiquitous or pervasive computing was first proposed by Mark Weiser. His seminal paper in 1991 (Weiser, 1991) defines a ubiquitous computing environment as a world where computers which are wirelessly connected to each other disappear into the environment. In a ubiquitous environment, physical "computation-free" everyday objects can interact with mobile computing devices as long as they are recognised by the device (Fischer et al., 2004). For instance, Mark Weiser talks about the hundred writing boards and pads in any typical office room turning into computers, embedded within the environment, which interact with each other and with other objects around them (Weiser, 1991).

Wearable computing has a longer history which goes back as far as early 1960s with the invention of wearable analogue computers which were used for gambling (Thorp, 1998). A Wearable Computer is broadly defined as any computer that can be worn. Mann (1998) defines a wearable computer as (Mann, 1998b; Mann, 1998a):

"… a computer that is subsumed into the personal space of the

> *user, controlled by the user, and has both operational and interactional constancy, i.e. is always on and always accessible."*

He has also identified six attributes for wearable computers: 1- unrestrictive to the user, 2- unmonopolizing of the user's attention, 3- observable by the user, 4- controllable by the user, 5- attentive to the environment, and 6- communicative to others.

Mobile computing devices, as defined by Weiss (2002) are portable and self contained devices which can be used for information management. Also, with the addition of the current wireless and geographical positioning systems, many mobile computing applications offer situated and context aware interaction. Several companies have attempted to develop mobile computing devices since early 1980s. However, the term Personal Digital Assistant (PDA) was first used by Apple's chairman, John Sculley, in 1992 to refer to handheld computers that typically operate via a stylus on a LCD display (Polsson, 2008).

The main focus of the research in this thesis is on mobile computing devices that are generally referred to as handheld computers as described by John Sculley and these terms will be used interchangeably throughout this thesis. Having said this, many of the findings of this research can be applied to wearable computers.

2.2. Applications of Mobile Computing Devices

2.2.1. Introduction

The characteristics of handheld computers have led to their wide application in various industries for different purposes. Although research has suggested that mobile computing devices will first and foremost be used as communication tools and less significantly as information providing devices (Harper, 2003), there are many examples in the literature that study application of such devices for purposes other than communication. These applications range from devices which have been designed to enhance students' learning experience to location-aware digital maps and portable data gathering devices for medical applications.

Zimmerman (1999) has identified three benefits for implementing mobile computing within organisations through a detailed analysis of mobile computing technologies. These benefits are (Zimmerman, 1999): 1- Improved information accessibility, 2- Increased operational efficiency, and 3- Increased management effectiveness.

This section reviews the published work in relation to the applications of mobile computing devices. Although the main focus of this thesis is on mobile computing, in many cases the tasks and contexts of use of mobile computers are very similar to those of wearable computers. Therefore some examples of applications of wearable computers have also been reviewed.

2.2.2. Rail Industry Applications

As it was mentioned earlier, much of the research on applications of mobile computing devices has been conducted in other industries; however a few studies have looked at the rail industry. Examples of such studies include two reports provided by the U.S. Department of Transport on effects of introducing a wireless handheld computer on the performance of dispatch workers (Masquelier et al., 2004) and also on field worker's performance (Oriol et al., 2004). A prototype communication application has been developed with the aim of performing two tasks: requesting work authorisations and acquiring information about operational conditions. The main objective of this system is to support field workers' communications. This system makes use of a wireless modem in order to improve the communication functionality of track side workers. The device also provides location information using Global Positioning System (GPS) and offers the potential to improve safety and productivity of railroad operations. The researchers evaluated the level of improvement in terms of safety, efficiency and productivity. The result of their evaluation suggests that the proposed system increases communication efficiency, safety and also situation awareness.

Another example of applications of mobile computers in the rail industry is the development of a handheld computer terminal for trackside workers to support the European Rail Traffic Management System (ERTMS). This handheld terminal enables the trackside worker to directly control the protection of the work zones. The objective of this system is to enhance the safety of the trackside worker (Rich et al., 2002).

Despite the growth in applying mobile computing devices to different maintenance and inspection tasks, in many cases the applications of handheld computers have remained limited to information recording and there are rare cases of live data transfers between the handheld computer in the field and the office based computers. Sato and his colleagues (2007) have addressed this issue by building a "sophisticated maintenance work support system" that enables data exchange between the staff working on field and those based in the office. They have also developed an accident report system which operates on a Personal Digital Assistant (PDA) with a Personal Handy Phone Service (PHS) card for mobile internet use. The system enables accident investigators to transfer photographs and rough sketches of the accident scene as well as descriptions of the accident condition in form of audio files directly to the head office from the accident site (Sato et al., 2007).

Another example of applications of mobile computing devices in the rail industry is the research conducted by Brookhuis and Taroni (2007). They have examined the impact of presenting accurate and dynamic digital maps to train drivers on a PDA. Drivers' objective and subjective responses to the provided information were measured. The result of this study shows the positive impact of presenting forward information on driver's awareness and decision making abilities. Furthermore, train drivers believe that the additional information has enhanced safety and personal satisfaction (Brookhuis and Taroni, 2007).

2.2.3. Maintenance and Inspection Field Tasks

In recent years there has been a widespread growth in implementing handheld computers for maintenance and inspection tasks. The number of studies in this field is an indicator of the importance and potential advantages of using handheld computers for such tasks. It is important to note that the tasks and contexts of use studied in the research reviewed here are very similar to those of the rail industry and therefore it might be possible to establish a cross industry link between different applications of handheld computers.

Combining mobile computing devices with innovative interaction styles such as speech based interaction has expanded the applications of mobile computers for fieldwork. Kondratova (2005) studies the advantages and challenges of using speech recognition systems on mobile devices for field data entry and real time communication for a field quality control task (Kondratova, 2005). This research has illustrated the advantages of using multimodal inputting technologies as well as some of the challenges and issues associated with developing successful applications.

The Mobile Reality framework is another system which is based completely on a pocket PC, synchronises a hybrid tracking solution to offer the users a seamless, location dependent, multimodal mobile interface which provides mobile collaboration support (Goose et al., 2002). Goose and his colleagues have reported on an exemplar application scenario which involves supporting a typical mobile maintenance task with the proposed framework.

Schwirtz and Baber (2005) also propose a system where tools used for maintenance activities are fitted with RFID tags to monitor when and how the tool was used. Adding this data to information about the identification and location of the maintenance worker results in a "sophisticated paperless maintenance logging system" which can help minimise maintenance errors and consequently lead to a safer system of work by: 1- ensuring that the operator is complying with the procedures by providing guidance on site, 2- completion of paperwork while performing the task which can replace signing off with activity recording, and 3- providing advice and guidance on site for training or operational purposes. Figure 2-2 illustrates an overview for an experimental setup of such system.

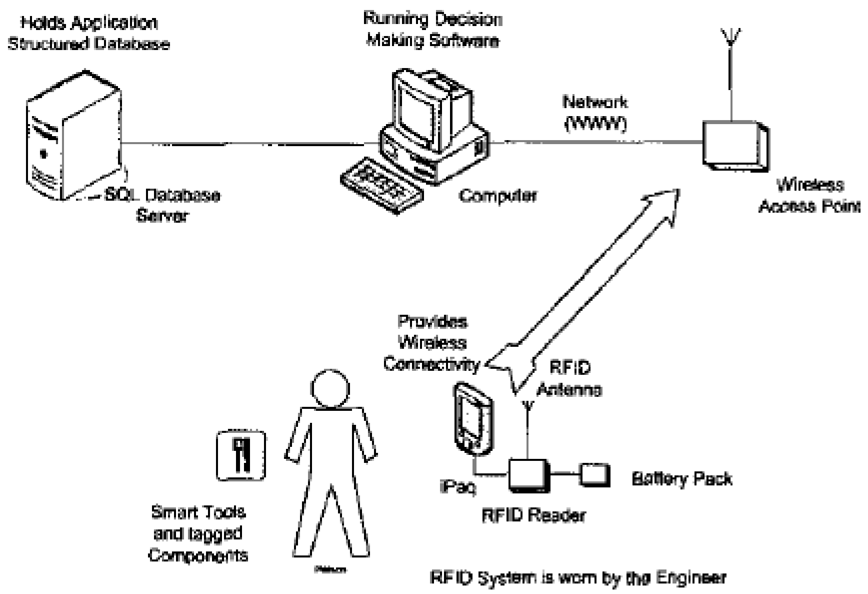

Figure 2-2 - Overview of smart tools RFID experimental setup (Schwirtz and Baber, 2005)

Industrial control rooms have been the subject of much research in terms of information technology. Advances in computing technology have led to introduction of applications of wearable and mobile computers for control rooms of process plants and there are examples of these applications in the literature (Binder and Messeter, 2001; Loer and Harrison, 2005). One such system is the Pucketizer (Personal Bucket Organiser) which has been designed to aid the operator at a wastewater treatment plant to "smooth the transition between interacting with physical objects in process control and digital presentations of the same objects". The system provides the setting for a more flexible and dynamic configuration of process monitoring compared with the traditional centralised control systems (Nilsson et al., 2000).

Bridge maintenance and inspection is one of the other domains that have deployed mobile and handheld computing devices. Hu and Hammad (2005) report on development of a location based mobile computing device to support data collection activities for bridge inspection. Their system is equipped with a 3D detailed model of the bridge where all the inspection results are registered. The system is also equipped with navigation systems which guide the inspector to the desired location (Hu and Hammad, 2005). Another PDA based field data collection system which is being used for bridge inspection is “Inspection on Hand” (IoH) which enables inspectors to capture data on site and share it with the office based staff (Trilon, 2004). An earlier attempt for deploying mobile and handheld computers for bridge inspection was the system developed at the University of Florida (Kuo et al., 1994). This system provides fieldworkers with a pen-based notebook computer which assists inspectors with field data collection. Mobile Inspection Assistant (MIA) is another system which has been developed with the objective of collecting bridge inspection data. This system utilises a speech recognition user interface which runs on a wearable computer (Sunkpho et al., 2002).

Mobile computing devices are believed to be beneficial tools for different applications in risk critical industries. Hajdukiewicz and Reising (2004) interviewed stakeholders across six production facilities in the refining and petrochemicals industry in order to find out more information about their culture, current mobile use and potential needs. They have identified four factors which affect the successful deployment of mobile computing devices for field operations. These factors are: 1- organisation, policies, and processes; 2- applications; 3- infrastructure, hardware and software; and 4- training (Hajdukiewicz and Reising, 2004).

Another example is the research reported by Kjeldskov and Stage (2002) where the user interface of a handheld mobile communication device has been designed with the objective of improving the coordination between parties that are conducting a complex work task in a high-risk environment. The results of their study indicate that using mobile computing systems for “standardizing the communications” will enhance coordination between different parties. They have used a very large container ship as their example for a risk critical environment in their study (Kjeldskov and Stage, 2002).

The aviation industry has also made use of handheld and wearable computers for aircraft maintenance and inspection. Much of the research in the field of aircraft maintenance and inspection considers the use of wearable computing (Fallman, 2003; Nicolai et al., 2005; Witt et al., 2006). For instance, Ockerman and Pritchett (1998) describe how wearable computers can be used as a task guidance tool for pre-flight inspection (Ockerman and Pritchett, 1998). In another example at Frankfort airport a Radio Frequency Identification (RFID) based maintenance system has been developed which integrates RFID tagging with a mobile device to improve planning, control and documentation of maintenance technicians' work (Legner and Thiesse, 2006).

Another study in this field proposes the development of a ubiquitous computing environment where objects in the physical world are equipped with sensors and therefore can provide the maintenance engineer with information about the maintenance process. The operator is integrated in the environment using a handheld computer which displays information obtained from "smart tools" and "smart toolboxes" and enables the operator to communicate with the smart objects (Lampe et al., 2004).

Another category of field work in which mobile computing has been introduced is the construction industry and there are many examples in the literature that have investigated the use of mobile computers in this domain. Most of these studies have focused on providing access to information for mobile users and therefore transcend physical distance (Kimoto et al., 2005; May et al., 2005; Rebolj et al., 2001). Despite the fact that these devices provide great opportunities in terms of data collection and immediate access to information at a construction site, the constraints imposed on the application of such devices due to the limitations of interaction methods have led researchers to develop a series of customized Navigational Models with the objective of reducing the amount of physical interaction with the device (Reinhardt et al., 2002).

In the rest of this section, other major industries and domains that have been deploying handheld computers will be studied. The reason for attending to these fields individually is the amount of research published in these domains.

2.2.4. Medical Applications

In recent years, the healthcare industry has become more distributed and therefore healthcare providers have introduced handheld computers for various clinical applications (Garritty and Emam, 2006). Using handheld computers will enable the clinicians to instantly update patient records at the bedside and validate the information against a centralised database which will result in a reduction in medical errors and will increase personnel efficiency (Grasso, 2004). Furthermore, handheld computers have the potential of satisfying healthcare professionals' information needs by providing evidence based guidelines, medical and drug references as well as patient information (Lu et al., 2005).

The literature in relation to medical applications of handheld computers has focused mainly on the use of mobile computers as bedside data entry tools (Lapinsky et al., 2001; Tschopp and Geissbuhler, 2001; Young et al., 2001) or as information provider devices with wireless connections to the medical data (Duncan and Shabot, 2000). Moreover, there is evidence of research on electronic documentation for chronic illnesses (Smith and Haquw, 2006) and also paediatricians' use of handheld computers for different applications such as personal scheduling, drug reference, medical calculations or writing prescriptions (Carroll and Christakis, 2004).

The applications of location aware mobile computers have also been explored. MobileWard is a context aware system which reacts autonomously according to changes in the environment and, depending on users' tasks, provides relevant information and services (Skov and Høegh, 2006).

In addition to providing immediate and up to date information to medical staff, it has been proposed that handheld computers can be used as decision support devices. An example is the prototype developed by Zupan and colleagues, called LogReg, which runs on a Palm™ handheld computer. This system supports models obtained by logistic regression which is a modern statistical technique used for medical decision making (Zupan et al., 2001).

2.2.5. Educational Applications

Handheld and mobile computers have become important tools in the learning environment. There are many examples of research on attempts for introducing mobile computing at different levels of the education system. Handheld computers have been used to develop mobile learning environments which enable students and instructors to collaborate (Heath et al., 2005). They have also been used as test administration tools in schools and universities (Segall et al., 2005). Sharples (2000) has studied the application of handheld computers as memory aids, concept maps and communication tools with the objective of supporting lifelong learning from any location (Sharples, 2000). Handheld computers have also been widely used for education purposes in the medical domain (Kho et al., 2006; Martinez-Mota et al., 2004; Torre and Wright, 2003).

It seems that the main reason for deploying handheld computers for educational purposes is the potential for establishing collaborative learning environments. Zurita and Nussbaum (2004) report the results of a study conducted with six and seven year old primary students. They claim that using Mobile Computer Supported Collaborative Learning (MCSCL), it will be possible to address issues such as weaknesses in coordination, communication, organisation of materials, negotiation, interactivity, and lack of mobility (zurita and Nussbaum, 2004).

In a recent case study, a teacher from a technical education institution explored the educational “affordances” of PDA technology over a period of six months. Five affordances were identified: 1- multimedia access tool which can be used to deliver multimedia resources and courseware; 2- connectivity tool which can be used by students to exchange ideas and engage in discussions; 3- capture tool which enables students to capture video and audio footage as well as taking notes; 4- representation tool which provides the students with the opportunity for presenting their knowledge and ideas; and 5- analytical tool such as basic and advanced calculators (Churchill and Churchill, 2008).

2.2.6. Location Aware Navigational Applications

One of the most common applications of handheld computers is location aware navigational systems. In fact location based, and in a broader sense, context aware systems are the main focus of much of the research conducted in relation to mobile computing. The result of the review of research across various industries clearly illustrates the importance of location awareness for many of the mobile computing applications. The primary benefit of a location aware system is that it will assist users in way finding and navigation. Moreover, despite the fact that location based mobile computing devices only provide basic context awareness, they still offer the mobile user two advantages. Firstly they provide the mobile worker with cartographic information in real time and secondly, based on the position of the user, these systems can provide the user with additional data through distributed connected networks (Clarke et al., 2002).

Numerous papers have studied the opportunities and challenges of presenting spatial information on handheld computer screens (Aslan et al., 2006; Baus et al., 2002; Li and Willis, 2006; Liarokapis and Conradi, 2007; Reilly et al., 2006).

There are several studies that address the issues of developing location aware applications on a handheld platform for tourists. Projects and systems such as Cybershot (Nakashima, 2002), TellMaris (Laakso et al., 2003), Deep Map (Malaka and Zipf, 2000), HIPS (Broadbent and Marti, 1997), and LOL@ (Pospischil et al., 2002) are some of the examples of the studies conducted in this field. All of these systems are location aware and provide guidance and information to the users. The earliest study in the field of mobile tourist guides is the Cyberguide project which comprises a series of prototypes of a context aware, mobile tour guide (Abowd et al., 1997). Motivated by the work of Cyberguide researchers in the United States, researchers at Lancaster University started the GUIDE Project in the same year (Cheverst et al., 2000; Davis et al., 2001). The GUIDE system combines mobile computing, wireless communication, context awareness and adaptive hypermedia in order to provide tailored tours and information for visitors to the city of Lancaster. In an interesting study, researchers in the city of Oulu, Finland, have developed a cultural-spatio-temporal model of the city on a handheld computer which provides visitors with a presentation of the city in different eras (Peltonen et al., 2003).

2.2.7. Entertainment and Personal Applications

Ubiquitous computing has been widely used for entertaining purposes. For instance, mobile computing gaming has attracted the attention of researchers. Human Pacman (Cheok et al., 2004), SpyGame, Multi Monster Mania, and The Guild are a few of the examples of mobile computing games (Björk et al., 2002).

Computer gaming industry has not been the only beneficiary of the technological advances of mobile computers. There is evidence of applications of mobile computing systems in the music industry (Wiberg, 2004). The growth in the development of mobile devices that are capable of presenting video and audio files reflects the impact of pervasive computing on entertainment industry.

2.2.8. Summary

Researchers have identified a set of "secondary tasks" for mobile computer users which seem to be independent of their main and "primary task". In other words, the typical tasks the handheld computers are being used for can be generalised regardless of the users' primary tasks. Examples of these "secondary tasks" which are supported by handheld computers include communication, collaboration, coordination, reporting, handling logistics, etc (Skattør et al., 2007).

In summary, it can be proposed that the applications of handheld computers in different industries can be divided into three main categories:

1. Spatially aware systems for navigation and way finding

These systems are (Simon et al., 2006,):

> *"smart, spatially aware personal geographical assistants: devices which themselves possess locally stored knowledge about the [structure, geometry, and visual appearance of the] environment around them and their own relative position and situation therein."*

Technological advances in the field of mobile wireless networking as well as progresses in the development of positioning systems have provided the necessary infrastructure for designing context aware mobile systems.

2. Information retrieval and recording systems

The majority of mobile computing systems have been designed with the aim of reducing the amount of paperwork by providing digital data retrieval and recording means. According to Zimmerman (1999), mobile computing devices enable the user to: 1- create, 2- access, 3- process, 4- store, and 5- communicate information. The first four features clearly reflect the fact that retrieving and recording information is one of the main applications of mobile computing systems.

Using mobile computing devices, field workers are able to collect video and audio information as well as text. Furthermore, speech recognition systems have enabled hands free data entry which has expanded the possibilities of implementing mobile devices for highly dynamic and mobile tasks of a fieldwork.

3. Communication and collaboration

Initially the only perceived application for mobile devices was as a communication tool (Harper, 2003). This application has remained central to the design of mobile computing systems. The primary objective of many of the systems discussed in this section has been to support collaboration and communication amongst geographically distributed users. The introduction of wireless networking systems has also enabled system developers to pioneer new and innovative mobile collaborative systems.

2.2.8.1. *Link to this Research*

The complex nature of the rail industry provides a great opportunity for adopting mobile computing devices. The three categories of applications mentioned above are all applicable to the rail industry. Maintaining the geographically scattered rail infrastructure essentially requires the workers to be able to find their way; hence, location aware systems. Form filling and recording the status of the infrastructure also requires data capture and storage. Finally, rail engineering work is performed in teams and could be coordinated remotely and therefore, maintenance workers need to be able to communicate and work in a collaborative environment.

2.3. Mobile Human Computer Interaction

2.3.1. Introduction

The term Human Computer Interaction was adopted in mid 1980s to address the different aspects that contribute to the success or failure of interacting with a computer system. Although there is still no agreed definition for Human Computer Interaction, it is generally and broadly defined as the study of interaction between people and computers (Preece et al., 1994). The definition suggested by Special Interest Group on Computer Human Interaction (SIGCHI) committee is (SGCHI, 1992):

> *"Human-computer interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them."*

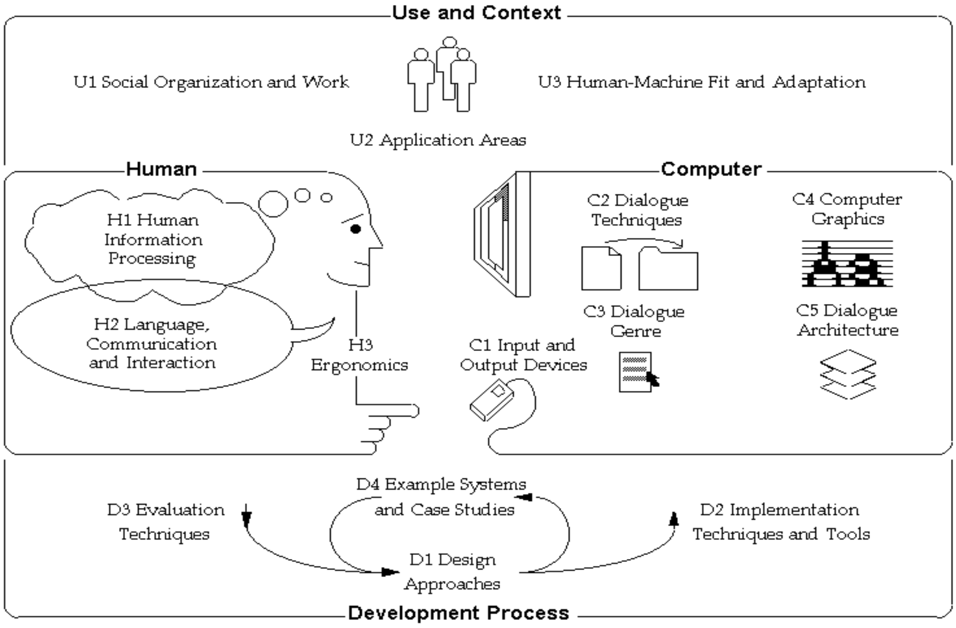

Figure 2-3 - Human Computer Interaction described by SIGCHI committee (SGCHI, 1992)

Figure 2-3 shows SIGCHI's description of Human Computer Interaction. Looking at the representation of "computer" in this figure, it seems that it has been assumed that computers are generally used as desktop tools, i.e., devices that will be used in a static work environment. But in recent years there has been a dramatic change in the field of computing due to the expansion of mobile computing technologies. Mobile Computing has been defined as (Zimmerman, 1999, P. 2):

> *"… use of computing devices – which usually interact in some fashion with a central information system – while away from the normal fixed workplace."*

Handheld computers and mobile computing devices are not just an extension of the Internet and the desktop computer but also of the person and his or her information environment (Pownell and Bailey, 2000). In other words, interaction is not confined to one system and one user. The complexity of mobile computing devices extends the concept of a system to be more than just one device (Ketola and Röykkee, 2002). The challenges of interacting with handheld computers are in many cases beyond the traditional discipline of HCI. As a result, in 1998, the first Conference on Human-Computer Interaction with Mobile Devices and

Services (MobileHCI) was held as a standalone workshop so that the HCI community could address the new challenging issues of using mobile computers in greater detail.

Bødker (2006) has acknowledged that the focus of the HCI discipline has shifted from "Second Wave HCI", where the main emphasis was on groups working with a collection of applications, to "Third Wave HCI" which attempts to include other aspects of our daily lives in the human-computer interaction issues. The use contexts and applications have broadened and intermixed and as a result there has been a shift to the "third wave" of human computer interaction. She continues by recognising the fact that many of these changes are due to developments in mobile computing (Bødker 2006):

> *"New technologies servicing these developments [including new elements of daily life in HCI] have appeared: pervasive technologies, augmented reality, small interfaces, etc. seems to be changing the nature of Human-Computer Interaction in ways that we do not quite understand."*

Weiser and Brown (2001) have also identified the changes in the HCI discipline and have defined the following four phases for the technological changes in the computing industry: 1- the mainframe era, 2- the Personal Computer era, 3- the internet and distributed computing era, and 4- the Ubiquitous Computing era (Weiser and Brown, 1996). Table 2-2 summarises these trends.

Table 2-2 - The major trends in computing (Weiser and Brown, 1996, P. 1)

Mainframe	**Many people share a computer**
Personal computer	One computer, one person
Internet, widespread distributed computing	…transition to...
Ubiquitous computing	Many computers share each of us

The main focus of most of the published work in the field of mobile HCI is on the human experience. The objective of research in recent years has been to turn mobile computing devices into tools that assist users in their everyday life and not overwhelm them (Abowd et al., 2002). It has not been long since the first mobile computing devices were introduced in the early nineties which imply that there are still many problems with their usability, network speed, connectivity and computational performance. Although it has been promised that the performance of the next generation of wireless devices will match the computational powers of the desktop computers, this in itself will not guarantee improved usability for devices and applications (Kjeldskov, 2002). These difficulties have led the scientific community to address usability and interaction issues of mobile computing systems.

In this section, the studies and published work related to the challenges and opportunities of designing usable mobile computing systems will be studied. The second part of this section will review the literature on different interaction styles proposed for mobile computing.

2.3.2. Mobile Human Computer Interaction Challenges and Opportunities

Characteristics of mobile and handheld computers have introduced a whole host of new challenges as well as opportunities to designers and system developers which had not been experienced with desktop computers. These qualities have attracted the attention of the research community. Mobile HCI researchers have recognised the fact that unless these challenges are clearly identified and tackled, designing a successful and usable mobile system would be impossible.

Many of the problems and limitations of mobile human computer interaction are due to adopting guidance from traditional Graphical User interface (GUI) practices (Poupyrev et al., 2002). These principles have failed because of the specific characteristics of mobile computing devices and also attributes of mobile users. The limited input and output devices, for instance, fundamentally change the way users interact with mobile computing devices and traditional GUI design principles fail to take these into account.

Pascoe and his colleagues (2000) have identified four characteristics that distinguish a mobile field worker from desktop computer user (Pascoe et al., 2000): 1- Dynamic user configuration, i.e., access to information anywhere, anytime, 2- Limited attention capacity, 3- High-speed interaction, and 4- Context dependency.

Features of the mobile computing device and its user are not the only limiting factors. Bürgy and Garrett (2002) have identified five constraint categories: 1- task, 2- environment, 3- application, 4- user, and 5- device (Bürgy and Garrett, 2002). These constraints apply to any computer system, desktop or mobile; but they need to be addressed and considered in the light of the characteristics of the mobile computing devices and their users. Dunlop and Brewster (2002) have also identified the following five challenges faced by designers and system developers when designing mobile computing systems which sum up and cover all the issues stated by various researchers (Dunlop and Brewster, 2002):

1. Designing for mobility
2. Designing for widespread population
3. Designing for limited input and output facilities
4. Designing for (incomplete and varying) context information
5. Designing for users multitasking at levels unfamiliar to most desktop users

Although these issues impose great challenges on designers and system developers, they are not the only problems that threaten successful deployment of mobile computing devices. Davies and Gellersen (2002) believe that other problems such as technical, social, legal, and economic issues also play a significant role in failure of some of the mobile computing systems.

The challenges and issues mentioned here have shaped the structure of the literature review in this section. Although all these issues need to be addressed to have a truly usable handheld computer system, the amount of research conducted in different fields is various. The following sections will explore these challenges in greater detail and will review the published articles that have addressed these difficulties.

2.3.2.1. *Designing for Mobility*

Mobility is the characteristic of contemporary working environment. It is perhaps the most important feature of handheld computers too. One of the main reasons for the recent increase in mobility of everyday actions is the expansion of mobile computing devices and the new ways of working afforded by these technologies which provide access to information and people anytime, anywhere.

An important aspect of working in a mobile environment as opposed to an office setting, according to Kristoffersen and Ljungberg (1999), is the obvious fact that users might be physically highly mobile. Static interaction with handheld computers introduces new challenges and difficulties for designers. However, as Pascoe and colleagues have rightly pointed out, at least the work environment is similar to desktop computer usage. Therefore, it is clear that adding the aspect of mobility to the interaction with handheld computers will lead to more challenges and problems (Pascoe et al., 2000).

It is very important to understand the meaning of “mobility” for different user groups. Mobility means that interaction with the computer is not confined to the remote office environment. A review of the literature on applications of handheld computers makes it clear that many of the studies in this field have attempted to address the issues caused by the “mobility” of users and systems. Researchers have attempted to explore the meaning of “anywhere” and “anytime” in the context of mobile interaction (Perry et al., 2001; Wiberg and Ljungberg, 1999).

The inherent diversity of the mobile computing environment means that the users will inevitably face environmental factors which might affect their interaction with the mobile computer (Hinckley et al., 2000). For instance, a voice recognition system might not be suitable for an environment with high noise levels (Baber and Noyes, 1996). Differences in the light level will also lead to issues such as glare which affects the readability of the screen (Hinckley et al., 2000). Moreover, severe weather conditions might impact users' physical interaction with the device (Baber, 1997). Despite the obvious impact of environmental factors on mobile HCI, there has been little research into how these factors influence interaction with any form of mobile computing device in recent years.

In addition to the environmental issues that affect interaction, it is clear that mobility imposes considerable cognitive demands on the interaction and consequently has an impact on the usability and ease of use of mobile devices (Gorienko and Merrick, 2003). These issues will be discussed later in more detail when studying limited attention interaction.

2.3.2.2. *Designing for a Widespread Population*

One of the consequences of the ever decreasing cost, rapid growth and universal expansion of mobile computer usage is a very diverse user community ranging from children at schools to healthcare professionals in hospitals and engineers in the field not to mention the applications of such devices for disabled and elderly users. In other words, the applications of these technologies have moved from the professional market to the mass market. Therefore, there should be a distinction between the perceived robustness and usability of these devices for the widespread population (Broadbent and Marti, 1997).

It is not possible to have a generalised design for everybody due to the variations inbuilt in the mobile computing environment (Perry et al., 2001). However users will normally consider mobile computing devices as tools for performing their tasks and not as computers for which they might need training (Dunlop and Brewster, 2002). Office workers will use mobile computers to maintain a sense of awareness while they are away from the office and also to communicate with their colleagues (Brodie and Perry, 2001). However, a fieldworker relies on the mobile computer for various other reasons which are beyond the applications designed for the office worker (Pascoe et al., 2000). But both groups will consider the mobile computing device as a tool that should be intuitive to interact with.

Designing for widespread population also emphasises the need for considering inclusive and universal design concepts when designing applications for mobile computing devices. In fact, mobile and wearable computing devices and technologies have the potential to enable universal design through concepts such as context aware and implicit interaction.

2.3.2.3. *Designing for Limited Input and Output Facilities*

As it was mentioned earlier, mobility and portability are two of the most important attributes of mobile computers. Putting laptop and tablet PCs aside, in the case of other mobile computing devices, portability is a direct result of a reduction in device size. The small size of the device leads to small and limited input and output facilities.

The main output facility on a handheld computer is its screen. A typical handheld computer has a screen resolution of 240 x 320 pixels. Furthermore, considering the limited computing power of a typical handheld computer (Processing speed: 480 MHz; RAM: 128 MB; ROM: 48 MB) it can be concluded that many of the current applications of handheld computers are limited to information retrieval and recording which consequently means that there should be powerful means for presenting information to the users (Kajewski, 2001). Several researchers have attempted to address the issues associated with displaying and interacting with textual and pictorial information on small screens (Jones et al., 2002; Kjeldskov, 2002; Lam et al., 2006; Nicholson and Vickers, 2004; Rist and Brandmeier, 2002; Rohs and Essl, 2006). de Bruijn and colleagues believe that one way of addressing the problem of navigating information on small screens is to achieve a trade-off between time and space. They propose Rapid Serial Visual Presentation (RSVP) technique which is an equivalent to "riffling the pages of a book to get an idea of 'what's there?" (de Bruijn et al., 2002).

Input facilities are much more limited on mobile computing devices. In fact, while output facilities have improved in recent years (improved audio output, high resolution and high contrast screens), input devices have remained a major problem (Costanza and Leinss, 2006). Text entry is usually very cumbersome and time-consuming on typical mobile computing devices (Kajewski, 2001). Even use of the stylus is a two-handed interaction and research has shown that it will increase attention overhead on the user (Yee, 2003). Therefore, researchers have proposed innovative input methods such as using the on-board camera on a mobile device (Haro et al., 2005) or speech based data entry (Fischer et al., 2006).

2.3.2.4. *Designing for the Context Information*

The addition of location aware systems such as sensors and positioning systems which provide information from the environment, i.e., the context, to mobile computing devices has introduced novel opportunities as well as new challenges. The increased connectivity of mobile computing devices, through the establishment of Wireless Application Protocol (WAP), and the improved multimedia applications of such devices have made access to ubiquitous information simpler and more efficient (Costanza and Leinss, 2006). In other words, these systems have taken the applications of handheld computers, which were confined to providing static information, to another level and have promoted the concept of Context Aware Information Access (CAIA) (Jones and Brown, 2000).

Context itself is defined as (Dey et al., 2001):

> *"…the location, identity and state of people, groups and computational and physical objects"*

The combination of the task and the environment determines the context of use for mobile computing (York and Pendharkar, 2004). The concept of context awareness as we know it today was first proposed in 1994 when a software was designed that could examine and react to the individual's change of context (Schilit et al., 1994).

Schmidt and his colleagues (1999) have defined context awareness as (Schmidt et al., 1999):

> *"knowledge about the user's location and IT device's state, including surroundings, situation, and to a lesser extent location"*

Their model of context, presented in Figure 2-4, contains three dimensions: 1- environment, 2- self, and 3- activity. Tarasewich (2003) has proposed a four dimensional model for context which contains time as well as the other three dimensions proposed in the original model (Tarasewich, 2003).

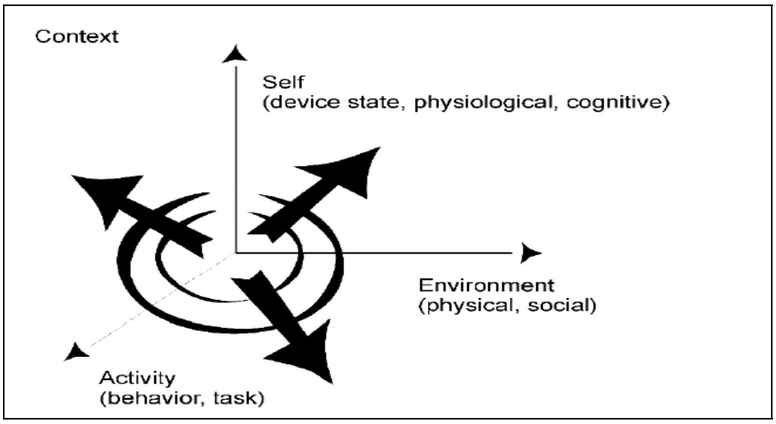

Figure 2-4 - Context model (Schmidt et al., 1999)

Much of the context aware interaction is facilitated by forming a short range mobile ad hoc network between the mobile computing device and the stationary device as well as sensors and other computing resources (Yau and Karim, 2004). While much of the published research on context aware systems focuses on locating the individual, there is more to context than "location" and "identity". As Abowd and his colleagues have stated (Abowd et al., 2002):

> *"Although a complete definition of context remains an illusive research challenge, it is clear that in addition to who and where, context awareness involves when, what, and why."*

Tamminen and Colleagues (2004) go even further and claim that a context-aware system needs to be aware of several contextual factors including social, psychological, and physical just to name a few. Their perception of context is similar to the definition of the "Context of Use" suggested by (ISO-13407, 1999):

> *"users, tasks, equipment (hardware, software and materials), and the physical and social environments in which a product is used"*

Therefore, they have concluded that in order to design a "socially acceptable and useful" context aware device, it is necessary to have an empirical knowledge of the context from the user's point of view (Tamminen et al., 2004).

Context aware systems promise richer and easier interaction. However, the state of research in this field is still not satisfactory due to three reasons: 1- no agreed definition for the notion of context, 2- lack of conceptual models and methods to help drive the design of such applications, and 3- lack of necessary tools to initiate the development of context-aware applications (Dey et al., 2001).

In a loose classification, interaction with context information can be divided into 1- interaction with places, e.g., location-based mobile services and mobile guides, 2- interaction with other computing devices through wireless networks, and 3- interaction with "real world objects" such as usage of barcode and RFID equipped mobile devices. While there seems to be an increased interest in the first category, mobile interaction with smart objects has not received the same attention (Rukzio et al., 2006b).

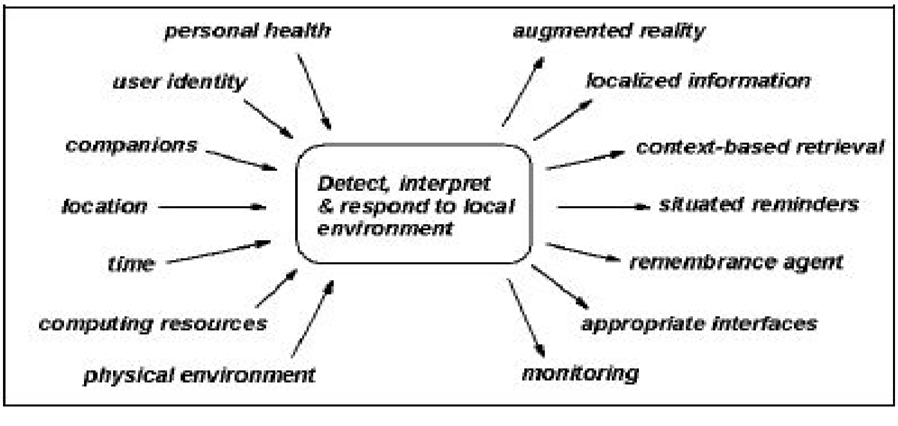

Figure 2-5 - Overview of situated Computing (Hull et al., 1997)

Figure 2-5 summarises some of the different aspects that influence interaction with location based devices. Depending on the type of the context information, the design challenges are varied. For instance, in addition to issues of displaying maps and spatial information on small screens, many other factors need to be considered when designing a mobile system which provides geographical and spatial information. Some of these factors are issues such as presenting the right scale and extent of the maps which seem to have been largely overlooked in the literature (Dillemuth et al., 2007) or special features of interaction with mobile way finding devices such as change of orientation and position (Hinckley et al., 2000). There are also technical issues of privacy and data protection. Because of the openness of these systems users need to be able to protect themselves and their data from unwanted interactions (Julien et al., 2005).

Although these systems provide users with new information which will assist them to perform their tasks with higher efficiency and effectiveness, the changing nature of such information causes many problems (Dunlop and Brewster, 2002). The change of context information can be frequent or infrequent, rapid or slow, smooth or erratic, predictable or unpredictable and these features might cause difficulties for interacting with and designing context aware devices (Jones and Brown, 2000).

Hammad and his colleagues have identified eight requirements for successful implementation of Location Based Computing systems for field tasks: 1- availability, 2- reliability, 3- data storage, 4- real time processing, 5- wireless communication throughput and range, 6- interoperability, 7- scalability, and 8- usability (Hammad et al., 2004). Considering these requirements and comparing them with the available technological resources clearly show the long way ahead of researchers for designing usable and effective location based handheld computer systems.

2.3.2.5. *Designing for Users Multitasking*

Multitasking and support for task interruption are crucial for the success of a mobile computing system (Dunlop and Brewster, 2002). The characteristics of mobile field work clearly emphasise the fact that interacting with the handheld computer in many cases is user's secondary task.

Kristoffersen and Ljungberg (1999) have identified four aspects of the work contexts for use of mobile computers. These aspects, which are listed below, set the scene for understanding the notion of multitasking and clarify some of the characteristics of working in a mobile environment (Kristoffersen and Ljungberg, 1999b):

1. Tasks external to operating the mobile computer
2. Users' hands are occupied manipulating other objects
3. Users might be performing other tasks which require high level of visual attention
4. Users may be highly mobile during the task

All of these suggest that the mobile computer user is almost always performing more than one task. Kristoffersen and Ljungberg (1999) believe that while with desktop computers, the primary work tasks of the users are "inside" the computer, for a mobile user, e.g., a maintenance worker or sales personnel, the primary task is "outside" the computer (Kristoffersen and Ljungberg, 1999a). In other words, there are other tasks to be performed in addition to the task of interacting with the mobile device which the mobile device needs to integrate with and support.

2.3.2.6. *Other Issues*

Many of the factors that affect users' interaction with mobile computing devices were mentioned above. Other factors such as economical, social and legal issues might not directly influence the interaction and usability of a mobile computing device, however, these concerns seem to have a great impact on practical deployment of such devices in our daily lives (Davies and Gellersen, 2002). In other words, even if all the technical difficulties of embedding computing systems in our daily lives are solved, there are still many social and legal issues that need to be addressed before mobile computing systems can be used effectively.

Ideally, the concept of ubiquitous computing assumed that computers will disappear into the physical environment (Weiser, 1991).This invisibility in itself creates various problems such as privacy and security of information. The invisibility of the systems might make users wonder what the computer is doing "behind their back". Therefore, it is important to ensure that any design solution addresses these issues and provides visibility and control of information to users (Abowd and Mynatt, 2000).

Privacy is the most cited criticism of ubiquitous computing and according to Hong and Landay (2004) might be the most important barrier to its lasting success. Many studies have addressed the issues of privacy and security in the context of mobile computing systems (Bellotti and Sellen, 1993; Hong and Landay, 2004; Langheinrich, 2001; Want, 2007). Despite the importance of these issues, their implications in many cases remain unforeseen to the researchers unless new technologies and new applications are invented and designed (Abowd and Mynatt, 2000).

2.3.3. Interacting with Mobile Computing Systems

A great number of studies in the field of mobile HCI have focused on the issues associated with physical interaction with mobile computing devices. Numerous studies have attempted to address the issues discussed in the previous section by proposing alternative methods for interaction with handheld computers. In this section the literature on development of alternative methods for interacting with handheld computers will be reviewed. The size of the handheld computers leads to small displaying interfaces and limited input facilities. Therefore, interacting with these devices requires a high level of attention, visual and cognitive, in the mobile use context (Kjeldskov, 2002). Holland and his colleagues (2002) have identified four general problems that affect mobile interaction: 1- limited screen real estate, 2- restricted bandwidth, precision and convenience of input devices, 3- use of mobile devices in minimal attention situations, and 4- need to make two or more devices to interoperate (Holland et al., 2002b).

Insisting on having desktop like applications on mobile computing devices means that these devices need to support very strong interaction techniques (Silfverberg et al., 2001; Witt et al., 2006). It seems that the rationales for using mobile computing devices justify user interface design decisions and interaction methods.

Physical interaction styles have been the subject of research in many studies. Research suggests that the most promising physical interaction techniques are touching, pointing and scanning. For the first two, the user has to touch or point to the screen in order to interact. In the last technique, the mobile device is used to discover if any controllable devices are available (Rukzio et al., 2006a). Rukzio and his colleagues have empirically compared these three techniques. The result of their comparison is presented in Table 2-3.

Table 2-3 - Comparison of properties of the physical mobile interaction techniques (Rukzio et al., 2006a)

	Touching	**Pointing**	**Scanning**
Natural interaction, intuitiveness	Good	Good	Average
Felt error resistance, non ambiguous	Good	Average	Bad
Performance (within interaction distance)	Good	Average	Bad
Cognitive load	Low	Medium	High
Physical effort (outside interaction distance)	High	Medium	Low

The “Isometric Joystick” is another physical interaction method which has been proposed as a Graphical User Interface (GUI) style point and click device for mobile computing interaction. The empirical examination of this device suggests that it is suitable for mobile interaction and it will provide a powerful interaction technique for interacting with desktop like applications on handheld computers (Silfverberg et al., 2001). There are also some futuristic one-handed input devices proposed in the literature like the "Finger-Joint-Gesture Palm-Keypad Glove" which uses fingers as keys or the "Invisible Phone Clock" which uses the metaphor of a wristwatch to present the 12 keys of a mobile phone keypad (Goldstein et al., 2000).

It has been implied that "Direct Manipulation" is one of the main interaction methods used for mobile computing devices. But Kristoffersen and colleagues (1999) argue that this style fails to meet the specific requirements of mobile interaction. They propose MOTILE as an alternative style which they believe will address issues such as limited visual attention and will provide tactile and audio feedback. MOTILE is an interaction technique and a system for operating mobile computers. MOTILE attempts to consider the following three propositions: 1- no or little visual attention, 2- structured and tactile input, and 3- use of audio feedback (Kristoffersen and Ljungberg, 1999a).

In many cases, the alternative and innovative interaction styles have been developed as a way for tackling issues associated with limited input and output facilities. For instance, Nicholson and Vickers (2004) have proposed using pen-based gestures instead of visual controls on the screen for a way of decreasing clutter on small screens (Nicholson and Vickers, 2004). In another study, three different interaction styles - fisheye, zoom, and panning - for interacting with "big interfaces" on small screens have been compared. The researchers have concluded that fisheye technique, which provides both an overview and a detailed view, is the most preferred method for navigating websites on small screens and panning is the slowest interaction technique (Gutwin and Fedak, 2004).

In sum, reviewing the literature shows that mobile computing interaction styles can be classified into three main categories:

1. Minimal Attention Interaction

2. Context Aware Interaction

3. Implicit Interaction

These groups will be studied in greater detail in the following sections.

2.3.3.1. *Minimal Attention interaction*

Typically interacting with a handheld computer requires high levels of visual and cognitive attention (Kjeldskov, 2002). This is mainly due to the small size of the screen. Even when the number of actions required to perform a task is minimal, the small size of the screen means that the users need to allocate a big part of their visual attention to the task.

The concept of Minimal Attention User Interfaces (MAUI) was first formulated by Pascoe and his colleagues (2000). They argued that the type of tasks that a mobile computing device is usually used for occupies user's visual and cognitive attention and therefore there will be minimum resources left that can be devoted to interacting with a handheld computer. Therefore a MAUI will (Pascoe et al., 2000):

> *"attempt to remedy this situation by transferring tasks to interaction modes that take less of the user's attention away from their current activity."*

In an attempt to avoid the problem of visual attention allocation, researchers have developed interaction styles for alternative input and output methods that make use of other senses rather than the visual sense. Reviewing the literature reveals a set of studies which have focused on ambient and peripheral awareness interfaces. For instance, TouchEngine™ is an example of a miniature, lower-power tactile actuator which has been designed specifically for mobile computing devices. This system will provide the user with a tactile interface to receive ambient feedback through a set of tactile pulse sequences which vibrate with different rhythms and intensities to notify the users about a change of status (Poupyrev et al., 2002). Another example is the use of Electromyography (EMG) as a controller for mobile interaction. EMG can sense isometric muscular activity which is a type of activity that does not translate to movement. This characteristic makes it possible to "define a class of subtle motionless gestures" as means of interacting with a mobile computing device and therefore creating a "hands-free" and "eyes-free" interaction style (Costanza et al., 2004). Hinckley and colleagues (2000) propose integrating a set of sensors into a handheld computer which provide the user with several new functionalities. For instance, touching the device will automatically turn it on, tilting the device will scroll the screen, and depending on the orientation of the device, the display switches between landscape and portrait modes (Hinckley et al., 2000).

In other research, Luk and his colleagues (2006) have attempted to address issues caused by inadequate haptic technologies which obstruct the integration of effective haptic interaction into mobile computing devices. In their paper, they present the initial stages of a systematic design effort which is aimed at matching the capabilities of haptic technology to the problems of contemporary mobile interaction (Luk et al., 2006).

Audio input and output has also been used as a way for freeing users' visual attention from attending the screen. There are examples in the literature of applications of speech recognition systems and audio output as alternative interaction methods for mobile computing devices. AudioGPS is one such system which by using non-speech spatial audio output enables users to perform location finding tasks (Holland et al., 2002a). Kondratova (2005) has studied the industrial applications of voice recognition systems for field work data collection and real time communication. The objective of all these systems is to help the user to interact with the mobile computing device without having to take away their attention from the main task at hand. Wearable computers seem to have the potential for solving the problems of attention allocation to a great deal. However, the technological limitations in developing successful wearable computers impose a challenge to researchers and system developers.

2.3.3.2. *Context Aware interaction*

Interacting with mobile computing devices depends heavily on the context in which the interaction is taking place. Therefore, "context aware" interactions seem to be an inevitable part of the mobile HCI research.

Different researchers seem to have various definitions for "context-awareness" and they have used various terms to describe it. "Just-in-Place" information is the term Kjeldskov (2002) has used to explain the integration of user's physical location with time into a mobile device (Kjeldskov, 2002):

> *"Physical Space becomes part of the interface, providing the user with information and functionality adopted to a location in space and time."*

Pascoe and his colleagues (2000) suggest that providing context information to the user through embedding sensors into mobile computing devices will enhance the user's performance. "Wear-UCAM" is another example of a context aware system which provides users with personalised services based on their context and without their explicit input (Hong et al., 2006). Another example of context aware interaction is the study conducted by Bonnani and colleagues (2005) where implementation of sensors within a set of automatic interfaces at a kitchen sink have improved safety, hygiene and ecology (Bonnani et al., 2005).

2.3.3.3. *Implicit Interaction*

"Implicit interaction" is based on the two concepts of perception and interpretation and is defined as (Schmidt, 2000):

> *"an action performed by the user that is not primarily aimed to interact with a computerised system but which such system understands as input."*

"Off-the-desktop" human computer interaction is an essential element of mobile and ubiquitous computing. This concept also suggests that the physical interaction will not be similar to the conventional keyboard, mouse and display paradigm. Instead, the mobile HCI should match the way humans interact with physical objects in the world. Implicit physical input requires the input methods to be closer to more natural forms of human communication (Abowd et al., 2002).

It should be noted that in most applications the interaction styles are a mixture of explicit and implicit interaction. Figure 2-6, illustrates the "interaction continuum".

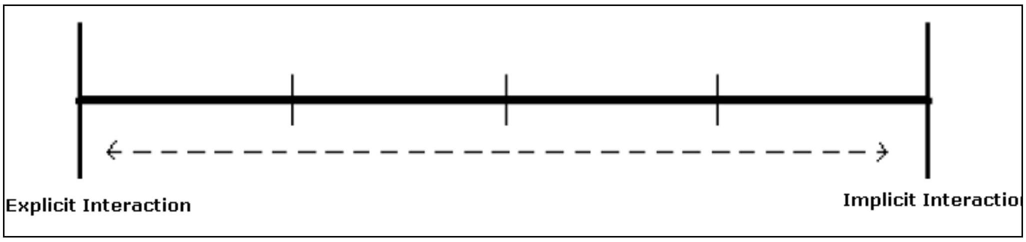

Figure 2-6 - The Interaction Continuum (O'Hare et al., 2006)

Reviewing the published work on mobile interaction styles shows that in most cases the interaction methods adopted for a mobile device are a combination of implicit interaction with explicit interaction and therefore, most devices lie somewhere in the middle of the interaction continuum. For instance, multimodal user Interfaces (MMUIs) typically combine explicit and implicit interaction styles (O'Hare et al., 2006). The concept of "mixed initiative interaction" proposed by Villar and colleagues (2005) which aims to integrate environment-controlled and user-controlled interaction is also an example of attempts to reach a balance between two ends of the continuum (Villar et al., 2005).

Pascoe and colleagues (2000) have acknowledged the fact that the handheld computer is not the only equipment that the mobile field worker uses and it should be integrated with other tools. But it will not help to generate an "electronic copy" of other tools on the handheld computer; instead the other equipment needs to be embedded within the appropriate function which will consequently lead to implicit interaction between the user and all the different applications on the mobile computing device.

Context aware systems provide seamless interaction methods updating the status of the device and providing users with information without the need for users to explicitly ask for this information. Capturing and interpreting users' implicit interaction requires the environment or the device to have some sort of embedded awareness or intelligence (O'Hare et al., 2006). Therefore, there seems to be a strong relationship between context aware systems and implicit interaction. A context aware system that adapts the input or output style according to the environmental conditions provides implicit interaction through context (Schmidt, 2000).

2.3.4. Summary

Work and leisure activities in modern life have become increasingly mobile. Wiberg and Ljungberg (1999) have identified three reasons for increased mobility of the modern life:

1. Emergence of service work which very often takes place at the client's workpace
2. Increased importance of cooperation in and between organisations
3. Extensive adoption of mobile phones

The third reason seems to be more influential and has had a greater impact in terms of shaping novel and unanticipated forms of work in many organisations (Perry et al., 2001).

Despite being written almost two decades ago, even today many of the ideas proposed by Mark Weiser in 1991 seem futuristic. Some of the reasons for this slow progress have been discussed here. Many different aspects, ranging from interaction and usability issues to technical and sociological factors, need to be addressed before Weiser's idea of ubiquitous computing where computers disappear into the environment are realised (Davies and Gellersen, 2002).

2.3.4.1. *Link to this Research*

Many of the issue and challenges identified in the literature are applicable to the context of the rail industry. However, characteristics of working in a rail context necessitate further investigation. One of the main objectives of this research, as mentioned before, was to understand the way rail maintenance workers interact with the current handheld computer systems. This understanding was necessary to identify the mobile HCI issues users experience in this specific context.

2.4. Mobile HCI Research Methods

2.4.1. Introduction

Mobile HCI is a very technology-focused enterprise (Brewster, 2008). However, despite rapid technological advances in the field of mobile computing, it seems that the speed of generating new theories and research methods does not match the requirements of this growth (Rogers, 2004). Furthermore, the body of research regarding the appropriate choice of method, data collection and analysis for evaluation of mobile computing systems is not as strong as it is for desktop computer systems (Kjeldskov and Skov, 2003b).

Models and theories provide a structured description of different components of a complex system like a ubiquitous computing environment. Therefore, despite criticisms from researchers who find models and theories superficial and sometimes even useless, they have proved to be useful tools for system developers (Myers et al., 2000; Paternò, 2005).

Having discussed the applications of handheld computers and also the design challenges as well as the usability issues of interacting with these devices, it seems necessary for the purposes of this research to study the research methods and theories used for understanding, designing and evaluating mobile interaction. In this section, first the mobile human computer interaction theories will be reviewed. Techniques and methods used for evaluating mobile computing systems will then be examined in the final section of this chapter.

2.4.2. Mobile HCI Theories

Traditionally, researchers depended on the theories borrowed from cognitive psychology to explain Human Computer Interaction issues. However, advances in the field of HCI and the introduction of new technologies have introduced new dimensions to the interaction with computing devices which could not be addressed by deploying cognitive psychology theories as the only form of theoretical framework. The advances and changes in this field have led to proposition of concepts such as "Third Wave HCI" which expand the challenges of HCI beyond the scope of traditional theoretical frameworks (Bødker 2006).

Table 2-4 - Summary of theoretical approaches in HCI (Adapted from Rogers (2004))

Theoretical Approach	Some of the most influential Models and Frameworks	Main Researchers
Early theoretical developments	Model Human Processor (MHP); Goals, Operators, Methods, and Selection Rules (GOMS)	(Card et al., 1983)
	Heuristic Evaluation	(Nielsen and Molich, 1990)
	Cognitive Walkthrough	(Polson et al., 1992)
Ecological Approach	Ecological Interface Design (EID) Framework	(Vicente and Rassmussen, 1992)
	Concept of Affordances	(Nielsen and Molich, 1990)
Activity Theory	Activity System Model	(Bødker 1991)
External Cognition Approach		(Scaife and Rogers, 1996)
Distributed Cognition Approach	The Resources Model	(Holland et al., 2002b); (Wright et al., 2000)
Situated Action Approach		(Suchman, 1983)
Ethnomethodological Approach	Technomethodology	(Dourish and Button, 1998)
Hybrid and Overarching Approaches	Systems of Interactors	(Barnard et al., 2000)

Rogers (2004) has extensively and critically reviewed theories in the field of HCI in her paper (Rogers, 2004). Reviewing the literature on HCI theories in detail is beyond the scope of this thesis.

Table 2-4 presents a very brief summary of these methods as well as some of the most influential and most important models and frameworks developed based on these approaches.

Looking at this table, it is clear that there has been a shift in the way researchers regard HCI due to the demands and perceived requirements of the systems which were being developed. The earlier theories and models were derived from traditional cognitive psychology theories. However, the more recent theories attempt to adopt a more holistic approach; hence the notion of distributed cognition or the concept of hybrid models.

Studies from the last few years clearly show a new trend amongst mobile HCI researchers for applying HCI theories to mobile computing issues. Table 2-5 shows number of papers that have focused on different research methods used in the field of Mobile HCI and the purposes these methods have been used for. This table has been based on a total of 102 papers which were published between 2000 and 2002 (Kjeldskov and Graham, 2003).

Table 2-5 - Classification of mobile HCI research adapted from (Kjeldskov and Graham, 2003)

	Research Methods								
Research Purpose		Case Study	Field Study	Action research	Lab Exp.	Survey	Applied research	Basic research	Normative Writings
	Understand	3	4	0	1	4	1	3	2

	Engineer	2	5	0	0	0	45	0	0
	Re-engineer	1	0	0	0	0	9	0	0
	Evaluate	0	8	0	30	4	0	0	0
	Describe	0	3	0	1	0	1	0	5

As it can be seen from the table, the majority of the research in the field of mobile HCI, 55% of the published papers, is devoted to applied research which concentrates on developing and engineering new systems. Therefore, it seems that the main focus of the research community has been on inventing new applications for mobile computing devices.

Interestingly, none of the papers reviewed in Kjeldskov and Graham's article have used "action research" which is the method used for generating and testing new theories and hypotheses. This statistic might suggest reasons for slow advances in generating strong research methods and techniques to support the rapid technological advances in the field of mobile computing.

In recent years, there have been some attempts of changing this pattern. For instance, Zimmerman and his colleagues suggest a model for interaction design research within HCI. Their model, presented in Figure 2-7, attempts to complement current methods of HCI research and offers a method for research through design (Zimmerman et al., 2007).

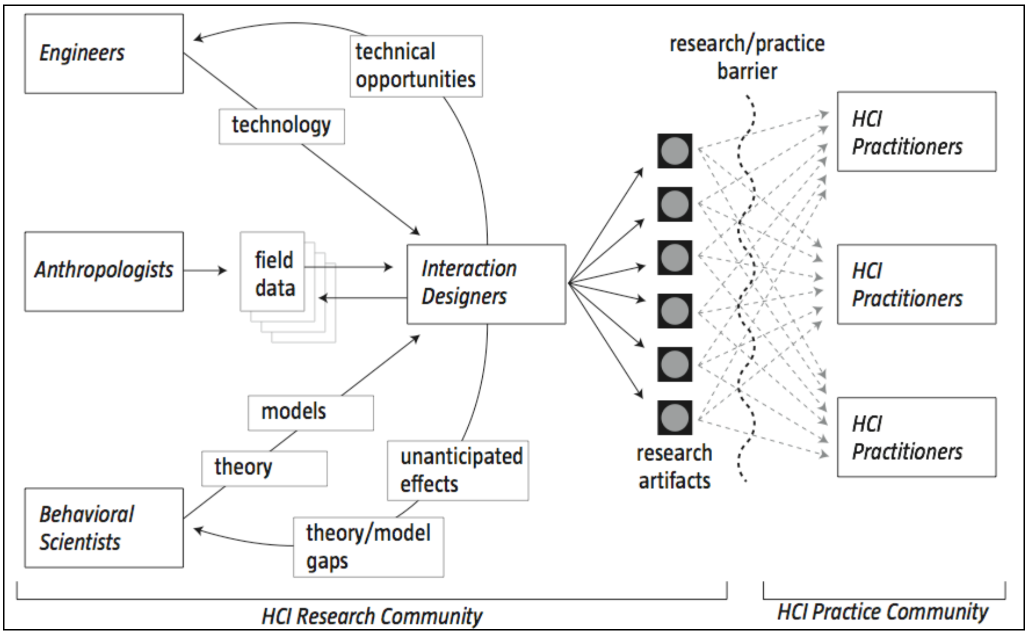

Figure 2-7 - Model of interaction design research within HCI research (Zimmerman et al., 2007)

The model "illustrates the pathways and deliverables between and among Interaction Design Researchers and other HCI researchers" and as Zimmerman and his colleagues point out, will support integration of design in research.

2.4.3. Evaluation of Mobile Computing Systems

The evolution of theoretical frameworks in the field of mobile HCI has affected research methods and consequently evaluation techniques used in the field of mobile computing. Evaluation is intertwined with the design of any application and should be treated as the core element of any design process. However, characteristics of mobile computing devices and their users have posed new challenges to researchers for evaluating the usability of mobile computing systems. As Pedell and colleagues (2003) have pointed out, in addition to the difficulties of evaluating a system that is inherently mobile, there are also various issues in relation to generating an authentic mobile environment (Pedell et al., 2003).

A literature review in 2004 studied 104 papers in the field of mobile HCI and compared them in terms of the techniques used for evaluating the usability of mobile computing systems (Kjeldskov and Stage, 2004).

Table 2-6 summarises the result of this study.

Table 2-6 - Comparison of papers in terms of the evaluation techniques (Adapted from Kjeldskov and Stage (2004))

	Number of Papers
General aspects of usability evaluation	2
Usability evaluation on device simulator	11
Usability evaluation with traditional techniques	44
Usability evaluation with new techniques	6
Usability evaluation not described	15
No usability evaluations performed	36

The statistics in this table clearly show that more than one third of all the studies conducted in the field of mobile HCI do not perform any sort of usability evaluation. Abowd and Mynatt (2000) believe that this relatively little published work on usability evaluation in the field of ubiquitous computing is due to the fact that there are no reliable systems to evaluate. In other words, because much of the research conducted in this field is based on cutting edge technology, more than often the studies focus on reporting demonstrational prototypes. Moreover, they believe that these techniques are inappropriate for evaluating everyday mobile computing situations and perhaps do not reflect the multitasking nature of the mobile user.

More importantly, 38% of the all the studies have employed traditional usability techniques and as it was mentioned earlier it can be debated whether these techniques, which have essentially been developed to evaluate desktop computers, are suitable for evaluating the usability of mobile computing devices.

A more recent literature review on empirical mobile usability studies since 2000 resulted in the identification of 45 papers and articles. An analysis of the methodological strategies adopted by these papers show that 58% of the studies are laboratory-based experiments where 51% of the information is device data (Coursaris and Kim, 2006; Coursaris and Kim, 2007). Perhaps the most important challenge is the fact that there is no widely agreed method for conducting evaluation studies (Jones and Marsden, 2006). Furthermore, Most of the evaluation techniques that are being used by researchers are "task centric" techniques where the fitness of the system is evaluated in terms of performing a specific task.

2.4.3.1. *Mobile Evaluation Techniques*

Jones and Marsden (2006) have identified six evaluation techniques that they believe have proven useful for evaluating mobile systems. These techniques are: 1- quick and dirty, 2- conceptual model extraction, 3- direct observation, 4- interviews, 5- questionnaires, non-user methods such as heuristic evaluation, and 6- experimental evaluation. All of these techniques have been developed for evaluating desktop computers. As it can be seen from Table 2-6, the majority of the evaluation studies conducted in the field of mobile HCI, 39% of the total papers, deploy traditional evaluation techniques. In other words, the majority of the studies have deployed techniques which had been developed for desktop computers and therefore not suitable to address the usability issues of interacting with mobile computing devices.

It is not always easy to apply these techniques to mobile computing settings. For instance, despite the importance and strengths of experimental evaluation, issues in managing experimental studies for mobile computing systems often affect the results of the evaluation. Limited device memory and resources, multiple data sources, and the need for an integrated experimental environment are some of these problems. In order to address some of these issues Gray and colleagues (2005) have introduced a "lightweight experiment management system" for evaluating mobile computing devices (Gray et al., 2005).

Another traditional technique which has been applied to mobile computing research is "heuristic evaluation" (Nielsen, 1994). However, performing heuristic evaluation for mobile technologies can be problematic since the impact of contextual factors is poorly presented. For instance, heuristic inspection performed by an expert evaluator has been compared to a user-based evaluation technique, i.e., usability testing with think aloud protocol for evaluating. The results of this study show that heuristic evaluation merely identifies the general interaction issues and falls short in detecting usability problems related to the support of the collaborative work (Kjeldskov and Skov, 2003b).

The difficulties of conducting heuristic evaluation for mobile computers have inspired researchers to propose alternative variations of heuristic evaluation. Two alternatives have been proposed by Po and colleagues (2004): 1- Heuristic Walkthrough which combines heuristic evaluation with scenarios of use, and 2- Contextual Walkthrough which involves conducting the Heuristic Walkthrough in the field. The result of assessing these evaluation techniques reveals that while contextualising the heuristic evaluation improves evaluation results, introducing contextual detail through scenarios is sufficient for "bridging the realism gap" between mobile computer evaluation and context of use (Po et al., 2004).

Questionnaires are also one of the main techniques for evaluating the usability of computing devices and several questionnaires and scales have been designed for this purpose. QUIS, SUS, and ASQ are only a few examples of such attempts (Brooke, 1996; Chin et al., 1988; Lewis, 1990). However, researchers claim that these questionnaires are too generic and therefore there have been attempts to develop specific usability questionnaires. For instance, Mobile Phone Usability Questionnaire (MPUQ) has been specifically designed to measure the usability of mobile phones (Ryu and Smith-Jackson, 2005). A usability Questionnaire for Handheld Computers has also been developed as part of this research to measure the usability issues of the systems used in Network Rail.

Prototypes have also been a favourite evaluation artefact amongst human computer interaction researchers. However, it is not always easy to reach a balance between cost and benefit in developing functional prototypes. Therefore, there have been efforts to find ways for simplifying the prototype development process. Cogtool is an example of a prototyping technique for assessing user interface of pervasive computing systems (John and Salvucci, 2005). Another instance is the Context Toolkit which is a tool designed by Dey and Colleagues (2001) for rapid prototyping of a "rich space of context aware applications".

Observation is also a much applied data gathering method for evaluation of computing devices. However, collecting useful observation data about the user's experience with the mobile computing device can be very challenging due to the dynamic and varied conditions of use contexts. Therefore, researchers have suggested alternative techniques. For instance, Isomursu and colleagues (2004) asked their participants to collect video and audio data using the camera on a mobile phone. Their technique seems to have provided a richer emotional and more resourceful usage situation than traditional observation methods (Isomursu et al., 2004).

Despite the dominance of traditional evaluation techniques, there have been rare attempts to deploy alternative methods. An example is the study conducted by Pedell and colleagues where they studied the effectiveness of "metadata". They define metadata as (Pedell et al., 2003):

> *"a series of observations on the user data collection process itself, including minutes of the evaluator and evaluator diaries."*

The objective of their study was to study the effectiveness of different techniques and also combination of techniques. They concluded that metadata provides a helpful insight into the main problems of the interface, but there is the danger of a biased impact from individual researchers' subjective theories.

Another example of such attempts is the development of the "rapid user-cantered evaluation technique for context aware systems". This evaluation platform presents the context of use through a 3D virtual reality simulation and this way delivers repeatable, instrumental, and context dependent evaluation of context aware systems. The objective of this system is to reduce the cost of prototype development (O'Neill et al., 2006).

Jensen and Larsen (2008) state that evaluating User Experience (UX) when considering mobile computing devices is fundamentally different to other computing devices, to the extent that they introduce a new shorthand notion for mobile and ubiquitous user experience (μX) which they define as:

> *"The user experience arising from systems, services, and applications with which interaction is essentially mobile and ubiquitous."*

They believe that since μX applications are used in the wild, the evaluation should take place in the field. They suggest that using the sensing and processing capabilities of mobile computing devices, researchers will be able to automate time and resource consuming parts of field studies (Jensen and Larsen, 2008).

2.4.3.2. *Field-Based versus Laboratory-Based Evaluation*

Mobile computing systems are being used in highly dynamic contexts and researchers have raised concerns about suitable and effective evaluation techniques for such mobile devices. A particular problem that researchers are concerned with is the challenge of including context in evaluating mobile systems. In other words, one of the most important challenges for Mobile HCI evaluators is the question of creating a "context of authentic use" (Abowd and Mynatt, 2000). This question forms one of the most important debates in the mobile HCI community. Some researchers believe that in order to effectively evaluate the usability of mobile computing systems, and in particular context aware systems, it is necessary to realistically deploy devices into their environment of expected use. In other words, it seems that it is implicitly believed that field based evaluation is a necessity (Abowd and Mynatt, 2000; Brewster, 2002; Jensen and Larsen, 2008).

However, looking at Table 2-5 indicates that 30% of all the evaluative studies have been conducted in laboratories and only 8% of the papers have reported studies conducted in the field. This is because despite all of the advantages and strengths of a field based evaluation, researchers find them difficult to conduct. They are time consuming, difficult to control, involve complicated data collection activities and researchers have raised questions about their value (Kjeldskov and Stage, 2004; Nielsen, 1998; Pascoe et al., 2000). For instance, the results of an experiment conducted by Kjeldskov and colleagues (2004) reveal that the added value of conducting field based usability evaluations is very little.

These difficulties and shortcomings have led researchers to try development of "realistic laboratory settings" (Kjeldskov and Skov, 2003a). Researchers suggest that recreating the central aspects of the context of use in a laboratory setting will discover the same usability issues that a field study could detect (Kjeldskov et al., 2004). Nielsen (1998) argues that bringing aspects of the field based study into the laboratory can be very beneficial and can help avoiding difficulties and limitations of field based studies. For instance, it will be helpful if researchers could create the physical context of the field in the laboratory in order to generate a more realistic setting. Also using scenarios can enrich the testing in the lab (Nielsen, 1998):

> *"…so as to bring in user's perspective on their work/use situation instead of just the usability workers' and designers' understanding of their artefact."*

In another study Kjeldskov and Stage (2004) have developed and evaluated six alternative evaluation techniques. The objective of these techniques is to assist data collection processes in a controlled environment while identifying usability problems of a mobile use context. They have attempted to incorporate varying degrees of mobility into the evaluation process. The techniques they assessed ranged from evaluating the device while seated on a chair at a table, i.e., laboratory based evaluation, to walking on a pedestrian street, i.e., field based evaluation. Interestingly, the results of their study shows that evaluating the device in a laboratory while seated on a chair at a table detects more usability problems than any of the other techniques. Results of another experiment reported in (Pedell et al., 2003) have shown that laboratory based evaluations identify usability problems at a more detailed level whereas the field based techniques mainly discover "characteristic problems of mobile use".

Laboratory based evaluations create difficulties and challenges too. It is difficult to establish a relation between the mobile computing device and activities in the physical world and to realistically simulate the physical surroundings in the laboratory is very difficult. Conversely, evaluating domain-specific devices requires expert knowledge which might hinder the study. Kjeldskov and Skov (2003a) have compared three different laboratory settings combining high and low fidelity simulations with presence or absence of participants who have domain specific knowledge. They found that employing test subjects who have domain specific knowledge in a simulated laboratory is the most effective technique for evaluating mobile systems. The result of this study also emphasises the difficulties of designing a reliable experiment for evaluation of mobile computing devices.

2.4.4.Summary

In this section mobile HCI research methods and in particular the evaluation techniques used in this field were discussed. Characteristics of mobile computer devices have imposed various limitations and challenges on the research methods and in particular on evaluation techniques used. These challenges have motivated designers and system developers to produce alternative and innovative methods for evaluating mobile computing systems.

2.4.4.1. *Link to this Research*

Understanding Mobile HCI research methods was a necessary first step in this research. More importantly, the literature review reported here pointed out the importance of context of use in understanding Mobile HCI issues more thoroughly.

This chapter provides some evidence of applying mobile HCI research methods in the context of the rail industry. For the purposes of this study, some of the methods and techniques had to be adapted to match the specific nature of the rail context. For instance, as mentioned before, the Handheld Computer Usability Questionnaire was developed specifically to investigate users' interaction with handheld computers in the rail industry.

3. Chapter 3 – Maintenance Operation in the Rail Industry

3.1. Introduction

Explaining the total structure of the rail industry, or even all of maintenance operations, is beyond the scope of this thesis. However, it is necessary to describe the context of this research to help the reader to have a better understanding of the way in which the maintenance department works and what impact handheld computers could have on maintenance and inspection operations.

This chapter is comprised of two main sections. In the first part of this chapter, the role of the maintenance function in running the railway network is explained. This section briefly describes the history of the maintenance operations in Network Rail and the process of bringing the maintenance "in-house". Also, the current structure of the Infrastructure Maintenance Department in Network Rail is explained.

The structure of a typical maintenance team and two of the most important roles in the context of this research are also explained in more detail in this section. Finally, at the end of this part, the history of introducing handheld computer systems to maintenance operations in the rail industry is briefly reviewed. The sources of information for writing the first part this chapter are various. The data has been gathered through field studies, formal and informal discussions with staff associated with maintenance operations at depots, Subject Matter Experts within the Ergonomics team, and online information and documents on the corporate intranet and internet.

In the second part of the chapter, the development of the EDARE framework is explained. First, the background of the research is described. The next section reports on the methods used for gathering user requirements and information obtained at each stage. Finally, the framework and a summary of the results are presented in the last part of this chapter.

At the end of this chapter, the research conceptual framework has been re-presented in order to elaborate the next stages of the research and the detailed methods deployed at every stage are illustrated.

3.2. The Role of the Maintenance Department in Operating the Railway Network

In the Strategic Business Plan published in October 2007, Network Rail has set seven outputs for control period four (2009 to 2014): 1- safety, 2- environment, 3- reliability and punctuality, 4- capacity and capability, 5- asset reliability and stewardship, 6- stations, and 7- network availability (Network Rail, 2007a). Many functions are involved in delivering these outputs and providing an operational railway. Figure 3-1 displays the main functional teams that work together to maintain the railway.

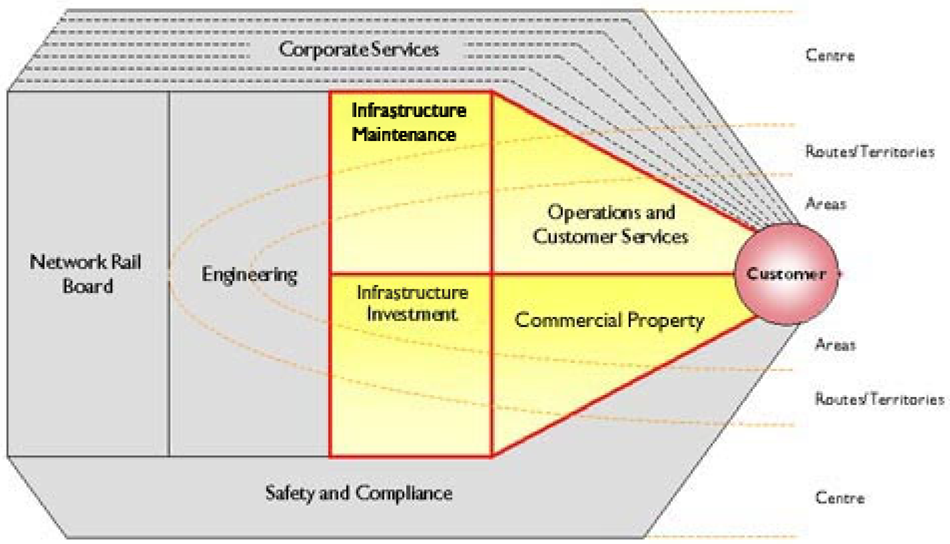

Figure 3-1 - The key functional teams (within Network Rail) involved in maintaining the railway (Network Rail Intranet)

While all teams need to co-operate closely to deliver the desired outputs, some functions are central to ensuring that the desired objectives have been achieved. Achieving improved asset reliability and stewardship is the core task of the maintenance function and one in which maintenance function is directly involved.

However, the contribution of the maintenance function is not limited to this output. Safety, reliability and punctuality, capacity and capability, and track availability can also be linked to the performance of the maintenance function. Successful delivery of all these outputs depends on effective and efficient performance of the maintenance team. Safety, both in terms of the workforce safety as well as safety of the trains on the network, requires that the maintenance team maintain the infrastructure to the highest standards. Track availability is also a function of efficient and on time delivery of engineering work. Reliability and punctuality of the services and consequently Network Rail's image can be greatly damaged if maintenance and engineering work overrun. These reasons all confirm the importance of enhancing the performance of the maintenance team.

3.2.1. History of Maintenance Operations in Network Rail

After privatisation, the rail industry was transferred into a complex body of various organisations, each with different roles, responsibilities, and objectives. This complexity was believed to be one of the reasons for an increased rate of incidents and accidents on the rail network. Three major incidents; Southall in 1997, Ladbroke Grove in 1999, and Hatfield in 2000; which led to a total of 42 fatalities, exposed further the fragility of safety procedures within Railtrack. In all of these incidents, maintenance issues were identified as either the main or contributory cause of the accidents. Although various factors contributed to demise of Railtrack in October 2002, these incidents are often identified as the main reason for company's collapse.

The experience of failures of the Railtrack made it clear that it is necessary that all responsibilities for delivering maintenance activities, as a core activity, remain with the network operator. Therefore, in October 2003, about one year after it was founded, Network Rail announced that all day-to-day maintenance operations of the railway would be brought in-house. This decision is believed to be the most "fundamental change in the industry since privatisation" (Connect, 2008). John Armitt, the then chief executive of Network Rail, explained that (BBC, 27 March 2003):

> *"Bringing these contracts in-house will help us to understand the reasons why costs have risen and obtain a clear understanding of the maintenance delivery activity. Improving the efficiency of maintenance will help optimise our renewals expenditure; the two are inextricably linked."*

By the middle of 2004, Network Rail had finalised the transfer of nearly 16,000 maintenance workers; almost doubling the size of the company and bringing the maintenance of the rail infrastructure completely in-house (Network Rail, 2008b).

The next step in improving the performance of the maintenance function was to standardise and simplify the way that the maintenance department works. Therefore, in an attempt to improve performance and efficiency, the Infrastructure Maintenance department in Network Rail underwent a major reorganisation in September 2008. This reorganisation is believed to be the biggest organisational change since privatisation.

3.2.2. Infrastructure Maintenance Department

Infrastructure Maintenance Department in Network Rail comprises 40 delivery units aligned to nine route infrastructure maintenance directors. However, in terms of delivering maintenance operations, the department is divided into three sub-groups: Signalling and Telecommunication, Track and Off Track, and Electrification and Plant Maintenance Engineering.

The detailed structure of the Infrastructure Maintenance Department and all the various roles and responsibilities within each sub-group is beyond the scope of this chapter. Nevertheless, it is essential to briefly describe the duties and tasks of these sub-groups.

3.2.2.1. *Signalling and Telecommunication Maintenance Engineering*

Signalling systems are used in order to regulate the train traffic and keep trains apart. There are thousands of signals across the network. The signalling system plays a vital role in safety, reliability and punctuality of the rail traffic. Moreover, a vast network of digital and analogue telecommunications systems are used to control safe passage of trains. Maintaining any electrical equipment on the infrastructure which is associated with the signalling or telecommunications structures is the responsibility of the S&T team.

There are various documents and standards that address testing and maintaining S&T equipments: Signalling Maintenance Testing Handbook, Signalling Maintenance Specifications, and a whole host of documents on telecommunications technical issues (Network Rail, 2006c; Network Rail, 2006a; Network Rail, 2007b). A brief review of these documents reveals that the range of the assets managed by S&T maintenance team is very broad and varied. Signals and any associated equipments such as cables and lamps, equipment that operate switches and crossings, and trackside telephones are only a few examples of these assets.

3.2.2.2. *Track Maintenance Engineering*

The track maintenance section is responsible for inspecting, patrolling and maintaining various track and off track assets and features. Network rail maintains and manages 20,000 miles of track as well as 20,000 switches, crossings, and points across the network. Track is defined as "various components which constitute the structure on which trains run" (Network Rail, 2005a). Off track assets, as the name suggests, are any assets that are on the trackside and are not part of the main track infrastructure. The main objective of track inspection is to identify faults when they first appear in order to prevent any further degradation which might become dangerous. In other words, it is necessary to ensure that the rails are stable and aligned smoothly; horizontally and vertically.

Table 3-1 summarises some of the different track and off track assets (Network Rail, 2005b; Network Rail, 2007c):

Table 3-1 - Track and Off Track Assets maintained by Track Engineering Team

Track or off track	Assets on the Infrastructure
Track assets	Ballast, switches and crossings, rail fastenings, sleepers, stretcher bars and brackets, expansion switches, and bridges and other structures

Off Track assets	Fencing, foot crossing, telephones, tunnels, trees and vegetation, access point steps, drains, ditch courses and waterways, culverts, and catch pits

Responsibility of the track maintenance department varies depending on the type of the asset and its features. For instance, in case of level crossings, Track Maintenance Engineering is responsible for managing level crossing inspections. However, depending on the asset on the level crossing, the maintenance activities could be performed by other teams.

3.2.2.3. *Electrification and Plant Maintenance Engineering*

40% of the entire rail network is electrified and over 60% of the rail traffic operates electrically. The Electrification and Plant (E&P) maintenance team are responsible for various mechanical and electrical assets on the network ranging from high voltage electrical distribution equipment to signalling power supplies.

In a very broad classification, E&P equipment can be divided into three categories: 1- contact system which allows trains to pick up electrical current; i.e., overhead lines and conductor rails, 2- distribution which delivers power from the National Grid to the lines, and 3 – plant which covers all the fixed trackside machinery (Network Rail, 2008a).

Figure 3-2 - E&P team maintaining overhead electrification lines

Figure 3-2 illustrates a team of E&P workers maintaining high voltage overhead electrification equipment.

3.2.3. Track Staff Role

In this section, the roles and responsibilities of various track staff will be briefly explained. The reasons for gathering this information were twofold. First, the researcher needed to understand how workers perform their tasks and, more importantly, the information requirements for performing each task and thus the potential impact of handheld technologies. Secondly, this data will allow the reader to obtain a better and more thorough understanding of the context of work.

The information requirements of track staff will only be briefly reviewed in this section. The second part of this chapter will discuss these in greater detail.

3.2.3.1. *Typical Roles within a Maintenance Team*

Depending on the type of the protection required, the roles within a maintenance team varies. Protection is the generic term used to describe arrangements where personnel are "protected" against the possibility of a train entering the area they are working in. There are two types of protection arrangements: 1- green zone and 2- red zone. Green zone refers to an area where track workers have been segregated from train movements. A red zone, on the contrary, is an area where track workers are working and trains have not been stopped. Table 3-2 summarises the typical roles required for each of the arrangements for each type of protection.

Table 3-2 - Different roles in green and red zone protection areas

Protection Type	Role	Responsibilities and tasks
Green Zone	COSS	Establishes a suitable and safe work setting
	Track Workers	Variable depending on the task
Red Zone	COSS	Establishes a suitable and safe work setting
	Lookout or site warden	Informs track workers of an approaching train
	Track Workers	Variable depending on the task

Controller of Site Safety (COSS), as the name suggests, is responsible for establishing green or red zone requirements for the safety of the personnel working on the track. A lookout is defined as a person who is competent to undertake lookout duties which involves informing track workers of any approaching trains. Track workers are referred to any member of staff who undertakes the actual engineering and maintenance task on the track. Figure 3-3 shows a group of track workers being briefed by a COSS. The worker holding the blue and white flag is a lookout.

Figure 3-3 - COSS briefing the track workers on safety arrangements

In this research, the main focus has been on two groups of track workers: maintenance track staff and Mobile Operations Managers (MOM). These two roles will be discussed in greater detail here.

3.2.3.2. *Track workers*

A track worker, in this thesis, has been defined as someone who is involved in some sort of maintenance or inspection task on the track. Their tasks vary from digging ballast, laying rails, building bridges, to maintaining electrical equipment and performing cyclic inspections (Murphy, 2003). Track workers may have various competencies and grades.

The information requirements of track workers are variable based on the type of the job they perform. However, all track workers need some generic information. The main and perhaps most important item of data for a track worker is local spatial knowledge. The reason for the importance of this knowledge is the fact that the initial step for performing any maintenance task is getting to the location and finding the asset which needs to be maintained. Furthermore, local knowledge is essential for establishing a safe system of work.

Table 3-3 - Track worker: Summary of main responsibilities and key information requirements

Main responsibilities	Varies depending on the task
Key information requirements	Local and spatial information Task specific information Safety related information (from COSS briefing forms)

3.2.3.3. *Mobile Operations Managers*

Mobile Operations Manager (MOM) is in fact an operations role rather than a maintenance role and falls within the Operations and Customer Services Department in Network Rail. However, since they were interviewed and used as participants for various experiments, it is necessary to explain their role here. MOMs are frontline staff and as the job title suggests, they are mobile and field based. MOMs are also contacted in case of any accidents and incidents by the signaller or the controller and should be the first to attend to an incident and to help resolve the issue.

Like track workers, local and spatial knowledge is crucial to MOMs. This information is in particular important to them since their role involves attending to accidents and failures. An accident can happen anywhere on the railway and therefore MOMs are required to know their area of work thoroughly and accurately.

Table 3-4 - MOM: Summary of main responsibilities and key information requirements

Main responsibilities	Front line incident management Audit trails of signalling staff and level crossings including signal post telephones
Key information requirements	Local and spatial information Task specific information Contact details of different teams and functions within their area Rules and regulations

3.2.4. Handheld Computers for Maintenance Operations

Although handheld computers can be used for a whole host of various applications in the rail industry, the portable nature of these devices makes them an obvious option for mobile tasks such as maintenance and inspection operations.

Attempts at introducing handheld computers for rail engineering operations began as early as 1992 with the implementation of a handheld computer device for S&T inspectors. This device was introduced by one of Railtrack contractors and it was not considered to be a successful system. In 2000, another handheld computer system was introduced to maintenance operations, but the project was not followed when the maintenance function was brought in house.

In 2006, the Signalling and Telecommunication (S&T) handheld computer system project was taken up again. The system was mainly based on the earlier version introduced in the 1990s and it was implemented on a different hardware. Currently there are two handheld computer systems in Network Rail: Signalling and Telecommunication (S&T) and Level Crossing (LX) inspection handheld systems. Both systems are now being used nationally by S&T and LX inspectors and there are plans for introducing handheld computers to other operations within the Infrastructure Maintenance department.

In the next part of this chapter, the development of the EDARE framework, which was generated with the aim of analysing and structuring information requirements of track workers, will be explained.

3.3. Electronic Device Applications in Rail Engineering (EDARE)

3.3.1. Background

It has long been accepted that the key to the success of any interactive system is to include users in the design process (ISO-13407, 1999). Focusing on users and the tasks they perform very early on in the process of interface design and eliciting user requirements accurately and thoroughly are considered to be some of the most important principles of User-Centred Design (Gould and Lewis, 1983).

It is difficult to imagine how a system can be designed if the designer is not aware of users' tasks, requirements, and context of work. In fact, all HCI design models start with the concept of requirements gathering. The first step towards identifying user requirements necessitates understanding the users, the tasks they perform, the information they require to perform these tasks, and the context of work. Therefore, some user centred HCI design models distinguish between requirements specifications and user needs analysis. Requirements specification is a complicated and detailed procedure which generates a list of detailed functional and non functional requirements for the design of the application. A user needs analysis activity however, focuses on gathering "informal, fuzzy statements" from users in order to understand users (Lindgaard et al., 2006). It seems necessary to form this understanding prior to generating a detailed requirements specification document.

Many usability engineering methods assume that a previous generation system already exists and that experienced users are already performing the tasks the system is intended to support, and suggest methods for capturing user requirements based on these assumptions. More often than not these assumptions are not met and there is a gap between the methods recommended in theory and those used in real world settings for capturing user requirements (Lindgaard et al., 2006). For instance, in the case of the handheld computers used in Network Rail, systems in their current form have been designed for the first time and there is no past experience to base the design on. Moreover, the intent of the mobile technology project was to open up a new method for work routines.

The Information Management (IM) department in Network Rail is responsible for design and development of all computer systems. IM uses a dedicated requirements management tool which is used for capturing and managing business requirements. This tool is part of the Service Development Lifecycle (SDL) process which covers all the technical products and deliverables (see appendix 3.1 for an overview diagram).

Although from a human factors point of view many aspects of this lifecycle are debateable, this method still offers detailed plans and tools for gathering and managing user requirements.

Handheld computer projects also need to follow these procedures. However, a personal conversation[1] with the business analyst who was involved in development of the Signalling and Telecommunication (S&T) and Level Crossing (LX) handheld computer projects revealed some of the limitations of this procedure, in particular when dealing with large end user populations. In terms of the S&T and LX handheld computers, according to the project's business analyst, apart from a "couple of workshops with representatives of the end users", most of the decisions were made within a "working party" which implies that in most cases end users were not involved in the requirements specification process.

Studying the reference manual for business analysts, which has been provided by the IM department to guide business analysts throughout the design lifecycle, showed some of the shortcomings of these procedures. For instance, although the method suggests using techniques such as interviewing stakeholders and prototyping for identifying functional and non-functional requirements, there are no clear strategies for designers and system developers to study users' tasks. It is not clear how designers should obtain and develop an understanding of the tasks for which the application is being designed. For instance, there is no mention of activities and techniques such as site visits or task analysis. It seems that the main focus of this process is on defining a technical application as opposed to defining an application for a group of users.

These considerations highlight the importance of understanding user needs accurately and thoroughly before attempting to create a requirements specifications document. Therefore, developing a framework

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[1] Informal conversation on the phone on 7 June 2007.

to assist user needs analysis activities for mobile and handheld computing systems might help improve the current requirements management process. As a result, the next stage of this research focused on identifying information requirements of maintenance workers for engineering tasks and proposing potential mobile computing solutions for the identified requirements.

The framework developed in this research is not designed to substitute for existing requirements management procedures by identifying detailed functional and non functional requirements; instead it aims to complement the process by providing a user-centred starting point. Also, it is important to note that this framework focuses on mobile computing solutions for mobile tasks. The following are the objectives of the Electronic Device Applications in Rail Engineering (EDARE) framework:

1. Providing mobile application designers and system developers with a means of understanding maintenance worker tasks and context of work,

2. Summarising users' information requirements in the context of rail engineering operations and therefore providing designers with a reference,

3. Proposing potential handheld and mobile computing solutions for the identified requirements.

In the next section the methods used for developing the framework will be discussed.

3.4. Method

There are several methods for eliciting user requirements ranging from interviews and focus groups to task analysis and scenario building (McClelland and Fulton Suri, 2005). Different methods and techniques were considered in order to choose the most appropriate approach.

Due to the complexity of the tasks and context of use, it was important to ensure that the selected methods provide a good and thorough understanding of the context of use, users, and their tasks. But it was equally important to ensure that the data which is being collected is understandable and manageable. Moreover, this framework was not being developed for any specific solution and therefore, it was necessary to maintain the generalisability of the information. For all these reasons it was decided to use a range of exploratory methods.

The methods used for developing the EDARE framework and in fact the framework itself have evolved during the course of the research. In other words, the data gathered at each stage has been used to shape the data gathering strategy in the next phase and each stage has complemented and added to the information in the framework. As Figure 3-4 illustrates, different methodological strategies were adopted for developing the EDARE framework.

Figure 3-4 - Different Stages of the methodological strategy for developing the EDARE framework

The information used for generating the framework came from three sources: 1- site visits, 2- brainstorming sessions with researchers and subject matter experts, and 3 – semi-structured interviews with maintenance workers. Development of the methods and information obtained at each stage has been explained in detail in the following sections.

3.4.1. Information from Site Visits

Site visits conducted during the early stages of this research provided valuable and rich information about the context of work and users' tasks.

During these site visits, the author shadowed the maintenance workers throughout their shift and took note of their activities and any information they required to perform these activities including any paper-based forms, documents, guidelines, and track diagrams.

3.4.1.1. *Information Obtained*

The data collected at these site visits was a hand written list of information requirements of maintenance workers. This list contained individual detailed items of information required by users for performing their tasks. At the end of each site visit, the maintenance workers were asked to review the generated list of information and confirm that it was accurate and complete.

Considering the amount of data that was gathered and also the quality of the information, it became apparent that it would be difficult to derive user needs information from this data. Therefore, it was essential to organise and group the data in a manageable structure.

3.4.2. Brainstorming sessions with Human Factors Researchers and Subject Matter Experts

Studying the scattered nature of the information gathered in the previous stage indicated the need for a more structured function analysis approach towards data gathering. In order to achieve this objective, two brainstorming sessions were organised which aimed to identify high level functional needs of maintenance workers. This structure was gradually expanded to include detailed items of functional and information needs.

The first session was with three human factors researchers in the Human Factors Research Group at University of Nottingham who had experience of working with maintenance workers on various research projects. The second session was organised with two Subject Matter Experts (SMEs) who have several years of experience of working in the railway and provide the Ergonomics Team in Network Rail with practical experience and information.

3.4.2.1. *Procedure*

At the brainstorming sessions the author introduced herself and explained the aim of the session. As mentioned above, the objective of these sessions was to find a way for structuring the functional needs of maintenance workers and grouping user’s information requirements.

The method used at this stage was based on the idea of Functional Flow Analysis. Functional Flow Analysis is believed to be the most useful technique for decomposing the functions that must be performed and classifying them into zero, first, second, third, and higher level functions (Chapanis, 1996).

During the sessions, the researchers and SMEs were asked to:

1. List different stages of any typical maintenance or engineering work. The participants were asked to start the list at a very high level which can be generalised to any engineering work. This list was considered to contain the zero level functions.

2. They were then asked to expand each category further, i.e., identify subcategories, but mainly focusing on information requirements. The subcategories generated created the first level functions.

Participants were also asked to keep the explanations independent of any specific maintenance or inspection task. Each session took between one to two hours. At the end of the discussions, the researcher summarised the findings and asked the participants to confirm that they agreed with the generated lists.

3.4.2.2. *Analysis*

The information obtained was in form of handwritten notes. The following stages were followed for analysing this data:

1. The data was reviewed and high level categories and subcategories from the two sessions were compared,

2. The data was collated and summarised into a single list which presented high level categories and subcategories identified,

3. The lists were presented illustratively through a series of flow charts which were verified by subject matter experts.

3.4.2.3. *Information Obtained*

Figure 3-5 illustrates the zero level functions that were generated from the information gathered during the brainstorming sessions. The handheld computer symbols indicate the potential for introducing a handheld computing device to that stage of the task.

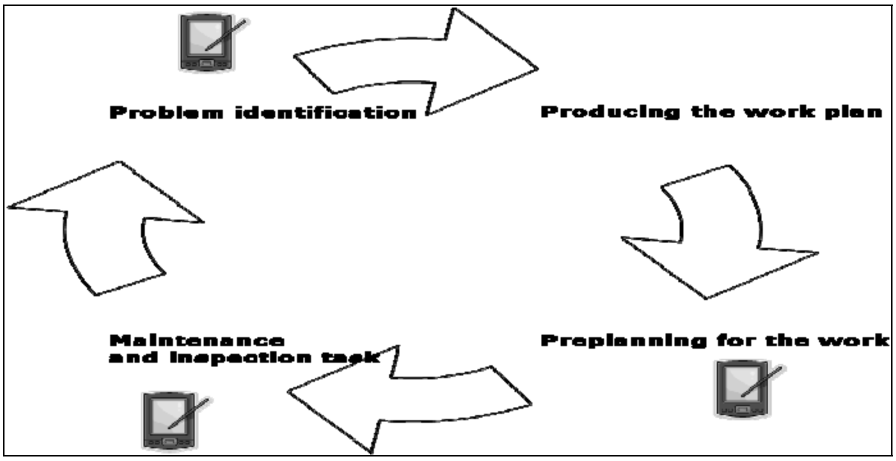
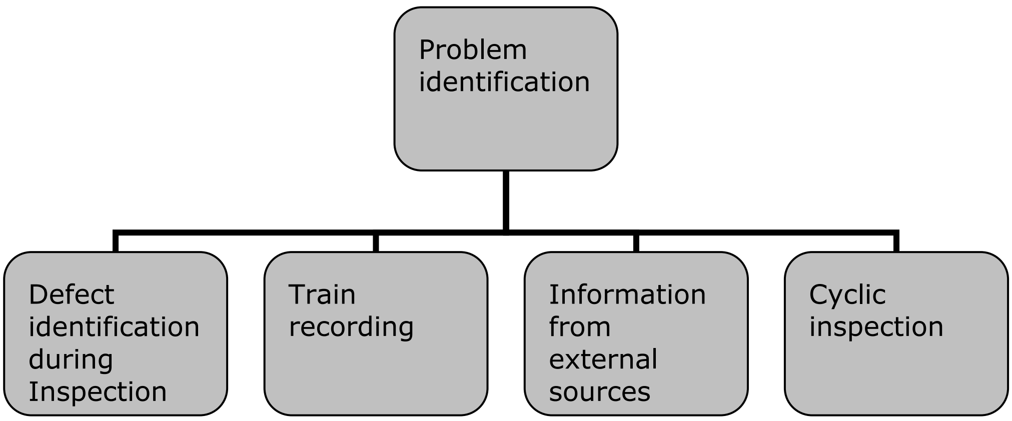


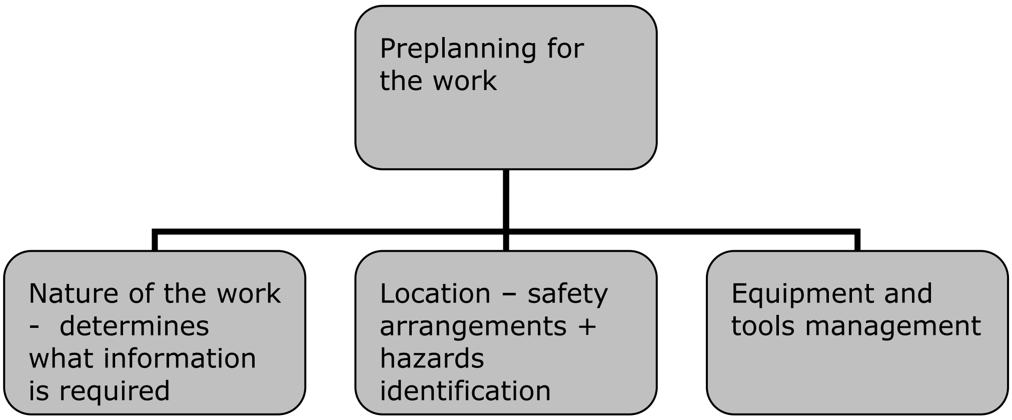
Figure 3-5 - Maintenance / inspection task information cycle

Any engineering work starts with identification of a problem. The problem is not necessarily an outstanding issue with the asset and can also include the need for the asset to be inspected on a regular basis to ensure its safety, i.e., a pre-planned inspection regime. The following diagram summarises the sources of information which might trigger an engineering work.



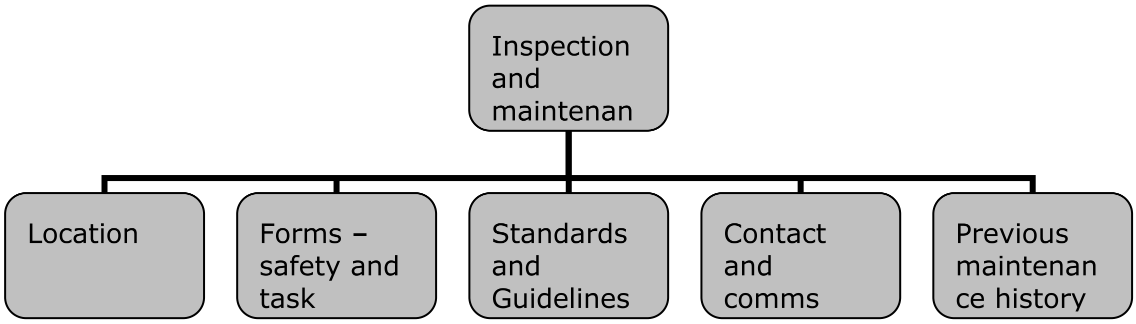
The next step is producing the work plan. At each maintenance depot, there is a planning team in charge of producing these work plans. The work plans provide information about the asset that needs to be maintained, its location which usually is presented in form of an asset number, and a time based programme for the inspections.

Once the work plans have been prepared and handed out to maintenance workers, they start preparing for performing the task. Maintenance workers need information about the location of the asset, nature of the task, the required safety arrangements, any hazards in the area, and necessary equipment and tools for performing the task.



The final stage is performing the maintenance and inspection task. The most important item of information at this stage is location. The workers need to be able to locate the asset and find a way for getting to the asset. Also, maintenance workers need to fill in various forms and checklists as part of their tasks. These forms range from safety briefing forms that inform the workers about the relevant safety arrangements to asset inspection checklists or defect reporting forms. They also might need to refer to several documents including standards and guidelines that determine the way the tasks should be performed.

Moreover, maintenance workers might need to contact signallers, controllers, Mobile Operations Managers (MOMs), etc. for various reasons while performing the engineering work and therefore it is necessary that they have all the relevant contact details. Finally, workers usually need to find out about previous maintenance history in order to avoid any duplications and unnecessary maintenance work and therefore it is important that they have such information available to them while working on site. The following diagram displays the high level information requirements of maintenance workers for performing the engineering work.



The information collected at this stage was grouped together and summarised into six main information requirements: 1 - location, 2 – material and store management, 3 – forms, 4 – standards and guidelines, 5 – previous maintenance history, and 6 – communication details. This information was then used to construct the initial framework (see appendix 3.2).

This framework was sent to all members of the Ergonomics National Specialist Team in Network Rail by email. The team members were asked to populate the table based on their own experience of dealing with maintenance workers. They were asked to expand the framework and add as much detail to it as they could. Specifically, they were asked to expand the six items of information requirements, determine the current source of information and state how the information is currently being presented to maintenance workers.

Six of the team members sent their comments: two Subject Matter Experts, and four human factors and ergonomics specialists who all had experience of working with maintenance workers on various projects. Once all the information was gathered, it was collated and summarised into a single framework.

Figure 3-6 displays the information requirements diagram developed at this stage (the highlighted blocks represent the information which was added after analysing interview data). This information is in fact the data presented in the first two columns of the framework.

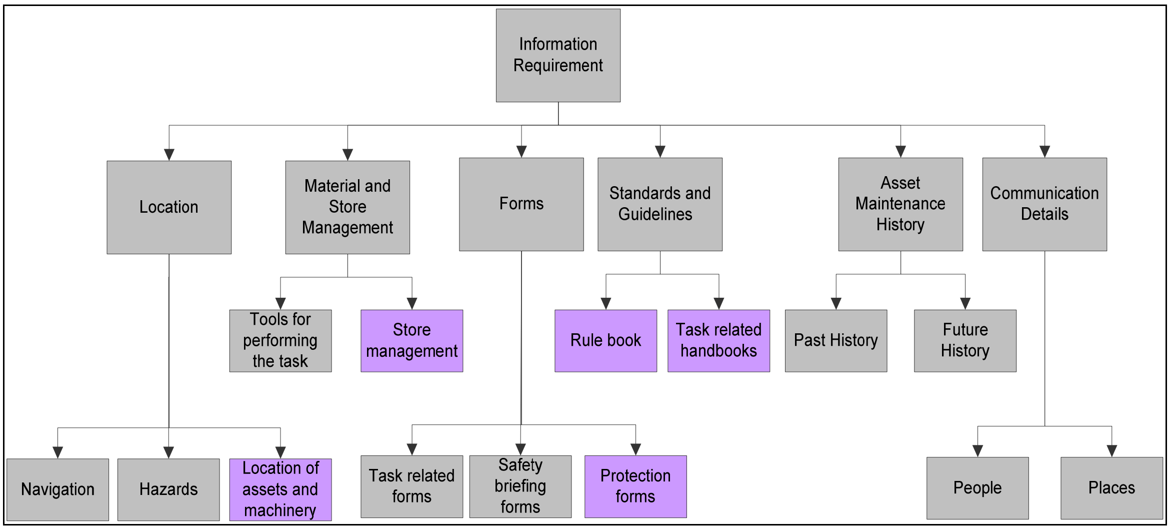


Figure 3-6 - Information requirements diagram

In the final stage of this study, a series of interviews with maintenance workers were conducted and the information collected was used to complete the framework.

3.4.3. Interviews with Maintenance workers

As mentioned before, the accuracy and comprehensiveness of a requirements specification document depends on the degree of involvement of end users and nature of data capturing methods. Furthermore, it was believed that the only way for ensuring that the framework represents the context of work accurately is to include maintenance workers in the requirements gathering process. Therefore, a series of semi structured interviews with maintenance workers were designed with the aim of complementing the information gathered at the previous two stages. The objective of these interviews was to find out how maintenance workers perform their tasks and more importantly what information they require for that. These interviews were used to add to and complement the EDARE framework.

3.4.3.1. *Participants*

Four maintenance workers were interviewed. It was important to ensure that the participants chosen for the interviews cover all the typical roles and responsibilities within maintenance and inspection operations.

Therefore, a Subject Matter Expert with extensive experience of the rail industry who was familiar with various roles and job titles was consulted during the participant selection stage. Table 3-5 summarises the role profile of the maintenance workers who were interviewed.

Table 3-5 - Role Profile of the interviewees

No.	Job Title	Main roles and responsibilities	mobile or office based tasks	Experience
P1	Local Operations Manager (LOM)	Managing 33 signallers and 3 supervisors Shift Signalling Manager (SSM) Responding to incidents Rail Incident Officer (RIO) in case of collisions and derailment Assessing signallers	Routinely office based and reactively mobile	Over five years in this position
P2	Relief Mobile Operations Manager (MOM)	Responds to any faults or incidents on the infrastructure Working as the duty Shift Signalling Manager (SSM)	Mainly mobile	11 years in this position and 27 years in the railway
P3	Maintenance worker	Person In Charge of Possession (PICOP) Track inspection duties and repairs Controller of Site Safety (COSS)	Mobile	20 years
P4	Maintenance worker	Track inspection and maintenance	Mobile	7 years

3.4.3.2. *Procedure*

A semi structured interview was designed. The questions in the interview were validated and verified with the help of SMEs (see appendix 3.3). The questions were used as a checklist to trigger the discussion, but the semi structured format allowed the researcher to investigate further any areas of interest which was raised during the interviews.

Robson (2002) explains the procedure for conducting semi structured interviews. This process was followed to set out the sequence of the interviews in this study (Robson, 2002):

1. Introductory comments: the author introduced herself and explained the purpose of the interview. She also handed out a consent form (see appendix 3.4) which described the aim of the study in detail and provided the participants with some background information as well as ensuring them about the confidentiality and anonymity of the gathered data.

2. List of possible questions: a list of 11 questions was prepared which contained key questions as well as some prompts to trigger further discussions. The key topics in the interview focused on three subjects:

2.1. Information and functional requirements: this section focused on finding information about maintenance workers' tasks and the information requirements for performing these tasks,

2.2. Forms: since paper work and filling in forms is an important part of maintenance workers' tasks and because of the potential for transferring paper based forms to handheld computer solutions, it was important to investigate these in more detail.

2.3. Where the information is needed: it was important to establish how much of this information is required on the trackside and therefore maintenance workers were asked weather their tasks depend on the availability of the information on site.

3. Closing comments: the author asked the participants if they had any comments or remarks and finally, the participants were thanked for their time.

3.4.3.3. *Analysis*

Each interview took, on average, between 30 to 45 minutes and all of the interviews were tape recorded. In order to analyse the interview data at this stage, the "template approach" was used (Robson, 2002). In this method, a set of provisional codes are created and used as a "start list" for analysing the data (Miles and Huberman, 1994). In this research the list of information requirements and sub-requirements, presented in Figure 6-3, were used for coding the data. The following stages were pursued for the analysis of the interview data:

1. The tape recorded interviews were transcribed and the document was transferred to the software package NVIVO,
2. The data was then categorised using the codes,
3. Once all the data was coded using the provisional, initial codes, it was reviewed again to detect any other themes or items of information that had not been picked up during the initial coding,
4. The coded items of information were then organised in the framework under relevant "requirements" and "sub-requirements".

3.4.3.4. *Information Obtained*

The information gathered at this stage duplicated many of the items identified in the previous stage; i.e., the brainstorming sessions. However, this data added some very interesting contextualised details to the framework that could only have been identified by maintenance workers who perform the tasks day in day out. Once the interviews were analysed, the collected information was used to populate the framework.

3.5. The EDARE Framework

Table 3-6 presents the EDARE framework. The first and second columns in the framework present the information requirements and sub-requirements. The third column summarises the individual items of information which are in fact a detailed extension of the sub-requirements. This data comes from maintenance worker interviews and comments made by researchers and SMEs. Column four displays the source of the data displayed in column three. Finally, Column five presents information about the current form of the information and column six summarises proposed handheld computer solutions for the identified requirements. The data presented in the framework is explained here in more detail.

Area knowledge comprises a large part of the maintenance workers' information requirements. They need local information for three purposes: 1 – to navigate to the desired location, 2 – to find out about potential hazards and set up the appropriate safety arrangements, and 3 – to find the asset that needs to be inspected or maintained. Most of the maintenance workers rely on their own personal experience for this information.

Information about potential hazards is found in the Hazard Directory. The Directory lists all the principle hazards such as buried cables, pipelines, and contaminated land to name just a few. However, this information is presented in mileage order and maintenance workers need to map this information onto the Sectional Appendix which contains information about the line speed, line direction, location name, etc on a schematic track diagram. Moreover, in the Sectional Appendix mileage is given in miles and chains, each chain being 22 yards, whereas in Hazard Directory miles and yards are used. Therefore, any planning requires maintenance workers to consult two documents which are not compatible in terms of measurement units and presentation of information. Also, although these documents are available to maintenance workers and are usually carried around in the vans, they are rarely taken out to the site. It seems that maintenance workers have attempted to make up for this problem with customised maps and personal satnav devices[2].

When it comes to finding assets on the infrastructure, depending on the type of asset and the nature of the maintenance activity, workers obtain

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[2] Mobile Operations Managers (MOMs) have recently been issued with satnav systems.

information from different sources. For any general task, at least two sources of geographical information need to be consulted: the Sectional Appendix and Hazard Directory. There are many examples of workers failing to find an asset mainly because they tend not to take the Sectional Appendix and other sources of paper-based spatial information to the trackside. The most important issue, which has led maintenance workers to leave the paper-based documents in their vehicles or at the depots, is difficulties of managing large amount of paper-based documents while working on the track. The other problem is the reliability and accuracy of the documents. Maintenance workers often expressed concerns about documents not being up-to-date. One of the interviewees gave the following example of consequences of such difficulties (interview 1, 13 August 2007):

> *"Like yesterday we had a points failure and I sent the staff out and he sprayed them [so that the technicians can find it]. The S&T spent two hours travelling to the point and they couldn't find it and then they travelled back."*

Another important factor for maintenance workers is ensuring that they have all the necessary tools and equipments. As mentioned before, all the necessary equipments are available in the vans and the vans are usually checked once a week to ensure that nothing is missing. At some depots, workers have created a database of the necessary tools and materials which they use as a source of information for managing the stores. These databases are usually produced in form of Excel spread sheets.

Forms are also considered to be an important part of the information requirements of the maintenance workers. Broadly speaking, forms can be classified into three categories: 1- safety briefing forms, 2 – protection forms, and 3- task related forms. Any kind of track visit, regardless of whether there is going to be an engineering work, requires the appropriate safety forms to be filled in. Different types of protection[3] arrangements also require specific forms. Moreover, recording the status of the assets or any detected defects requires maintenance workers to fill in relevant forms which depend on the type of asset and the type of engineering work. Although maintenance workers are expected to fill these forms in on site, it seems that they rarely take the forms out with them. Managing paper work while working on the trackside under varying weather conditions can be very difficult and time consuming. So as one of the interviewees explained (interview 3, 22 August 2007):

> *"What a lot of the lads tend to do is that they walk the path [i.e., perform the task] and then they get back to the van and there they transfer that information onto the forms."*

And this method creates some problems (interview 1, 13 August 2007):

> *"The form is quite lengthy and is really detailed and there are calculations that you need to do. So again, you really should be doing that on site, but really you are not going to. And because it is done afterwards, people make mistakes."*

The next item of information is standards and guidelines that maintenance workers refer to for performing their tasks. Again this can be either the rule book which contains general rules and regulations or task related guidance. Since maintenance workers receive on-the-job training and are assessed regularly, they very rarely refer to the guidelines. Despite this, some maintenance workers believe that they will benefit from having these documents with them on site (interview 4, 15 November 2007).

[3] Protection is the generic term to describe arrangements to protect engineering work against the possibility of a train entering the area in question.

Asset maintenance history is also considered to be useful to maintenance workers when performing maintenance and inspection task. This information can potentially help maintenance workers to avoid duplications. The same asset might be inspected by a different team each time and it is not possible for teams to pass on all the information they have gathered at different periods. Therefore, in some cases, maintenance workers perform the same task several times. Maintenance workers do not have access to this information unless they request for copies from their supervisors, but they believe that having this information will help them in performing their tasks (Interview 4, 15 November 2007):

> *"If we could have a system that as you come into a [previously reported] fault, it started beeping or something and show you the information you need to know about it, I think it would be good."*

Communication forms a crucial part in maintenance workers' day to day duties and they need to communicate with different parties in order to perform their tasks. For instance, in order to arrange a protection for an engineering work the PICOP (Person In Charge of Possession) needs to contact the signaller several times. In the absence of a signal post or line side telephone, workers usually use their mobile phones for contacting their colleagues. This means that maintenance workers should know which signal box or control centre they should contact and experience and local knowledge play an important role in determining this information.

The last column in the framework proposes potential ways of transferring the identified information requirements to handheld computer solutions. The information in this column has been derived from brainstorming sessions, comments during the interviews, suggestions from the SMEs and the author's personal experience. These solutions provide high level hypothetical examples of how a handheld computing device could satisfy any of the identified information requirements.

Table 3-6 - EDARE Framework – Electronic Device Applications in Rail Engineering Framework

Information requirements	Information sub-requirements	item of information	Where do the maintenance workers get the information from?	Current Form of Information	Proposed handheld computer solution
1- Location	1.1- Navigation	General area knowledge	Personal experience, A to Z maps, satnav systems	Paper based, digital maps	Digital track diagrams presented on mobile devices where information from the sectional appendix and hazard directory are merged and mapped onto a schematic scaled diagram. The device can be equipped with a location aware system such as GPS and therefore it can be used as a navigation tool for maintenance workers.
		Access and egress points	Hazard Directory	Paper based, also available electronically on the corporate intranet, customised documents at some depots	
		Signal number	Signalling diagrams	Paper based	
		Mileage	Sectional Appendix	Paper based, also available electronically on the corporate intranet	
		Engineering Line Reference	Hazard Directory	Paper based	
1 - Location		Place of safety	Hazard Directory	Paper based	

(cont)		Authorized walking route	Hazard Directory	Paper based	
		Track layout	Sectional Appendix	Paper based	
		Safe parking place near the access point	Personal local knowledge	Customised documents at some depots	This information can be mapped onto the track diagram
		Nearest gas station	NA		
		Easy access for police and emergency vehicle and personnel	Personal local knowledge	Customised documents at some depots	
	1.2-Positioning	Up and down line identification	Sectional Appendix	Paper based	Digital track diagrams presented on mobile devices where information from the sectional appendix and hazard directory are merged and mapped onto a schematic scaled diagram.
		Line speed	Sectional Appendix	Paper based	
		Red Zone Prohibited (RZP) locations	Hazard directory	Paper based	
		Line direction identification	Sectional Appendix	Paper based	
		Other hazards (buried	Hazard directory	Paper based	

		infrastructure)			
		Type of power (AC/DC)	Sectional Appendix	Paper based	
		Overhead stanchion	Hazard Directory	Paper based	
		Train detection system	Hazard Directory	Paper based	
		Tunnels	Hazard Directory	Paper based	
	1.3 – Location of Assets	Location of the asset	Depends on the asset and the task	Paper based	Can be mapped onto the track diagram where workers bring on the relevant information only when necessary.
		Location of on track vehicles working within a possession	Usually from PICOP booklet	Paper based	If the vehicles are equipped with tracking devices, then they could be displayed on the handheld computer screen.
2-Material and store management	Necessary tools to perform the task	Depends on the task, usually carried around in the van	Experience and task related knowledge from training	NA	The work orders (the list of tasks for a certain period) could contain this information and could prompt the maintenance worker.

	Store management	Information about what equipment is required for a job and what is available in the van	Customised data at each depot	Digital files (normally Excel sheets)	A database of the required tools and equipments. It would be possible to keep track of availability of the tools with a barcode scanning system.
3- Forms	3.1- Inspection forms / checklists	Type of form depends on the nature of the task	Various – some are available on the corporate intranet	paper-based forms	Digital forms, voice recognition can be used for inputting information to minimise text input. Also, providing a camera will enable maintenance workers to complement their reports with photographic evidence.
	3.2- safety briefing forms	COSS and RIMINI forms	Copies available at each depot and also in vans	paper-based forms	
	3.3 – Protection forms	Type of form depends on type of protection	Copies available at each depot and also in vans	paper-based forms	
4- Standards and guidelines	Rules and regulations	Rule book	Copies available at each depot and also in vans	Paper based, soft copy available on corporate intranet	Digital documents accessible online
	Task related handbooks	Type of document depends on the nature of the task	Hard and soft copies available	Paper based, soft copy available on corporate intranet	
5- Asset maintenance History	5.1- Past information	Date of last inspection	Available on previous forms	Paper based	Possibility of linking work orders to previous forms. Also, providing an alarm system that
		Notes and reminders from	Available on previous forms	Paper based	

		Last job	Available on previous forms	Paper based	informs workers of any previously reported defects.
		Parts replaced over time	Available on previous forms	Paper based	
6- Comms	6.1- People	Emergency services	COSS briefing forms, personal local knowledge	NA	This information could be mapped on the track diagrams for each location.
		Signallers, controllers, other maintenance staff, etc.	Mainly personal local knowledge	NA	Contact details could be linked to each asset on the track diagram and accessed as needed. Also, the handheld could be used for messaging enabling users to send and receive text and multimedia messages.
	6.2- Places	Signal boxes, control rooms	Personal local knowledge	NA	

3.6. Research Conceptual Framework

The research conceptual framework presented in chapter 1 summarises the research approaches and the high level methodological strategies deployed to achieve these aims. This framework, shown in Figure 1-1, has been developed further to include details of the methods used in this research, see Figure 3-7.

As it can be seen, much of the information is this thesis has been gathered using a combination of qualitative and quantitative methods and in most cases several research methods have been used. Although initially it was perceived that it would be possible to address the aims of the research through separate studies; effectively the findings of each of the studies have complemented each other in addressing the research questions. The research approaches, methods, and studies mentioned in this framework are explained in detail in chapters four through to seven.

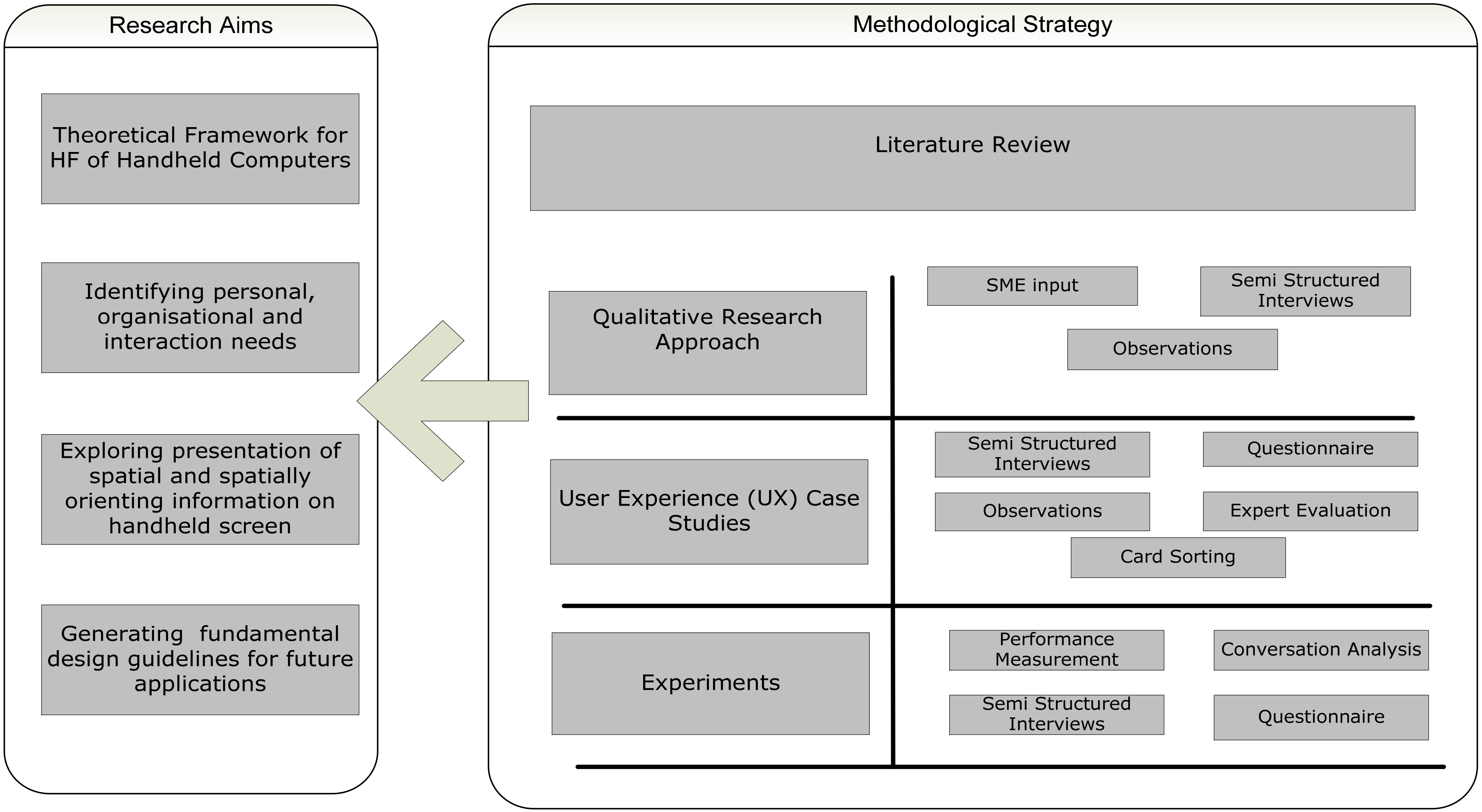

Figure 3-7 - Research Conceptual Framework

3.7. Discussion

This chapter attempts to explain the context of this research in more detail; offering a high level description of the maintenance department in Network Rail as well as a detailed and structured account of track workers' information requirements.

The principles of user centred design were used in a structured fashion to establish the information requirements of maintenance workers and the methods used for capturing the requirements were chosen based on these principles. The EDARE framework in its current form can serve as a reference for designers and system developers by providing information about requirements of maintenance workers and potential handheld computer applications. This framework provides a means for understanding the maintenance workers' tasks and more importantly places this information in the relevant context of work. Ideally, this framework should provide the basis for a more detailed and role specific requirements analysis.

In the next stage of this research, two handheld computer systems currently deployed in Network Rail were studied and the two systems were analysed and compared to understand users' experience when interacting with them in the field.

4. Chapter 4 – User Experience Case Studies

4.1. Introduction

Obtaining a thorough and comprehensive understanding of the current applications of handheld computers in the rail industry was considered necessary as a first step since this information provides an insight into the context of use in this research. Therefore, a series of User Experience (UX) case studies were conducted with the aim of studying two handheld computer systems which have been implemented within Network Rail for maintenance and inspection tasks. These systems have been introduced to the Signalling and Telecommunication (S&T) and the Level Crossing (LX) inspection tasks.

The aims of these case studies were:

1. To understand context of mobile working in rail infrastructure
2. To identify human factors issues associated with use of mobile devices in field
3. To develop principles for design and implementation of mobile device applications

As described in the project feasibility study report (Borland, 2005), the main advantage of substituting the paper-based system with the handheld computer is believed to be the productivity increase gained by direct input of information on the handheld device on the trackside which eliminates the need for data entry from paper based forms by data entry clerks and consequently leads to a tangible headcount reduction in the number of data entry clerks employed nationally. Furthermore, it has been claimed that there would be a reduction in the cost of producing and storing the paperwork. Other advantages of implementing the handheld computer system identified by the feasibility study report include: significant reduction in paper administration at the depot, reduction in paper work needed to be carried to the site, elimination of paper management activity of allocating work orders to work groups, increase in

Ellipse[4] data quality and improved data integrity through the reduction in inputting errors, and increased visibility of performance of the teams by the supervisors.

Also, the feasibility report suggests that implementation of these handheld systems would provide a national technology platform for ongoing initiatives in the maintenance work management, data collection and inspection area. For instance, it is believed that level crossing related accidents account for 42% of all rail accidents. An improved maintenance system is believed to reduce this level of risk by providing more accurate information for maintenance and engineering tasks (Network Rail, 2006b). Implementation of handheld computers for LX inspection might be one of the ways for improving maintenance and a way forward for other maintenance and inspection activities.

The objective of the UX studies in this chapter was to investigate the current handheld computer usage in Network Rail with the aim of detecting usability and interaction issues and using this knowledge to understand how to develop future new applications for handheld devices.

In this chapter, first different features of the hardware and software of the devices are explained. Then the methodological strategies adopted for studying these systems are described. The next section will report the results and findings for each individual system. Finally, the last section discusses the results of the UX case study and reports on the development of a descriptive model and theoretical framework that attempt to integrate the current HCI models and theories with the contextual understanding and information obtained from the UX case studies and also from the development of the EDARE framework.

[4] Network Rail's asset management database

4.1.1. Handheld Computer Hardware and Software

The software for both handheld computer systems have been designed by the same company and different features of the user interfaces such as the layout of data entry fields, colour schemes, text sizes, and structure of the menus are identical. Figure 4-1 illustrates examples of the interface of the LX and S&T handheld computer systems.

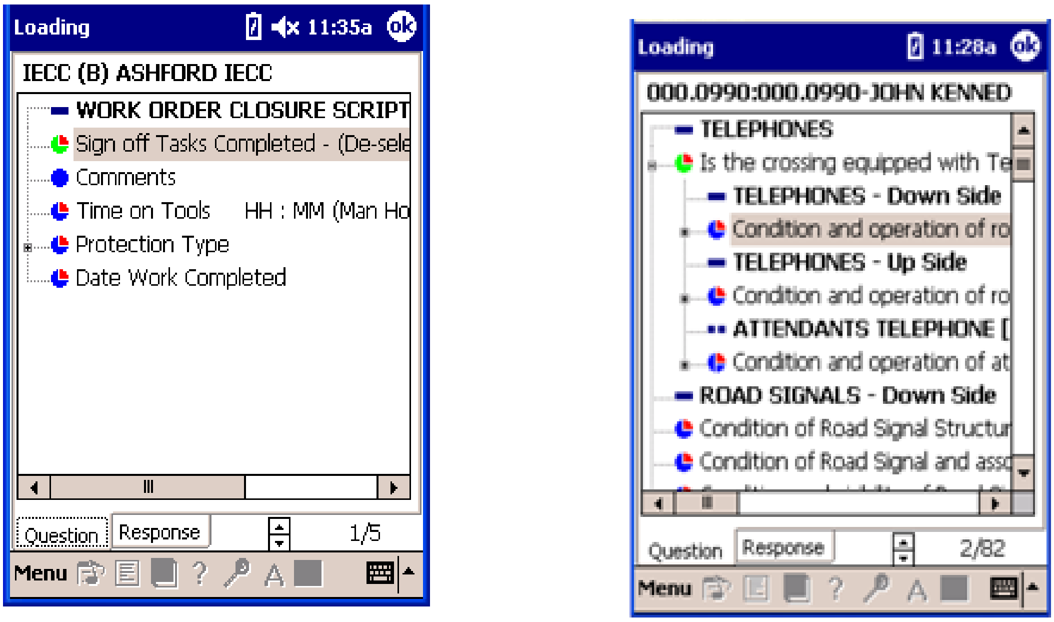

Figure 4-1 - screen shots of the S&T (left) and LX (right) handheld computer systems

Figure 4-2 illustrates the hardware used for this system which is a Motorola MC 9002. The hardware has been improved to protect the device against shock and it is waterproof. It has a long battery life of 24 hours and a five-year lifespan. It contains an alphabetic keyboard which is backlit.

Figure 4-2 - Handheld Computer used by S&T and LX inspection teams

The handheld computer has a 3.5 inch screen with a resolution of 240 X 320. The screen is tough and is not scratched easily. The device is equipped with an internal MultiMedia Card (MMC) which can be swapped in case of device damage or failure. All inputted data are immediately saved on the device.

The information gathered by both handheld systems is used to update Network Rail's asset management database system, Ellipse. Ellipse is the work and asset management system which is used to manage and schedule asset maintenance and inspection tasks. Maintenance schedule details are stored in the Ellipse for all assets. This information is uploaded to handheld computers and determines the future maintenance and inspection task. An integrated desktop system, Field Data Manager, is used for generating reports based on the collected information. This system provides reports of the faults and also generates a historical record of previous inspections.

4.2. Method

4.2.1. User Experience (UX) Case Studies vs. Usability Evaluation

Reviewing mobile HCI literature shows that the research regarding the appropriate choice of method, data collection and analysis for handheld computer evaluation is not as strong as it is for conventional systems (Kjeldskov and Skov, 2003b). One reason for this issue is the portability of the mobile computing devices which makes applying traditional usability methods very difficult. There are some suggestions in the literature on how to overcome some of these difficulties as reported in section 2.4.3 (Jensen and Larsen, 2008; Jones and Marsden, 2006; Po et al., 2004).

However, in deciding upon choosing one of these methods for evaluating the S&T and LX handheld computers, it was important to ensure that the methods provide a good understanding of the context of use and the task. Furthermore, the research approach in this thesis has been based on the assumption that in order to generate guidance for developing successful interfaces for handheld computers in the rail industry, it is necessary to obtain a clear understanding of current mobile computing device usage, users' culture and their experience of using the handheld computer devices. Obtaining this understanding requires going beyond studying usability of the GUI. Therefore, it was felt necessary to study "User's Experience" with the handheld computer devices.

There are three important differences between UX and the traditional view of usability (Hassenzahl et al., 2006; Hassenzahl and Tractinsky, 2006): 1 – while usability mainly focuses on users' tasks and how they accomplish their goals, UX takes a more "holistic approach" and considers non-task related aspects of using the device too, 2- UX explicitly focuses on how people judge and experience the product and therefore adopts a subjective approach, and 3 – usability attempts to identify barriers and problems associated with interaction, whereas UX considers the "positive" outcomes of technology use such as joy, excitement, and pride.

Studying the current use of handheld computers in the rail industry required a comprehensive approach in order to address all the different aspects of interacting with these devices. Therefore, a case study method was adopted. There is no standard definition for case study. Benbasat and colleagues propose the following definition (Benbasat et al., 1987):

> *"A case study examines a phenomenon in its natural setting, employing multiple methods of data collection to gather information from one or a few entities."*

The rest of this section will explain individual methodological strategies in more detail.

4.2.2.Expert Review

The main objective of expert review in this study was to provide the researcher with a better understanding of the application. These systems have been designed for specific tasks and therefore it was essential that the researcher understood the application thoroughly. Hence, as a first step, the information structure of the systems was studied and it was attempted to draw a visual map illustration of this structure. It was believed that a visual presentation of the information structure would help the researcher to understand different layers of the applications and would enable her to create a clearer understanding of the system.

The researcher explored different applications and summarised them in the form of a flow chart. These flow charts were verified by a Senior Application Support Analyst who is responsible for technical support of the S&T and LX applications. It is important to point out that this technique was not used as an evaluation method and was only adopted so that the researcher could understand the system better.

4.2.3. Field Visits – Observational Methods

4.2.3.1. *Procedure*

In order to obtain a more realistic insight about the usage of the handheld computer systems in real world settings, the researcher conducted a series of site visits in order to study the maintenance workers in their natural work setting. An "unobtrusive observation" technique was adopted in this research. Robson explains the purpose of this method as (Robson, 2002, P. 312):

> *"[Observation] is commonly used in an exploratory phase,*

> *typically in an unstructured form, to seek to find out what is going on in a situation as a precursor to subsequent testing out of the insights obtained."*

Only certified personnel who have a Personal Track Safety (PTS) Card are permitted to go on track. After acquiring relevant permissions, the author was allowed on the trackside for the observations. The following stages were followed:

1. The author explained the objectives of the site visit. Due to the safety critical nature of the engineering work on trackside, this had to be done either at the depot or in the van before getting on the track. She also ensured that the Controller of Site Safety (COSS) agrees that she takes notes or asks questions while walking on the track.

2. Once on site, after being briefed by the COSS and signing the COSS brief form, the researcher spent a whole shift with the workers observing them while they were performing their tasks.

3. Inspectors' activities during the shift as well as the equipments and documents they used were noted down. When possible, the researcher would ask one of the team members for more details about how they perform the task.

4.2.3.2. *Analysis*

In order to analyse the observation data, first, the handwritten notes were typed. Then the activities were divided into four main groups: 1 – locating the asset, 2 – inspecting the asset either visually or by using some sort of equipment, 3 – taking notes or filling in relevant forms, and 4 – phone communication with other colleagues. The notes were then used to form a description of how the task is performed.

4.2.4. Interviews and Subjective Measurements

4.2.4.1. *Procedure*

The first two techniques explained earlier in this chapter were adopted to provide the researcher with information about the handheld computer system and also about the task and the context of use. However, it was necessary to adopt a more rigid approach for studying the interaction between the users and the handheld computer systems. Therefore, a series of semi structured interviews were conducted in order to understand users' experience with the device as well as the way they feel about the system.

Robson's recommended procedures for conducting semi-structured interviews were followed (Robson, 2002):

1. Introductory comments: the researcher introduced herself and explained the objective of the research. A consent form was handed out as part of the questionnaire (see appendix 4.4) to inform the participants about the anonymity and confidentiality of the results.

2. List of possible questions: A set of eight interview questions were generated. These questions were used to trigger discussions and the researcher asked further questions whenever she felt that the issue should be explained and discussed in more detail. The researcher took note of participants' comments during the interviews. The interview questions are presented in Appendix 4.1. The key topics discussed in the interview were as follows:

2.1. advantages and disadvantages of the handheld computer systems,

2.2. impact of the handheld computer system on how inspectors perform their task,

2.3. what part of the application do inspectors use most often and what other functionalities they think should be added to application?

3. Closing comments: The notes taken during the interview were reviewed and confirmed by the interviewees at the end of each session and the participants complemented and added to the notes where necessary.

In addition to the semi-structured interviews which aimed at gathering some information about the user's interaction with the handheld computer, the users were asked to fill in a Handheld Usability Questionnaire which was specifically developed for evaluating handheld computer systems in Network Rail. The information gathered through the interviews and questionnaires complemented the previous two stages of the research.

4.2.4.2. *Development of the Handheld Computer Usability Questionnaire*

This questionnaire, which contains a set of statements that aim at measuring the usability of a handheld computer system, was developed specifically for the purposes of this research. While the methods used for developing this questionnaire can be categorised as "qualitative", administrating the questionnaire for the purpose of evaluating handheld computer systems generated data that can be classified as quantitative. The information gathered from the questionnaires complemented and verified the results of the qualitative data obtained through the semi structured interviews.

Traditionally, measuring people's attitude through a questionnaire is facilitated by employing the multiple-question or "scaling" approach (Oppenheim, 1992). Therefore, in this research, it was decided that the most suitable method for measuring the users' attitude towards the handheld computers would be through a set of scaling statements. However, it was believed that it might not be suitable to measure the usability of the Network Rail handheld computers with conventional usability questionnaires. Therefore, the objective of the questionnaire developed in this research was to provide a more suitable and matching tool for assessing the usability of handheld computers in the rail industry.

Most of the questionnaires that contain a set of statements as their measurement tools use factor analysis for grouping the statements and identifying a set of basic aspects. Oppenheim defines Factor Analysis as

(Oppenheim, 1992, P. 166): (Ryu, 2005)

> *"… an analytic statistical tool which enables us to find out what are the chief underlying dimensions of a set of variables, attributes, responses or observations."*

Normally, a factor analysis is performed by creating a pool of statements from which the "underlying dimensions" or factors are derived. But this method requires administrating the questionnaire for large number of respondents. However, in this study, the questionnaire was intended to be used to complement other information gathered from observing and interviewing participants. Therefore, it was not feasible to administrate the questionnaire with large number of participants, and as a result performing a factor analysis was not possible.

Despite this limitation, it was still necessary to determine the factors that affect the usability of handheld computer systems. Figure 4-3 illustrates the different stages of developing this questionnaire.

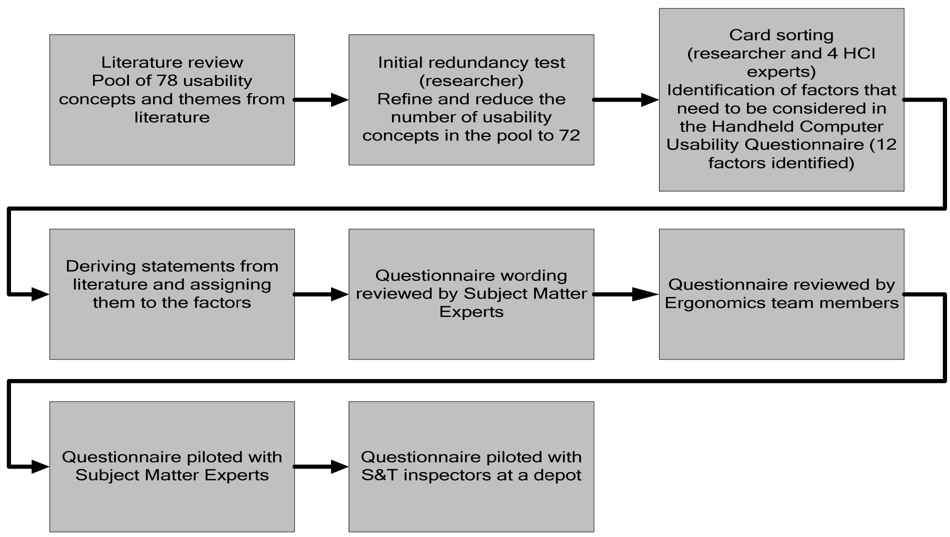

Figure 4-3 - Procedure of developing the Handheld Computer Usability Questionnaire

The initial stage was to determine the factors that affect usability of handheld computer systems. Instead of creating a pool of statements to derive the factors from, a pool of usability concepts and themes was created. In order to create this pool of usability concepts, several sources in the literature were consulted. These sources range from standards and design guidelines to research in the field of usability and in particular the published work that had focused on evaluating the usability of specific consumer electronic devices such as mobile phones. Any concepts or themes in the literature which were labelled as "usability dimensions", "aspects or elements of the interface", "characteristics of handheld computers", "requirements of interaction with handheld computers", "heuristics for heuristic evaluation" and "guidelines for designing user interfaces" were gathered in this pool.

After the literature review, it was necessary to conduct a redundancy check to ensure that none of the concepts were superfluous. An initial redundancy test was conducted by the researcher in order to eliminate the concepts that explicitly referred to the same idea or theme. For instance, it was believed that "make the system adaptable" and "adaptability" convey the same meaning and hence one of them was removed, in this case "make the system adaptable". Furthermore, all of the concepts which were believed to imply more than one theme were divided into individual concepts. For example, "affective aspect and multimedia properties" was divided into "affective aspect" and "multimedia properties". Other concepts were kept as they appeared in the literature. A total of 72 usability concepts were kept in the pool. Table 4-1 displays an extract of the concepts gathered at this stage and the total list has been presented in appendix 4.2.

Table 4-1 - An example of some of the usability concepts gathered in the pool

No.	Theme	Description	Source
8	Context dependency	The user's activities are intimately associated with their context.	(Pascoe et al., 2000)
9	Effectiveness	The required range of tasks must be accomplished at better than some required level of performance (e.g., in terms of speed and errors) By some required percentage of the specified target range of users Within some required proportion of the range of usage environments	(Shackel, 1991), (ISO-9241-11, 1998)
10	Learnability	Within some specified time from commissioning and start of user training, based upon some specified amount of training and user support and within some specified relearning time each time for intermittent users	(ISO/IEC-9126-1, 2001; Nielsen, 1994; Shackel, 1991)
11	Flexibility	With flexibility allowing adaptation to some specified percentage variation in tasks and/or environments beyond those first specified	(Shackel, 1991)
12	Attitude	Within acceptable levels of human costs in terms of tiredness, discomfort, frustration and personal effort so that satisfaction causes continued and enhanced usage of the system	(Shackel, 1991)
37	System capabilities	Factors according to Questionnaire for User Interface Satisfaction - QUIS	(Chin et al., 1988)
38	Overall reaction to software	Factors according to Questionnaire for User Interface Satisfaction - QUIS	(Chin et al., 1988)
39	External interface	User support, accessories, supporting software	(Ketola and Röykkee, 2002)

The next step was to group the items which referred to the same concept or theme together and generate a set of final usability factors for the questionnaire. This aim was achieved through a card sorting exercise. It is important to note that card sorting in this research has been performed as a grouping technique. Four usability experts participated in this part of the study, two of whom have extensive experience in the rail industry and in particular in relation to designing interactive systems for different rail related applications. The other two were researchers with experience in evaluating and studying interactive systems.

The 72 items were printed on cards and presented to participants. They were asked to group the similar concepts together and assign a meaningful label to each of the groups. The experts performed this exercise individually and the initial labels they had chosen for the groups were referred to as "hypothetical" factors. A copy of the instructions for this exercise is presented in appendix 4.3.

Since usability is the main focus of this questionnaire, it was important to decide upon a definition for usability. The definition of usability proposed by ISO 9241 – 11 (1998) was considered to be the most suitable for the purposes of this research (ISO-9241-11, 1998):

> *"The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use."*

Also, in order to ensure that the special attributes of handheld computers have been considered, it was essential to consider the definition of usability along with characteristics of handheld computers. The characteristics proposed by Pownell and Bailey were chosen for this study. These are: 1- portability, 2 - accessibility, 3 - mobility, and 4 - adaptability (Pownell and Bailey, 2000). This information, summarised in Table 4-2, was provided to the experts to guide them through the card sorting exercise. As the information in the table suggests, the experts were asked to check that each factor measures the "usability" of the "user interface" of a "purpose-built handheld computer system".

Table 4-2 - Information for the card sorting exercise

Product	Component	Scope of usability
Conventional and purpose-built handheld computers	User interface	ISO 9241 – 11 definition Characteristics of handheld computers (i.e., portability; accessibility; mobility; adaptability)

After each participant had individually completed both tasks, a discussion session was organized where the participants were asked to review the hypothetical factors. The objective of this session was to eliminate any variation in the grouping of the concepts and any inconsistencies in the selected names for the hypothetical factors. The participants were provided with their original results from the card sorting practice in order to reduce individual inconsistencies. The outcome of this session was a list of final factors for measuring the usability of handheld computers. 12 factors were identified: 1- ease of use, 2- user interface, 3- portability, 4- consistency and relevance to task, 5- feedback; 6- productivity, 7- adaptability, 8- affective design, 9- technology, 10 – workload, 11 – errors, and 12- help.

The last stage of the development of the questionnaire was to assign suitable statements to the factors. In order to select these statements, the initial concepts in each of the groups were considered. Since these concepts had been collected from various sources in the literature, it seemed appropriate to directly use the statements from the original sources. In some cases the wordings of the statements were slightly adjusted to match the attributes of handheld computers. The researcher proposed statements for any factor for which a suitable statement from the literature could not be found. These statements were verified by subject matter experts. Table 4-3 presents a list of all the items in the questionnaire and their original source in the literature.

Table 4-3 - List of all the statements and their source

No	Factor	Items	Source
1	Ease of Use	1.1- The handheld computer helps me to perform my tasks.	(Kwahk and Han, 2002; Lin et al., 1997; Ryu and Smith-Jackson, 2006)
		1.2- It is easy to learn how to use the handheld computer.	(Chin et al., 1988; Lin et al., 1997; Ryu and Smith-Jackson, 2006)
		1.3- It is easy to remember and navigate through the menus.	(Chin et al., 1988; Ryu and Smith-Jackson, 2006)
		1.4- Paper based forms and the handheld computer support are well integrated.	NR guidelines
		1.5- It is easy to use the handheld computer.	(Chin et al., 1988; Lin et al., 1997; Ryu and Smith-Jackson, 2006)
		1.6- I can access the information and applications I need quickly.	(Chin et al., 1988; Lin et al., 1997; Ryu and Smith-Jackson, 2006)
2	User Interface	2.1- The user interface of the handheld computer is clear and understandable.	(Chin et al., 1988; Lin et al., 1997; Ryu and Smith-Jackson, 2006)
		2.2- The information on the handheld interface is organised so that it is easy to find any application.	Researcher, SMEs
		2.3- It is easy to input text and information into the handheld computer.	(Lin et al., 1997; Ryu and Smith-Jackson, 2006; Szuc, 2002)
		2.4- The pictures on the handheld computer screen are of good size and quality.	(Chin et al., 1988; Ryu and Smith-Jackson, 2006)

3	Portability	3.1- The handheld computer allows me more freedom to move around on site.	(Pownell and Bailey, 2000)
		3.2- I can successfully perform the task on site using the handheld computer.	Researcher, SMEs
		3.3- The handheld computer is usable in all weather conditions.	Researcher, SMEs
		3.4- The handheld computer is usable in all light conditions.	Researcher, SMEs
		3.5- Using the handheld computer I am able to perform my tasks wherever and whenever necessary.	(Pascoe et al., 2000)
		3.6- The handheld size is convenient for transportation.	(Ryu and Smith-Jackson, 2006; Szuc, 2002)
		3.7- The handheld computer is tough and would not break easily.	(Szuc, 2002)
4	Consistency and task relevancy	4.1- The handheld computer is similar to other handheld and PC based systems I have used.	(Szuc, 2002)
		4.2- The format of all data entry fields is consistent.	(Chin et al., 1988; Lin et al., 1997; Ryu and Smith-Jackson, 2006)
		4.3- The words used within the handheld computer are consistent and understandable.	(Chin et al., 1988)
		4.4- The words used within the handheld are similar to those in other handheld and PC based systems.	NR guidelines
		4.5- The words used are usually related to the task I am doing.	(Chin et al., 1988)
		4.6- Design of icons and icon labels are usually related to the task I am doing.	(Chin et al., 1988; Ryu and Smith-Jackson, 2006)
5	Feedback	5.1- The handheld computer provides immediate and appropriate feedback.	NR guidelines
		5.2- The handheld computer gives me information about the percentage of the task completed.	Researcher, SMEs

		5.3- The system always informs me about where I am in the menus.	(Lin et al., 1997)
		5.4- Highlighting the selected menu options on screen is useful.	(Chin et al., 1988)
6	Productivity	6.1- The handheld computer usually provides correct default values.	(Lin et al., 1997)
		6.2- Using the handheld computer I am able to perform my tasks effectively and quickly.	(Ryu and Smith-Jackson, 2006)
		6.3- The amount of information displayed on the handheld screen is too much.	(Chin et al., 1988; Lin et al., 1997; Ryu and Smith-Jackson, 2006)
7	Adaptability	7.1- Using the handheld computer I can perform my tasks flexibly.	Researcher, SMEs
		7.2- I can customise the handheld interface to match my preferred way of working.	NR guidelines
8	Affective Design	8.1- I like using the handheld computer.	(Chin et al., 1988)
9	Technology	9.1- The handheld computer is reliable.	(Szuc, 2002)
		9.2- The handheld computer is fast enough.	(Chin et al., 1988)
10	Workload	10.1- Only the information I need at the time is presented to me on the handheld screen.	NR guidelines
11	Errors	11.1- It is easy to correct any mistakes on the handheld computer.	(Chin et al., 1988; Ryu and Smith-Jackson, 2006)
		11.2- The error messages are appropriate and helpful.	NR guidelines, (Chin et al., 1988)
		11.3- There are messages aimed at preventing me from making any mistakes.	(Ryu and Smith-Jackson, 2006)

12	Help	12.1- The help information given by the system is useful.	(Lin et al., 1997; Ryu and Smith-Jackson, 2006)
		12.2- The manual provided is easy to understand and clear.	Researcher, SMEs
		12.3- The training that I have received has equipped me with the necessary skills to use the handheld computer.	Researcher, SMEs

The first draft of the questionnaire was then reviewed by two SMEs in the Ergonomics National Specialist team to ensure that the wordings of the questions are appropriate. Furthermore, a copy of the revised questionnaire was sent to the members of the Ergonomics National Specialist team in Network Rail for further feedback. The final version of the questionnaire was piloted with the SMEs and some final changes were made.

The questionnaire was also piloted at one of the depots and the results of the pilot study led to minor changes in wording of some of the questions. Table 4-4 presents the statements which were changed. These modifications have been underlined.

Table 4-4 - Changes to the Statements after the pilot study

Statements before the pilot study	**Statements after the pilot study**
1.4- Paper based aspects of the task and the handheld computer support are well integrated.	1.4- Paper based forms and the handheld computer support are well integrated.
1.5- It is easy to use the handheld computer to complete my tasks.	1.5- It is easy to use the handheld computer.
3.6- The handheld computer size is convenient for transportation and storage.	3.6- The handheld computer size is convenient for transportation.
6.3- The amount of information displayed on the handheld screen is too much.	6.3- The amount of information displayed on the handheld screen is adequate.
11.3- There are enough messages aimed at preventing me from making any mistakes.	11.3- There are messages aimed at preventing me from making any mistakes.

In addition to these changes, an extra statement was added to the "user interface" factor which questions the organisation of the information on the handheld computer (statement 2.2). Also it was seemed more appropriate to move the statements about highlighting the menu options from "user interface" in the first draft questionnaire to "feedback" in the amended questionnaire (statement 5.4). A copy of the complete questionnaire is available in Appendix 4.4.

The statements were measured using a five point Likert scale where one and five represented "strongly disagree" and "strongly agree" respectively with three being the "neutral" and middle point in the scale. Since the questionnaire was designed as an evaluation tool for evaluating any handheld computer system within Network Rail, a "not applicable" option was also included for any question that was not relevant to the system which was being studied. All statements were worded positively and it was decided that a score of three or higher represents respondents' agreement with the statement and therefore, an average of three or higher for any of the factors should in theory indicate that the handheld computer has been successful in supporting the measured usability factor.

4.2.5. Analysis – Interviews and Questionnaire Results

4.2.5.1. *Interviews*

As it has been mentioned before the objective of the semi structured interviews was to understand the interaction between the users and the handheld computer devices. In order to analyse the interview data, it was decided to adopt an "inductive thematic" analysis approach (Hayes, 2000) or "editing approach" (Miles and Huberman, 1994). This approach, as the name suggests, is (Hayes, 2000, P. 173)

> *"… qualitative analysis which involves sorting information into themes. Themes, in this context, are recurrent ideas or topics which can be detected in the material which is being analysed, and which come up on more than one occasion".*

In order to analyse the results of these interviews, the following stages were followed:

1. The interview data which was recorded as hand written notes during the interviews were typed.

2. The researcher read through each interview and attempted to determine similar recurrent themes or topics in the data.

3. These topics were coded to simplify grouping of the data. Codes in this research were used as "labels for assigning units of meaning to the descriptive or inferential information compiled during the study" (Miles and Huberman, 1994, P. 56).

4. Once all the similar themes and topics were grouped together, it was attempted to assign a definition to each code which best explained the content of the information in that specific group.

5. These stages were repeated again to ensure that all the themes had been detected and also to ensure that the data had been coded consistently.

4.2.5.2. *Questionnaire*

Average ratings given to individual statements as well as the average ratings for each usability factor were calculated and analysed. In order to investigate any differences in users' responses between the S&T and LX handheld computers, a Mann-Whitney U test was performed on the ratings of each of the statements.

4.3. Results

In this section the result of the UX case studies is reported. The results are reported in three sections. First, the result of the expert review and field visits are described. These are mainly a description of the task and the context of work. The next section will explain results of the interview analysis for each of the devices and the last section summarises the results obtained from the questionnaire, and presents a comparison between the two systems.

4.3.1. Field Visits

4.3.1.1. Signalling and Telecommunication (S&T) Handheld Computer Systems

Before handheld computers were introduced, S&T inspection was performed by pen and paper. The teams received a list of all the assets that needed to be inspected based on the location of the assets. This list was produced by Network Rail’s asset management system, Ellipse. This list is now displayed on the handheld computer. Each team has been given a handheld computer on which they receive the list of works they need to perform for a specific period.

Having received the list, the teams need to get to the location of the assets. They usually have to drive several miles to the location they are scheduled to visit. Once they arrive at the location, different roles will be allocated to different people. In each team there are at least three people. One person is responsible for safety of the workers who is referred to as the Controller of Site Safety (COSS). He or she briefs the other workers about the location and gives them information about the line speed, line direction and potential hazards in the area. The team (and any visitors) then need to fill in and sign the COSS form. The COSS will then assign one or two members of the team as Lookouts. The Lookout, as the title suggests, “warns personnel working on or near the line of an approaching train” (Network Rail, 2005a). The remaining members of the team are responsible for inspecting the assets.

After this first stage, the team needs to find the first asset on the list of tasks. On the paper-based list, the asset is identified by a location number. Once the team has found the first asset, one of the team members would perform the inspection or any necessary maintenance task. He or she then ticks the asset off the list of tasks. If the inspectors need to take any notes, they do this either on the paper containing the list of work orders usually next to the item being inspected or on a separate sheet. The team then starts walking along the track until they find the next asset on their list. They would often walk between one to two miles on average. On occasion, depending on the type of the asset, the inspector or maintainer needs to contact the signaller and inform her/him in case the job interferes with the signalling system. If they notice any faults that have not been listed in their schedule, they fill in a Work Arising Identification Form (WAIF) which informs the supervisor about a defected asset. Finally, they sign and date the form, photocopy the form for their own records and hand it to the supervisor. The supervisor reviews the form and has it typed. This information is then used to update the asset management system and generate future inspection schedules.

Handheld computers were introduced to this procedure in September 2006 to replace the pen and paper data entry system on site and at the depot and facilitate workers with an improved way of logging the inspections. About 4000 staff at 240 locations are using these handheld computers. The handheld computer system is used by S&T inspectors for recording the completion of inspection tasks which they perform in any shift. The handheld computer presents a list of all the assets that need to be inspected in a specific period. The users are required to determine whether the assets in that location have been inspected by answering a series of questions on the handheld computer. They should also register any detected defects using the Work Arising Identification Form (WAIF) on the handheld computer.

After the first site visit (Didcot, 3 May 2007), it became apparent that the track workers are reluctant to take the handheld computers to the site with them and in many cases they in fact leave the handheld computer at the depot. Instead of using the handhelds to get the work orders of that week, they use paper-based lists of the work orders. The works planned for a typical day are printed on paper and taken out to the site. Once all the assets on the list of work orders have been inspected, the team would return to the depot. At the depot, one of the team members (usually the team leader) uses the paper based information to fill in the forms on the handheld computers.

The procedure explained here is typical practice at S&T maintenance depots. Table 4-5 presents a brief description of how the S&T

inspection task was performed before introduction of handheld computers, how it should be performed using the handheld computers and how it is in reality being performed currently.

Table 4-5 - A summary of S&T inspection procedure before and after introduction of handheld computers

S&T task with pen and paper	S&T task with handheld computer – in theory	S&T task with handheld computer – in practice
Work order list printed on paper	Work order list uploaded on handheld computer	Work order list uploaded on handheld computer and printed on paper
Driving to the location	Driving to the location	Driving to the location
Safety briefing verbally given	Safety briefing verbally given	Safety briefing verbally given
Start inspecting the assets in order presented on the printed list	Start inspecting the assets in order presented on the handheld computer	Start inspecting the assets in order presented on the printed list
After inspection, tick the inspected asset off the printed list of assets and add any comments on the paper	After inspection, close the work order on the handheld computer (see the flow chart for the procedure)	After inspection, tick next to the inspected asset and add any comments on the paper
Fill in a paper-based Work Arising Identification Form (WAIF) for any unlisted defects, i.e., any faults that are not listed on the work order list	Fill in a WAIF on handheld computer for any unlisted defects	Fill in a paper-based WAIF
Highlight any asset on the list that were not inspected	The handheld computer will automatically record the status of the work order (close or active)	Highlight any asset on the list that were not inspected

At the depot, hand in the forms to the supervisor	At the depot, dock the handheld computer in the docking station for information upload	At the depot, close the work orders on the handheld computer and add any comments based on the information recorded on paper
The inspection data is inputted into the asset management system.	NA	Dock the handheld computer in the docking station for information upload.

This table highlights that there are considerable differences between performing the tasks on paper and on handheld computer and that there are also differences between how the handheld computer system should be used in theory and how it is actually being used in practice.

4.3.1.2. *Level Crossing (LX) Handheld Computer System*

LX inspectors perform their tasks either individually or in groups of two. Before handheld computers were introduced, the level crossing inspectors used paper based checklists. They were provided with a list of all the level crossings they had to inspect. In Network Rail's Level Crossing Infrastructure Inspection and Maintenance Handbook, level crossing inspection has been defined as "Visual examination of level crossing, to detect hidden failures and deterioration of the assets" (Network Rail, 2006b). For instance, LX inspectors need to record the state of road signs and markings, warning lights and alarms, telephones, and line side signage.

Inspecting each level crossing depends on the type of the crossing and the number of assets and infrastructure at the crossing. There are various types of level crossings; public, private, Automatic, and controlled. Various infrastructure elements at level crossings have specific forms. These forms are referred to as inspection checklist. In total, there are 25 LX inspection checklists for different types of assets at various level crossings (Network Rail, 2006b).

Having received the list of the level crossings that needed to be inspected, the inspectors had to photocopy all the relevant checklists. They had to drive to each level crossing, inspect the condition of different assets at the crossing and fill in the related paper based checklist. At the depot, LX inspectors photocopied the forms for their own records. This information was typed and used for updating the database.

The LX handheld computer system has been designed with the aim of providing the LX inspectors with digital inspection checklists. Introducing handheld computers has changed the inspection procedure. The inspectors receive a list of level crossings that are scheduled for inspection on their handheld computers. They drive from the depot to the level crossing and start inspection. On the handheld computer, as soon as they tap on the name of the level crossing, the first question appears on the screen. They then start inspecting assets in the order the questions on the handheld computer determine.

Inspecting any type of level crossing takes approximately a minimum of 30 minutes. At the depot, they dock the handheld computer in its docking station and the information is uploaded to the Ellipse database. Since the inspectors have no means of accessing the uploaded data, they usually ask their supervisors for printed versions of the report so that they can keep a record of their job.

Like the S&T handheld system, the main advantage of the LX handheld computer is believed to be reduced workload compared to the management of a paper-based record-keeping system. According to the project's feasibility report, the robust management reporting system of LX inspections and associated asset condition is another benefit of using handheld computers. Furthermore, the system enables data validation to be enforced at the point of capture which leads to a comprehensive, accurate, and consistent database (Fell, 2005).

Results of the field visits revealed that, unlike S&T inspectors, LX inspectors take the handheld computer to the site. This device has now been delivered to 110 LX inspectors at 40 locations across the UK. Table 4-6 summarises the differences between performing the LX inspection task currently and before handheld computers were presented.

Table 4-6 - A summary of LX inspection procedure before and after introduction of handheld computers

LX task with pen and paper	LX task with handheld computer
List of the level crossings printed on paper	List of the level crossing on handheld computer
Depending the type of the LX, print the necessary checklists	NA
Drive to the location	Drive to the location
Inspect the LX and fill in the paper-based checklists	Inspect the LX based on the question asked on the handheld computer
Fill in a paper based WAIF form for any unlisted defects	Fill in a WAIF form on the handheld computer for any unlisted defects
At the depot, copy the forms and hand them to the supervisor	At the depot, dock the handheld computers in the docking stations for information upload
Inspection data is inputted into the asset management system.	NA

Comparing level crossing inspection tasks before and after implementation of handheld computers shows a significant change in the way inspectors perform their tasks. Successful implementation of the system means that unlike the S&T handheld computer system, the LX system is being used as it had been intended to be used.

4.3.2. Expert Review

4.3.2.1. *Signalling and Telecommunication (S&T) Handheld Computer System*

The application on the S&T handheld computer contains a list of cyclic inspections, referred to as “work orders”. This list constructs the main part of the application. The “work orders” on this list are the tasks that the teams need to perform in a specific period. The inspectors are required to fill in the necessary information about each work order into the handheld computer. Figure 4-4 displays the “work order” part of the information architecture of the application in detail.

The most frequent task performed on the handheld computer is "closing the work order" where the inspectors report that they have completed an inspection task and record any comments they might have about the inspected equipments using the questions on the "work order closure script" (see Figure 4-5).

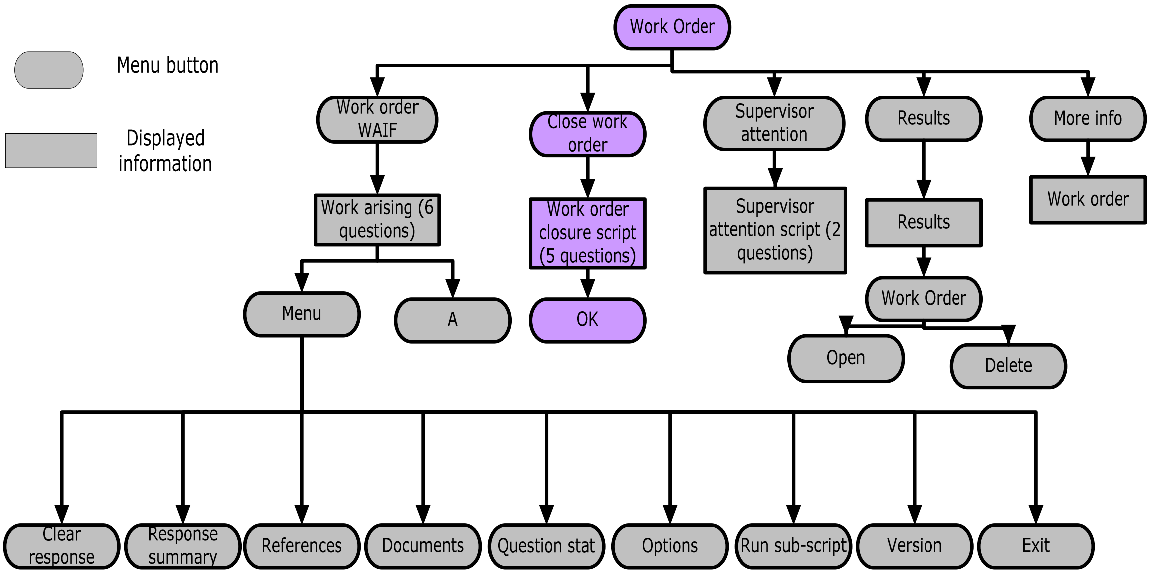

Figure 4-4 - Information Architecture of the S&T application

The highlighted section of the diagram displays the stages that should be followed to close a work order.

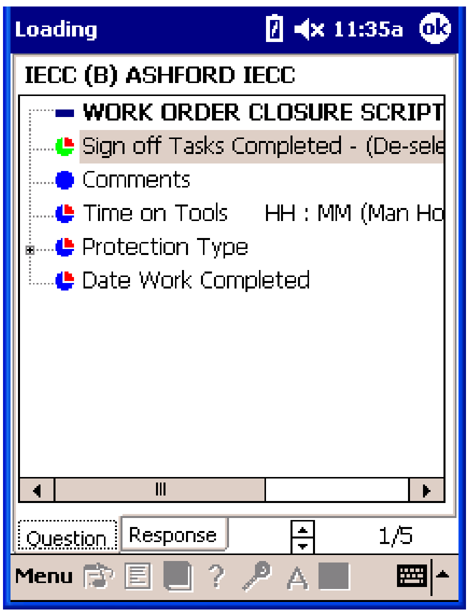

Figure 4-5 - Screenshot of the "work order closure script"

4.3.2.2. *Level Crossing (LX) Handheld Computer System*

In order to inspect a level crossing, LX inspectors need to log in to the system. The level crossings are organised based on Area Name and in each area, they are organised based on Engineering Line Reference (ELR). Each level crossing is then identified by its name and distance from the ELR.

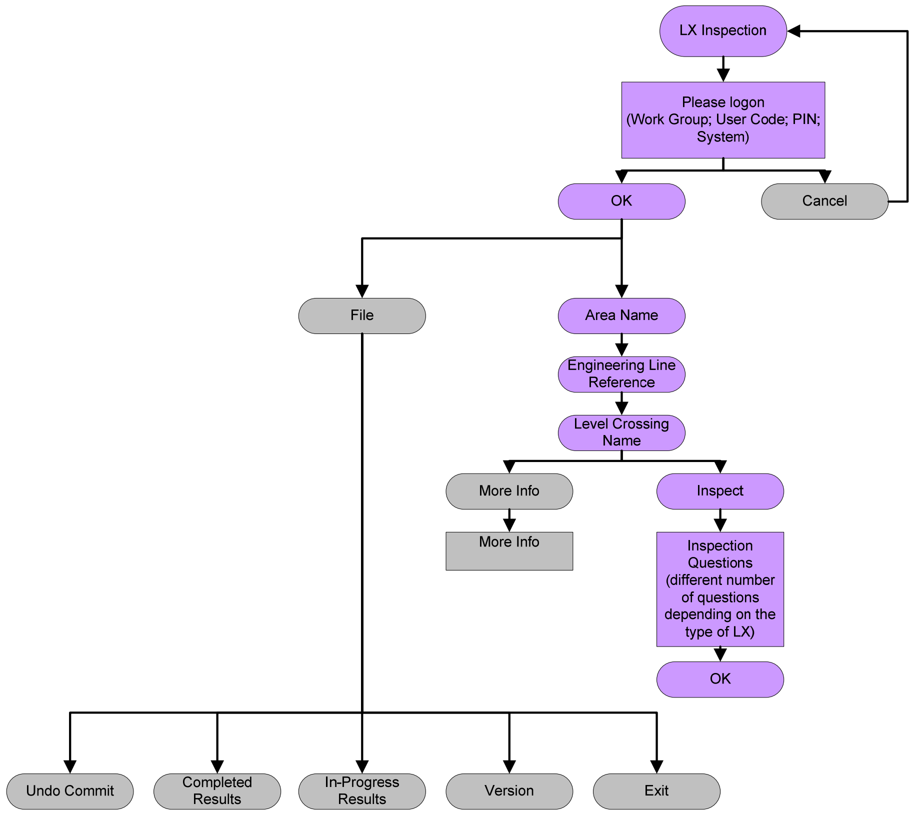

Figure 4-6 - Information Architecture of the LX inspection Application

Figure 4-6 illustrates the information architecture of the LX inspection application. The highlighted section of the diagram represents the procedure followed by inspectors to fill in the relevant checklists. In order to eliminate the need for paper based forms, a group of "scripts" of questions have been designed for the handheld computer application. Once the LX inspectors click on the specific level crossing, the first question that they need to answer appears on the screen.

Figure 4-7 shows an example of the response summary interface. The screen shot displays some of the assets on the level crossing that the inspectors need to check.

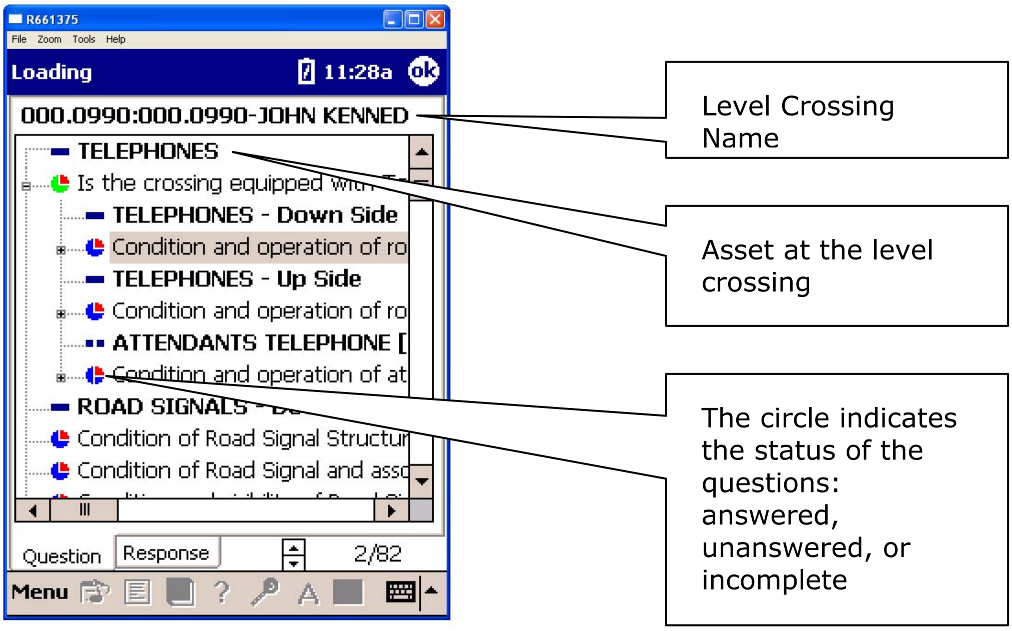

Figure 4-7 - Screen shot of the LX Handheld Computer

4.3.3. Interview Results

4.3.3.1. *Signalling and Telecommunication (S&T) Handheld Computer Systems*

16 S&T inspectors and supervisors from four depots filled in the questionnaire and were interviewed. In three of the depots, the inspectors filled in the questionnaires individually, but were interviewed as a group. The interview had been designed as a semi structured interview and therefore the researcher had prepared a list of questions. Interviewing the inspectors in groups instead of individually led to long discussions between the group members. The researcher took note during the discussions and at the end of each session reviewed the notes with the participants to ensure that all the issues have been recorded.

Due to organisational factors, the participants were reluctant to express any negative views about the S&T handheld system. Therefore, it was not always possible to interview them individually and in most cases they expressed their reluctance for being individually interviewed. The advantage of group interviews was that the interviewees were encouraged by their colleagues to express their views more freely. Also, the interviewees were less concerned about the confidentiality and anonymity of their comments because they seemed to feel that they are being supported by the rest of the team.

The results of the interviews clearly show that S&T inspectors do not consider the handheld system as a useful and helpful system and the general view is that the system has made their task more difficult. In many cases, inspectors believe that because of the handheld computers, they spend on average one hour more every day to perform the task.

Table 4-7 presents a list of the issues and comments raised by the users. The table also presents the frequency of the comments. The first column presents the themes which were derived from analysing interview data.

Table 4-7 – Issues with the S&T Handheld Computer System

Themes	Issues with the handheld d computer	Frequency
Task specific issues	Bad organisation of work orders: work orders can't be found and are missed/hidden somewhere in the system	16
	Some of the necessary documents should be added to the handheld, in particular Signalling Maintenance Specification (SMS) and Signal Maintenance Testing Handbook (SMTH)	7
	Irrelevant and repetitive questions	6
	The device is not customisable; the users can not organise the work orders to their preference and can not group them together to close all the works in a bulk	5
	Words used within the system and the way information is structured is not S&T oriented	2

Hardware Issues	Difficulties with the alphabetic keyboard, text input methods being uncomfortable and time consuming	4
	Users prefer a different type of hardware (desktop or tablet PC)	4
Reliability issues	Frequent loss of uploaded data because of technical issues	4
	Users still use the paper based system and do not take the handheld computer on site	7
Usability issues	Handheld computer is very time consuming: slow text entry, slow scrolling and long lists of information	15
	Handheld computer is not similar to other general IT systems users have used	4
	The system is not user friendly	4

Many of the S&T inspectors who were interviewed believe that the main reason for the interaction problems that they experience with the handheld computer is the ineffective organisation of data. Although there is a search facility that allows users to filter and group the associated equipments together, the search activity takes so long that users still prefer to find the asset by scrolling through the list.

It is very important that the information on the handheld computer match the requirements of the task and the way the user performs the task. This is particularly crucial when considering a portable device that has been designed for a mobile task. Perhaps one of the most significant problems with the S&T handheld computer system is the organisation of work orders. The organisation of information on the handheld is different to the way users perform the task. As it has been explained earlier, the S&T inspectors walk along the track and inspect assets in the order that they are located. They would start at the first location and continue to the last asset on their list. But on the S&T handheld computer, equipments in one location do not appear next to each other and therefore the inspectors have to scroll up and down the list to find the specific asset they are looking for. The following comments made by the interviewees indicate their frustration with the system:

> *"the work orders seem to be buried deep down in the system" (interview 31, 14 June 2007)*

> *"the problem is that we have to look for the work orders, they are not organised effectively and because of this jobs are often overlooked" (interview 1, 5 June 2007)*

This mismatch between the most important feature of this application, i.e., presentation of work orders, and the most important part of inspectors' tasks, i.e., finding the asset to be inspected, has led to the failure of this system.

In addition to the issues with organisation of work orders on the handheld computer system, there are problems with repetitive or irrelevant questions. This issue emphasises the fact that the application has not been designed in accordance with the way the inspectors perform their tasks. For instance:

> *"we don't have to answer the protection type question every single time, it is always the same protection" (interview 1, 5 June 2007)*

It is necessary that the application on the handheld computer match the information requirements of the users. One of the issues that the S&T handheld computer users pointed out during the interviews was that they will benefit from having electronic versions of the technical specifications and rulebooks that they use to perform the inspection task on the handheld computer. Also, as described in the feasibility study document of the project, one of the main objectives of introducing handheld computers to inspection operations is to reduce the paper work and the issues associated with inputting data. But the results of the observations have made it clear that not all of the necessary forms are available on the handheld computers and therefore users need to take out paper based forms with them. Interviewees' comments elaborate this issue:

> *"we can't use WAIF, because it doesn't have all the necessary data (interview 5, 14 June 2007)*

> *"it would be helpful to have SMS [signalling maintenance specification] and the rule book on the handheld, or at least giving the page number in SMS (interview 2, 5 June 2007).*

One of the other major problems that S&T inspectors have with the handheld computers is the frequent loss of data. Due to a technical problem, the handheld computer freezes and this leads to a loss of inputted data. This technical problem has led to a lack of trust in the device and is one of the important reasons for unsuccessful deployment of the device. The S&T handheld computer has been designed to be used on the track where users have no access to other computing devices and are expected to rely totally on the information provided by the handheld computer. S&T inspectors usually drive several miles to get to the location where they are required to perform the inspection task and in most cases they have to walk one or two miles on the track to find the assets they have to inspect. If the handheld computer breaks down, there is no other way of getting the work orders and therefore the inspectors would have to go back to the depot.

The hardware used for the S&T handheld computer has also led to some issues. For instance, the handheld computer is equipped with an alphabetic keyboard in addition to the virtual keyboard which appears on the screen. Many users reported that one of the reasons they do not take the handheld computers to the trackside is the fact that text entry is very cumbersome and time consuming.

> *"trying to input same amount of information on the handheld as you would on paper takes 2 or 3 times longer" (interview 6, 16 June 2007)*

It is important that any new computer system is consistent with other systems that users are familiar with and use frequently in their daily life.

Interacting with a familiar interface makes learning and using the interface easier for users. During the interviews many users commented about the position of the "OK" button on top of the screen (See Figure 4-8). They believed that it would be less confusing if the "OK" button was placed at the bottom of the page or at the end of the script. The other problem is how information is being presented to inspectors. The inspectors believed that the lists of work orders should be presented in a "natural way". For instance, one of the interviewees stated that "Excel spread sheets" would have been the ideal format for presenting the work orders to S&T inspectors. Figure 4-8 displays an example of how the work orders are presented to users currently.

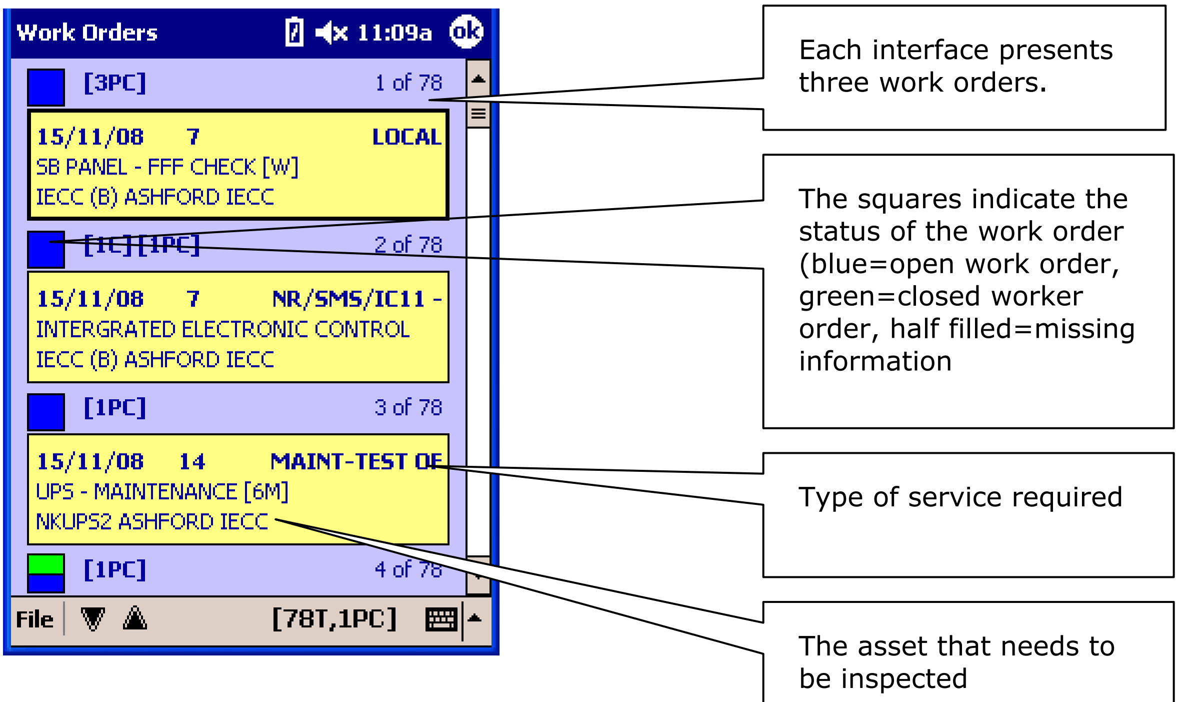

Figure 4-8 - screen shot of the work order list interface

Several users commented about lack of any help documents within the system. In addition, there are no error messages to prevent the users from making a mistake. More importantly the users have not been provided with suitable IT support.

> *"trying to correct any mistakes is very time consuming if possible at all" (interview 4, 12 June 2007)*

> *"training should have covered more specific tasks" (interview 2, 5*

June 2007)

These issues might hinder the success of any computing system, but they can be more problematic when handheld and mobile computing devices are considered. The reason is again the portability of such devices and the mobile nature of the tasks for which a handheld computer device is designed. These characteristics clearly emphasise the importance of sufficient support for mobile users.

The fact that the S&T handheld computers are not suitable for the task it has been designed for has also been confirmed by the result of a brain storming session organised by the project team. The results of this session show that the handheld computer is considered to be an ineffective device for S&T inspection. Many S&T inspectors believe that a tablet PC or even a desktop computer is more suitable for this application. This finding emphasises the importance of compatibility of the hardware as well as the software system with the task. It is important to note that this result might be due to the inappropriateness of the application. In other words, users' opinion about the usefulness of the system might have affected their attitude towards other aspects of the system including the choice of hardware.

4.3.3.2. *Level Crossing (LX) Handheld Computer Systems*

Six LX inspectors from three depots were interviewed and asked to fill in the usability questionnaire. Table 4-8 summarises all the interaction issues which were identified during the interviews. In the rest of this section, these issues will be discussed in more detail.

Table 4-8 - Issues of the LX Handheld Computer System

	Issues with the handheld computer	**Frequency**
Task specific issues	questions that are not applicable to the level crossing	3
	Better and more detailed questions	2

	Ability to plan some of the work themselves	1
	Repeated questions	3
	Not customisable	2
	No search option	2
Feedback	No access to the checklists after uploading	2
	Colour coded feedback very helpful	3
Usability issues	Faster than paper based	5
	Easy to use, very basic	4
Hardware issues	Provides great portability	2
	Screen not visible under all light conditions	1
	Text entry relatively easy	1

Generally most of the users believe that the handheld computer has improved the way they perform their tasks for many reasons. The most important of these are the elimination of most of the paper-based forms which has consequently led to a considerable decrease in the time of performing the task.

One of the main issues that LX inspectors have with the handheld computers is a mismatch between the questions on the checklists and the specific types of level crossing in their area. For instance, the users believe that about 25% of the questions for User Handled Barriers (UHBs) are not applicable. This can be due to the condition and structure of the infrastructure in that specific area which has made the questions slightly irrelevant to individual level crossings. Moreover, some of the crossing in a particular area might be out of use, but on the handheld computer these crossings still appear and users need to go through the checklist for these crossings.

"some questions are irrelevant, it might be helpful to create a

> *database of all the crossings and tailor the questions to each individual crossing" (interview 3, 1 August 2007)*

This result confirms the importance of customisability of the applications for any task. In other words, users should ideally have authority over the system and should be able to adjust the system to their preferred way of working.

The LX application provides clear and informative feedback about the task, but users do not have any way of accessing the completed reports. This has caused the inspectors to request for prints of the completed forms which consequently has led to an accumulation of paper based documents. However, this problem could have been avoided if users were provided with a means of connecting the handheld computer to their desktop PCs and view the reports on their computers.

> *"would be nice if we could have a copy of the forms on our PCs and not have to ask for prints" (Interview 1, 28 June 2007)*

The application provides the users with colour coded information about the status of the checklists, i.e., work orders, as well as individual questions within each checklist (see Figure 4-9). LX inspectors find this information very helpful and believe that this feedback has increased their efficiency, since they can easily notice which questions are incomplete.

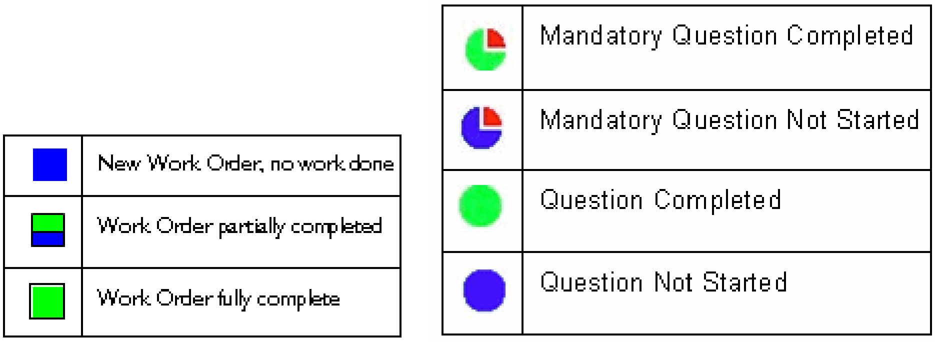

Figure 4-9 - work order and question status symbols

Considering the hardware, most users believed that the handheld computer is sufficiently portable.

> *"I put it in my pocket and get on with my task" (interview 5, 1 August 2007)*

However, the results of the field visits and interviews clearly indicate that there are some problems with screen glare. At one of the field visits which happened on a sunny day, the users complained about screen glare and the fact that nothing is visible on the screen. Interestingly, when the participants were informed that they can change the light settings and improve the visibility on the screen, some of them stated that they were not aware of this feature. This finding emphasises the importance of thorough and detailed training on different features of the device. In this case, although screen light adjustment is not a task related feature, knowledge of it seems to play an important role in performing the inspection task on site.

4.3.4. Questionnaire Results

16 S&T inspectors filled in the questionnaires. All of the participants were male with an average age of 37.5 years old. The majority of the participants had worked in their current position for an average of three years and less than a third of the participants had eight years experience. Two participants had more than 20 years experience. At the time of this study, all of the participants had used the device for about a year with the exception of one participant who had used the device for three months. None of the participants had any experience with handheld computers prior to this system.

Six LX inspectors from three depots[5] filled in the Handheld Usability Questionnaire. All six participants were male with an average age of 45 years old. They had around one year experience of using the device and none of the participants had used a handheld computer for performing

[5] At the time of this research, the handheld computer was being trialled at five locations. The system was rolled out nationally later in 2007.

their task before. The majority had spent three years in their current position.

Table 4-9 presents the results of the questionnaire for each device. The 12 factors in the usability questionnaire were aimed at measuring the usability of the handheld computer systems. The statements were measured using a five point Likert scale with one and five representing "strongly disagree" and "strongly agree" respectively. It was also decided that an average score of three (being the middle point of the scale) or less indicates participants' disagreement with the statements.

Table 4-9 - Results of the questionnaire for the LX and S&T handheld computers

Factors	Statements	S&T	LX
Ease of Use	1.1- The handheld computer helps me to perform my tasks.	2.00	4.67
	1.2- It is easy to learn how to use the handheld computer.	3.12	4.50
	1.3- It is easy to remember and navigate through the menus.	3.37	4.67
	1.4- Paper based forms and the handheld computer support are well integrated.	2.00	3.00
	1.5- It is easy to use the handheld computer.	3.44	4.80
	1.6- I can access the information and applications I need quickly.	2.25	4.50
User Interface	2.1- The user interface of the handheld computer is clear and understandable.	3.06	4.50
	2.2- The information on the handheld interface is organised so that it is easy to find any application.	2.31	4.00
	2.3- It is easy to input text and information into the handheld computer.	2.87	4.50
	2.4- The pictures on the handheld computer screen are of good size and quality.	3.09	4.50
Portability	3.1- The handheld computer allows me more freedom to move around on site.	1.87	4.60

	3.2- I can successfully perform the task on site using the handheld computer.	2.12	4.67
	3.3- The handheld computer is usable in all weather conditions.	3.06	4.83
	3.4- The handheld computer is usable in all light conditions.	3.44	3.33
	3.5- Using the handheld computer I am able to perform my tasks wherever and whenever necessary.	2.13	4.67
	3.6- The handheld size is convenient for transportation.	3.12	4.50
	3.7- The handheld computer is tough and would not break easily.	3.75	4.60
Consistency and task relevancy	4.1- The handheld computer is similar to other handheld and PC based systems I have used.	2.47	4.67
	4.2- The format of all data entry fields is consistent.	2.69	4.50
	4.3- The words used within the handheld computer are consistent and understandable.	3.37	4.50
	4.4- The words used within the handheld are similar to those in other handheld and PC based systems.	3.20	4.50
	4.5- The words used are usually related to the task I am doing.	3.06	4.50
	4.6- Design of icons and icon labels are usually related to the task I am doing.	2.71	4.50
Feedback	5.1- The handheld computer provides immediate and appropriate feedback.	1.93	3.67
	5.2- The handheld computer gives me information about the percentage of the task completed.	2.50	4.33
	5.3- The system always informs me about where I am in the menus.	2.44	3.00
	5.4- Highlighting the selected menu options on screen is useful.	2.53	4.33
Productivity	6.1- The handheld computer usually provides correct default values.	2.20	4.00

	6.2- Using the handheld computer I am able to perform my tasks effectively and quickly.	1.73	4.33
	6.3- The amount of information displayed on the handheld screen is too much.	1.87	4.50
Adaptability	7.1- Using the handheld computer I can perform my tasks flexibly.	1.62	4.50
	7.2- I can customise the handheld interface to match my preferred way of working.	2.12	2.83
Affective Design	8.1- I like using the handheld computer.	1.69	4.00
Technology	9.1- The handheld computer is reliable.	1.31	3.67
	9.2- The handheld computer is fast enough.	1.69	3.67
Workload	10.1- Only the information I need at the time is presented to me on the handheld screen.	1.94	4.33
Errors	11.1- It is easy to correct any mistakes on the handheld computer.	2.31	4.50
	11.2- The error messages are appropriate and helpful.	2.67	4.80
	11.3- There are messages aimed at preventing me from making any mistakes.	2.75	4.33
Help	12.1- The help information given by the system is useful.	2.69	4.17
	12.2- The manual provided is easy to understand and clear.	2.87	2.80
	12.3- The training that I have received has equipped me with the necessary skills to use the handheld computer.	2.00	3.00

The findings of the interviews and field visits clearly suggest that the two systems have been implemented with varying degrees of success. As it was mentioned earlier in this chapter, the S&T and LX systems have very similar and for some features almost identical user interfaces. While the LX handheld computer is considered to be a very useful tool, the S&T handheld system is believed to have decreased the efficiency of the workers. In this section, the questionnaire results will be reviewed again to find out the reasons for this difference.

The initial results of the studies showed that despite the similarities in the user interfaces of both systems, the S&T handheld computer is considered by the end users as a time consuming device that has just added to their problems. On the contrary, the LX inspectors believe that the handheld computer has enhanced the way they perform their tasks. Figure 4-10 summarises the overall average ratings of the usability factors for each of the handheld computer systems. The results presented in this figure clearly demonstrate the differences between the perceived usability of the two handheld computer systems.

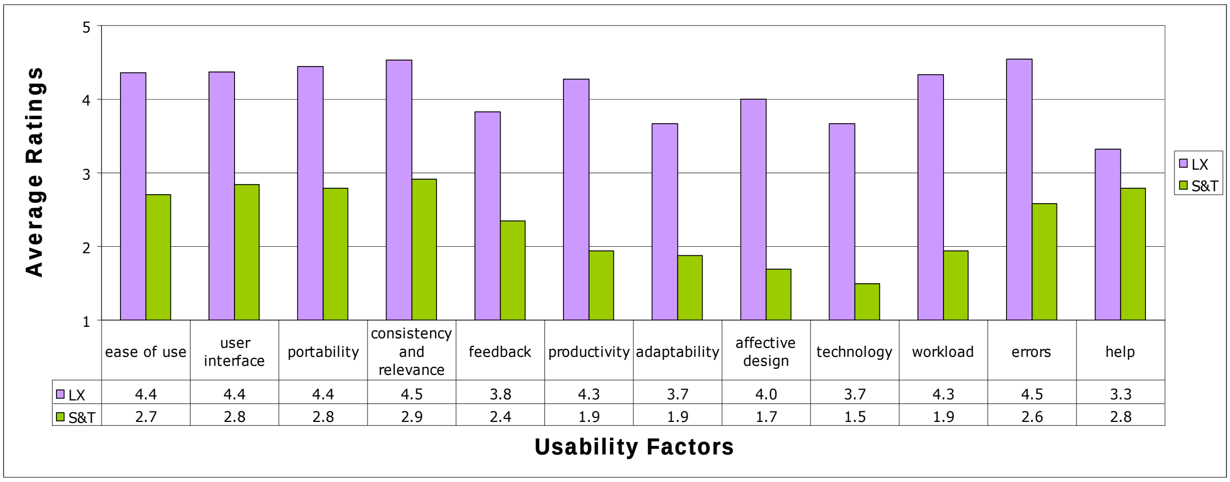

Figure 4-10 - Average overall ratings of usability factors for the S&T and LX handheld computers

The results obtained from the questionnaire show that none of the factors measuring the usability of the S&T handheld computer system received a rating of three or higher. This suggests that the S&T inspectors do not consider the handheld computer to be a usable system. The data gathered from the interviews and site visits revealed that the S&T inspectors do not take the handheld computers on site. The main reason for users' reluctance in using the handheld computers is that the information provided by the system is not sufficient for performing the inspection task and at times it is very difficult and time consuming to access the required information. S&T inspectors believe that their productivity has decreased considerably because of the time they spend filling in the forms on the handheld computers. The importance of this issue becomes clearer when the main objective of introducing handheld computers for S&T inspection is considered which is to increase productivity by reducing the amount of paperwork. Considering the factors have received ratings closer to three, which was the minimum acceptable score, it becomes apparent that the interface is relatively easy to use and learn, the device is sufficiently portable and the terminology used within the system is consistent and relevant to the task. The unsuccessful deployment of the device is likely due to the fact that the applications on the handheld computer do not comply with the way inspectors perform their tasks and it does not match their information requirements. The data gathered from semi structured interviews show that the only information the inspectors require to perform the inspection task is: 1- What the job is; 2- Where it is; and 3- What service it requires. The handheld computer contains this information, but in order to access this information, users have to navigate through several interfaces and search for the data which makes the task very time consuming.

As it can be seen in the graph, the results obtained from evaluating the LX handheld computer are different from the results of the first system. All of the 12 usability factors in the questionnaire received ratings higher than three. In other words, LX inspectors regard the handheld computer as a usable system. The application on the LX handheld computer has been designed to substitute the paper-based inspection forms. These forms are the most important item of information LX inspectors require to perform their daily task. Presenting these forms on a handheld computer has reduced the amount of paperwork and increased the speed of performing the task without compromising the quality of the collected information. Therefore, despite a few usability issues which were mentioned during the interviews, the users were very satisfied with the system and the way it has changed their work pattern.

In order to investigate the differences between LX and S&T handheld computers further, a Mann-Whitney U test was performed to identify any differences between the ratings given to the statements for each device. The results of the Mann Whitney tests showed that 32 of the statements are significantly different. However, the ratings given to ten of the statements were not significantly different. These statements and their average overall rating are presented in Table 4-10.

Table 4-10 – Statements which have not received significantly different ratings (based on the results of the Mann-Whitney U test)

Statements	S&T	LX
1.4 - Paper based forms and the handheld computer supports are well integrated.	2.00	2.00
1.5 - It is easy to use the handheld computer.	3.44	4.00
3.4 - The handheld computer is usable in all light conditions.	3.44	3.33
3.7 - The handheld computer is tough and would not break easily.	3.75	4.50
4.1 - The handheld computer is similar to other handheld and PC based systems I have used.	2.31	2.33
5.3 - The handheld computer always informs me about where I am in the menus.	2.44	3.00
6.1 - The handheld computer usually provides correct default values.	2.06	2.67
7.2 - I can customise the handheld interface to match my preferred way of working.	2.13	2.83
12.2 - The manual provided is clear and easy to understand.	2.88	2.31
12.3 - The training that I have received has equipped me with the necessary skills to use the handheld computer.	2.81	3.00

Studying these statements reveal some of the common advantages and disadvantages of the two systems. However, studying the results of the Mann-Whitney U test for statements which had received significantly different ratings, five statements were identified which are independent of the task and are only concerned with features of the interface which are not related to the tasks performed. The fact that these statements measure an aspect of the interface which is independent of the task means that regardless of the application, the statements should have received similar ratings. However, the data presented in Table 4-11 show that S&T inspectors have given significantly lower ratings to these statements compared to the scores given to the same statements for the LX handheld computer.

Table 4-11 - Average ratings of the statements which are independent of the tasks and have received significantly different ratings (based on the Mann-Whitney U test)

Statements	S&T	LX
2.3- It is easy to input text and information into the handheld computer.	2.88	4.5
3.3- The handheld computer is usable in all weather conditions.	3.06	4.83
3.6- The handheld computer size is convenient for transportation.	3.13	4.5
5.4- Highlighting the selected menu options on the handheld screen is useful.	2.53	4.33
9.2- The handheld computer is fast enough.	1.69	3.67

This result shows that a mismatch between the applications on the handheld computer and the task performed by end users, as it is the case with the S&T handheld computer, affects users' view about other aspects of the interface as well. In other words, the perceived usability of an application depends on how effectively it can address user's needs.

In sum, comparing the results of the two systems reveals that an easy to use system is not necessarily a usable system. The result of these UX case studies have formed part of the information necessary for generating a set of principles for context specific mobile interface design.

4.4. Discussion

The information gathered through these UX case studies has created a strong knowledge foundation for other studies in this research. These studies are the main source of real world information about the context, task, users, and applications and in fact, many of the research questions in this thesis have emerged as a result of the findings of the UX case studies. In other words, these studies have provided the researcher with a practical perception not only about the usage of the handheld computer system, but also about the way users perform their tasks.

In this section, first the results of the UX case studies and the principles derived from these findings will be discussed. The last part of the discussion explains the development of a descriptive model which illustrates mobile HCI in the rail industry currently. A theoretical framework has also been developed that attempts to integrate the current mobile HCI models and theories with the understanding obtained from the UX case studies and the EDARE framework. This framework has also been explained later in this section.

The following principles for developing a user interface for handheld computers have been derived from the results of the UX case studies reported in this chapter:

1. Consider match between the applications on the handheld computers and tasks and consistency with other systems and between different platforms:

The most important objective of any application is to assist its users with accomplishing a goal, i.e., performing a task. If the system fails at providing the user with necessary means for performing the task it has been designed for, it will become useless. Therefore, it is crucial to ensure that the application on the handheld computer matches the tasks users need to perform and also match the way users perform their tasks. This finding was illustrated by the results of the interviews with S&T inspectors.

It is also important that any new computer system is consistent with other systems that users are familiar with and use frequently. Moreover, it is essential to ensure that information is presented consistently across various platforms within the organization and in a way that is familiar and "natural" to users.

2. Consider adaptability and customisability of the system to user preferences:

No matter how effective the system is in meeting users' information and task requirements, it is still important to provide the user with some customisability capabilities. In other words, it is important for any system to provide its users with some degree of adjustability to ensure that the application does not dictate the way of work to users. One of the reasons for users' dissatisfaction with both S&T and LX handheld computer systems is the fact that (S&T interview 3):

> *"The device dictates what the teams have to do; i.e., the teams can not organise the jobs to match their preferences."*

Therefore, even in a perfect situation when the applications completely match the requirements of the tasks, the users should still be able to customise and change different features of the system.

3. Consider suitability of the hardware and reliability of the technology:

One of the main objectives of introducing handheld computers for maintenance and operation tasks is to provide track workers with a portable device. Therefore, this device is expected to support track workers in an ever changing mobile environment. The nature of the tasks and the portability of the handheld computer mean that it will be used in different weather and lighting conditions. Furthermore, the device should be of suitable size and weight so that it is easy to be carried around while working on site.

The handheld computer will be used for mobile tasks where users do not have access to other sources of information and rely totally on the handheld computer. The results of the interviews with S&T inspectors show that many of the participants believe that a handheld computer is not a suitable hardware for the current application and unless the system is further developed to offer more task-related applications and information, a desktop computer located at the depot is probably a more appropriate hardware. Therefore, it is important to ensure that the selected hardware matches the task requirements.

More important than suitability of the hardware is reliability of the technology. In most cases a handheld computing device is introduced to an application where there is a need for providing information to the users outside of the office environment. This means that a mobile worker is usually performing his or her task in an isolated location with no access to other devices. Therefore, reliability of the technology is crucial to a handheld computer user and it is probably more important for handheld and mobile computers than for desktop computers. The handheld computer is designed to be used as a portable device and in most cases it will be the users' main point of reference. Therefore it is very important that the system is reliable and does not break down.

Moreover, the handheld computer, in most cases, is not the only device that a maintenance worker uses to perform his or her tasks. Maintenance workers use a whole host of other tools. This means that the chosen hardware should ideally integrate all the different tools. For instance, one of the devices that maintenance workers use reasonably frequently is digital cameras. The digital camera on the current handheld computer has been disabled. Having to carry a digital camera as well as other devices and tools while walking on the track between locations is not very convenient. An integrated device could solve many of these problems.

4. Consider providing continuous training and support:

Designing a context specific application is not sufficient for its successful operation. Comprehensive training and continuous support are vital to successful implementation of a handheld system. Providing help messages for users of any system is one of the important factors which might lead to a more "usable" application. But it is crucial to ensure that these messages are clear, simple, understandable and easy to access. There are several guidelines in the literature that outline the requirements of an appropriate and usable help message. Designing a task and context specific application is not sufficient for successful deployment of a system. Comprehensive training and continuous support are vital to successful implementation of a handheld system. Several users commented about the lack of any help documents within the system. Also, many users mentioned that an online IT support would have been very helpful and might have encouraged them to use the device more freely.

The findings of this study confirm the fact that an “easy to use” system is not necessarily “usable”. S&T inspectors do not have any difficulties with operating the handheld computer. The system is not being used because it fails to meet the information requirements of performing the inspection task.

According to ISO 9241 – 11 (1998) usability is defined as “The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use.” Studying the results of these UX case studies, it might be possible to order the three dimensions of usability - effectiveness, efficiency, and satisfaction - in a hierarchy; borrowing Maslow’s idea of “hierarchy of needs” (Maslow, 1943). Figure 4-11 demonstrates this order.

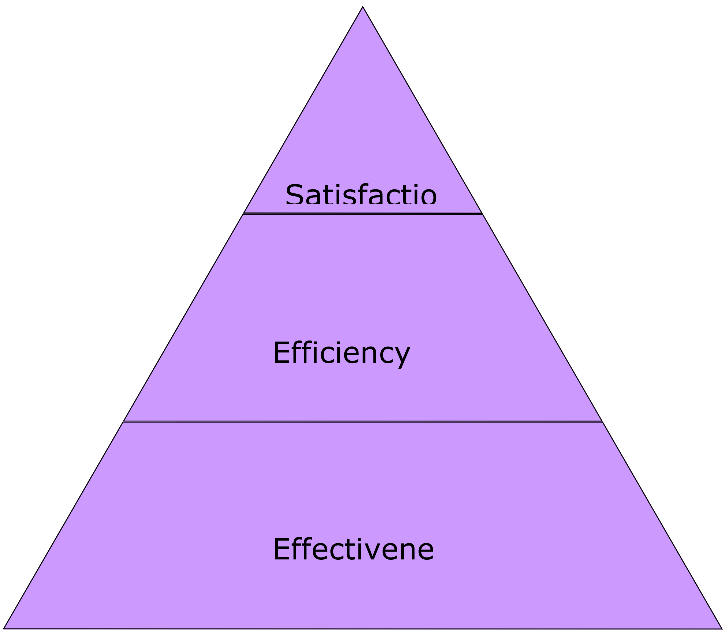

Figure 4-11 - Hierarchy of Usability Dimensions

Being able to perform the task using the application proves the effectiveness of the application. Efficiency means achieving this result effortlessly and easily, in other words an efficient system is a system where all the traditional usability issues have been addressed. Satisfaction, however, is about the users' experience and attitude.

Performing a task with satisfaction is a combination of effectiveness and efficiency. In other words, the boundaries between the different usability dimensions are not absolute and are rather fuzzy and there is an interaction between the three dimensions. Despite this interaction, it seems impossible to achieve efficiency before effectiveness and achieving a goal with satisfaction will not happen unless the user accomplishes the task with effectiveness and efficiency.

4.4.1. Descriptive Model of Mobile HCI in the Rail Industry

Studying the applications identified by the EDARE framework and the results of the UX case studies uncovered the complicated and versatile nature of interacting with handheld computers in the context of rail engineering. Providing a visual illustration of this interaction in light of current HCI models and theories was believed to be helpful in clarifying some of these complexities and providing the basis for a theoretical framework.

The descriptive model presented in this chapter is shown in Figure 4-12. It explains mobile HCI in the context of rail in its current state. The system where the user interacts with the handheld computer forms an "interactive worksystem". The term "interactive worksystem" was first suggested by Warren (1993) and consists of a user working with a computer system to perform a task (Warren, 1993). In the context of rail maintenance operations, currently, the Interactive Worksystem contains the handheld computer, but it also includes other tools and documents required for performing the task. Ideally, all of these requirements should be integrated into the handheld computer. The circles drawn around other track workers denote the devices and tools that they use for performing their tasks, but currently only one person within each maintenance team has a handheld computer.

Interaction with handheld computers is bound to be influenced by the environment and factors within the environment. Some of these factors have been presented in this model, e.g. organisational issues, training, environmental issues such as weather conditions, interaction with other assets on the infrastructure, etc. Therefore, a "distributed interactive worksystem" is embedded within the "environment" and there is an interaction between the worksystem as a whole as well as between individual "Interactive worksystems" and workers with the environment.

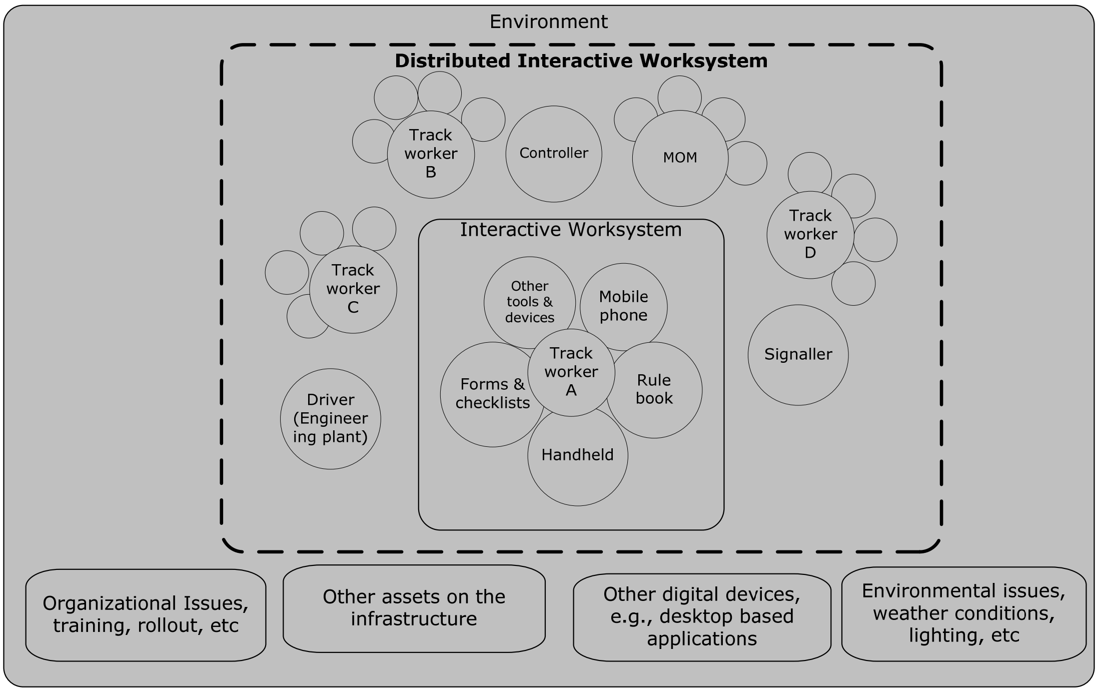

Figure 4-12 – Descriptive model illustrating interacting with handheld computers in the rail industry

While this model has no predictive capabilities, it has enabled the researcher to form a better understanding of mobile HCI in the rail industry and has provided her with a means of illustrating this understanding.

4.4.2. Proposed Theoretical Framework for Mobile HCI in the Rail Industry

The descriptive model explained above illustrates the interaction with handheld computers in the railway as is currently done. Therefore, the figure displays a maintenance worker interacting with a handheld computer and other tools and devices that are used for performing maintenance and engineering tasks. However, the track worker is isolated within his "interactive worksystem" and other members of the team, with whom he collaborates, are placed outside the worksystem where he interacts with the handheld computer. This model was revisited with the aim of adapting it to demonstrate the potentials that handheld computers offer. A new framework, shown in Figure 4-13, was developed which illustrates how handheld computers could be used in the rail industry in future.

The work on this framework has drawn from a number of theories and models, the most important of which are Model Human Processor (MHP), Distributed Cognition and Activity Theory (Bødker 1991; Card et al., 1983; Hollan et al., 2000).

MacKenzie (2003) describes a model as a simplification of reality (MacKenzie, 2003). The framework presented here is not a predictive model. It is rather a descriptive model that attempts to present different aspects of interacting with a handheld computer in an environment where the interaction is influenced by organisational, cultural and environmental issues and in accordance with the current theories that explain human computer interaction.

Cognitive psychology and information processing theories introduced to the HCI discipline in the early 80s have been the predominant theories ever since. One of the earliest models of HCI is the Model Human Processor (MHP) proposed by Card and his colleagues in 1983. As Hutchins and colleagues (2000) explain HCI began as a field at a time when human information processing was the prevailing theory.

The idea of decomposing work activities into single tasks and study each individual's interaction with the system while performing that single task had dominated the research in HCI for over 20 years. Distributed Cognition provides an alternative foundation for HCI by extending what is considered as cognition beyond individuals. This theory has been specifically tailored to understanding the interactions between people and technology (Hollan et al., 2000). A distributed cognitive perspective radically alters the way we consider HCI. In contrast to the traditional view of HCI that assumes cognition is confined to the individual, a distributed cognition view holds that cognition is distributed in the environment through time and space. There is a connection here with the joint cognitive systems (JCS) of Hollnagel and Woods (2005) in which cognition is distributed amongst people and computers (Hollnagel and Woods, 2005).

Activity theory examines people in their real environment and considers cultural and social factors (Kaptelinin, 1996). Activity Theory considers socially-distributed and tool mediated interaction and takes into account the historical development of social and tool systems. The theory puts great emphasis on goals of activities and classifies the levels of activity (Bødker 1991).

In this framework, instead of one "interactive worksystem", each maintenance worker would be working within a worksystem. The boundaries between these worksystems are fuzzy and therefore, the users in different systems might interact with each other, e.g. face to face communication, or they could collaborate through the handheld computers with each other, for instance through Bluetooth or other wireless technologies.

The interaction between the user and the handheld computer can be described by the hierarchical structure of activity which is one of the main principles in Activity Theory. The theory distinguishes between three levels of activity: 1- activities, 2- actions, and 3 automated operations. Activities are composed of goal directed actions that must be undertaken to fulfil the objective and actions are implemented through automatic operations (Bødker 1991). Automatic operations can perhaps be regarded as the lowest level in the interaction hierarchy and therefore can be explained by traditional cognitive psychology theories such as MHP.

The framework suggests that cognition is distributed amongst the interactive worksystems and is not confined to one individual or one system. Therefore, as can be seen, the activities are performed within a "Distributed Interactive Worksystem" where several workers (or several "Interactive Worksystems") collaborate and interact with each other. The "Distributed Interactive Worksystem" contains the knowledge and cognition of the whole of the system. This worksystem is embedded within a context which determines the environmental and organisational conditions that impact the interaction with the handheld computers. However, information contained by other digital devices such as desktop applications and more importantly information associated with the assets on the infrastructure could be transferred to the "Distributed Interactive Worksystem" by means of technologies such as RFID tagging, wireless connections, and location based systems and users could obtain this data through context aware and implicit interaction.

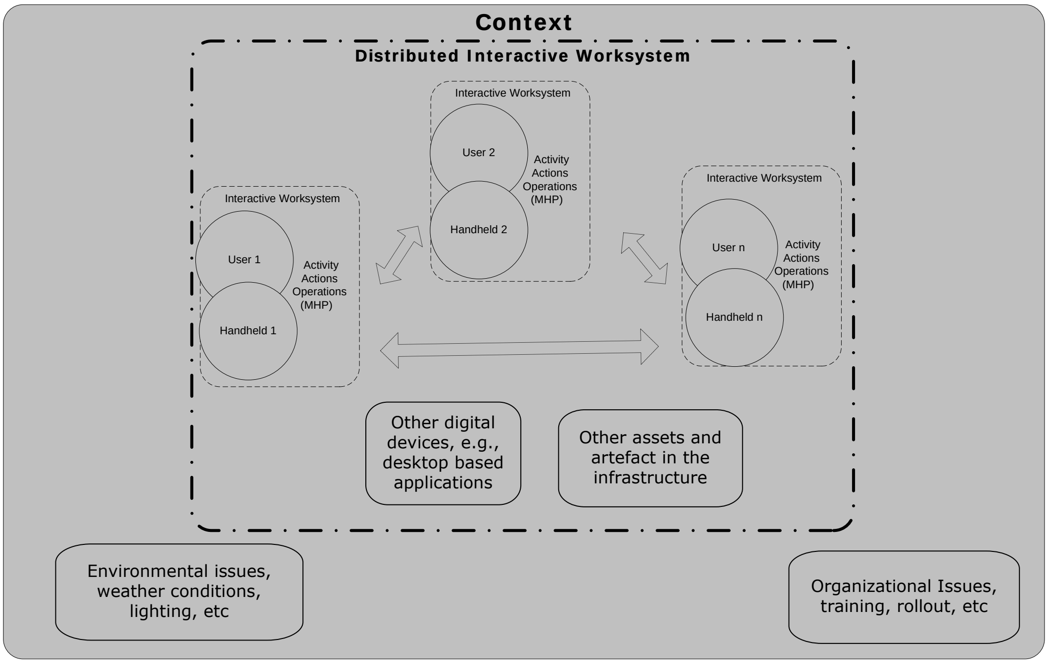

Figure 4-13 – Theoretical Framework for Human Factors of Handheld Computer Usage

The figure displays the handheld computer as the main equipment of the maintenance worker. This suggests integration of all the different equipments and tools into a single device. Nonetheless, the success of such an integrated device depends on the match between the application and users' tasks and the hardware chosen for the system. Allowing users to customise the device to their preferences is another factor that affects the users' experience with the device. A further principle that contributes to successful implementation and rollout of a handheld computer system in an organisation is providing sufficient training and continuous support for users.

Figure 4-14 displays a detailed expansion of the interaction between the "handheld computer" and "user" in the framework. The key characteristics and attributes of mobile computing devices and mobile users which are identified in this figure are prioritised on the basis of review of literature and empirical observation of handheld computer usage.

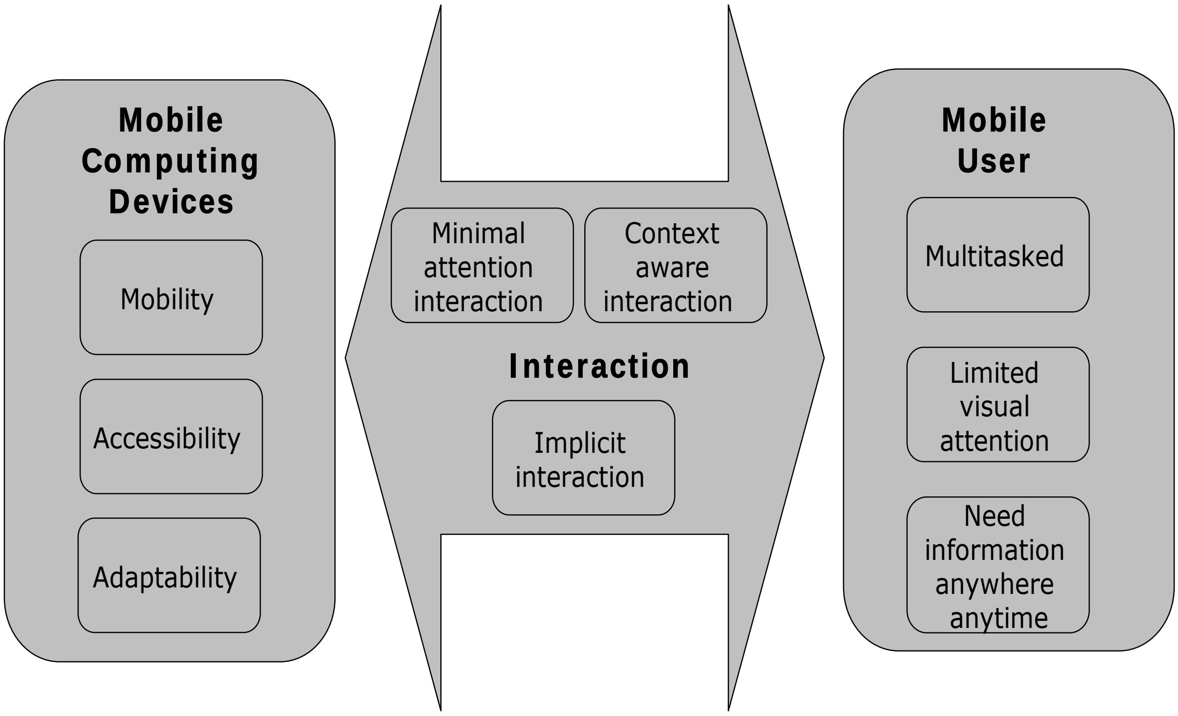

Figure 4-14 – Interaction between the mobile user and the mobile computing device

These characteristics introduce or imply many interaction issues; nevertheless they also provide the necessary means for addressing some of these issues. Mobile users might need information anywhere and anytime and can spare very limited attention resources to obtain this information through the limited input and output channels of a handheld computer. These issues can be dealt with by designing context aware interactions where information is adjusted to user needs and settings. For instance, in the context of rail maintenance, instead of searching for a specific asset in a list of work orders, context aware interaction could provide maintenance workers with information about the status of an asset automatically through some sort of wireless connection between the physical assets on the infrastructure and the application on the handheld computer. However, context aware interaction is only feasible on a portable device that can be carried around by the user. This example highlights some of the concepts summarised in Figure 4-14 and how these concepts are linked together.

The final part of this research focuses on investigating some of the fundamental issues associated with presenting rail specific spatial information on handheld computer screens. In order to achieve this objective, four experiments were designed and conducted. These have been reported in chapters five, six, and seven.

5. Chapter 5 – Experiment I: Handheld Computer vs. Paper

5.1. Introduction

The findings of the UX case studies and the EDARE framework provide an understanding of track workers' information requirements. As it was explained in chapter 3, six main information requirements were identified. However, the results of the interviews with track workers and SMEs show that local knowledge is crucial to track workers and an essential part of performing any task successfully.

A brief review of some of the recent accident reports reveals that lack of local knowledge has been linked to a number of incidents. In particular, the investigation following an incident at Newbridge where a member of staff was fatally injured in an accident identified lack of local knowledge on behalf of the planners and track workers as the causal effect. Therefore, a research study in Network Rail was launched to study the issues raised by this investigation. This study identified the most important items of local knowledge for track workers. These items are: 1- Up and down line identification; 2- Train traffic frequency; 3- Access and egress points; 4- Track layout and curvature; 5- Place of safety; and 6- Line speed (Lowe, 2005).

Interviews with track workers showed that, at the moment, workers depend on their experience and their own local knowledge in order to navigate on the trackside and locate the position of various assets. Less experienced workers have to either rely on paper-based documents such as the Sectional Appendix and Hazard Directory or attempt to obtain information from their colleagues. Despite the fact that most of the interviewees questioned the effectiveness of having spatial and local information provided to them on the trackside for navigation or way finding purposes, they still admitted that it could serve other purposes such as safety briefings and training new staff. Moreover, apart from the general spatial information, there are specific items of information about different infrastructure elements which track workers require to perform their tasks. This information is often presented on track diagrams and many of the interviewees commented about the advantages of having this information on a portable device. Therefore, in the final section of this research, a series of experiments were designed and conducted to investigate different aspects of presenting location information on handheld computer screens.

The overall objective of the experiments in this thesis is to study different aspects of interacting with spatial information on a handheld computer. In this chapter, first, the overall experimental programme followed in this research will be described. The rest of the chapter will explain the methods used for designing and running the first experiment as well as the results obtained.

5.1.1.Experimental Programme

Understanding the users and their tasks in this research has been mainly facilitated by using qualitative research methods. Also, the information gathered through applying the qualitative techniques led to identification of other research questions regarding the issues associated with interacting with handheld computers, in particular in relation to interacting with spatial information on these devices. Therefore, in order to verify and complement some of the findings of the qualitative studies, and to explore some detailed issues in more depth, it was considered that a laboratory experimental research method was also essential.

The results of earlier stages of the research clearly showed that spatial information is the most important item of information for track workers. Therefore, it seemed necessary to investigate different aspects of presenting spatial and spatially-orienting information on handheld computer screens. Another more important aim of these experiments was to generate a set of fundamental design guidelines.

In addition to the common issues of presenting spatial information on a handheld computer screen, displaying context-specific spatial information necessitates addressing other concerns. The most important question is what information should be displayed on the handheld computer screen. The answer to this question came from the EDARE framework and the Network Rail study reported above which listed the most important items of information. The next question that needs to be addressed is how much information can be displayed on the handheld computer. However, in order to address this question, it is necessary to determine how information is going to be displayed in the first place. Answering this question, which has been explained in 5.1.2, prompted the question of differences between interacting with rail specific spatial information on handheld computer screens compared with using paper-based documents to obtain this information. This question was investigated in experiment I.

The second question which was raised was about the suitable interaction style for interacting with rail specific spatial information on a handheld computer screen. Therefore, the second experiment in this thesis was designed to investigate the effectiveness of different interaction styles.

The most important question that needed to be answered was how much information can be displayed on the screen of a handheld computer. Therefore, experiment III was set up to investigate the optimum amount of information that can be presented on the handheld computer screens. Finally, studying the results of experiment III raised some questions about differences between presenting different items of information and therefore, the last experiment in this thesis examined the effect of type of information on users' performance. Figure 5-1 presents an overview of the experimental design strategy in this research:

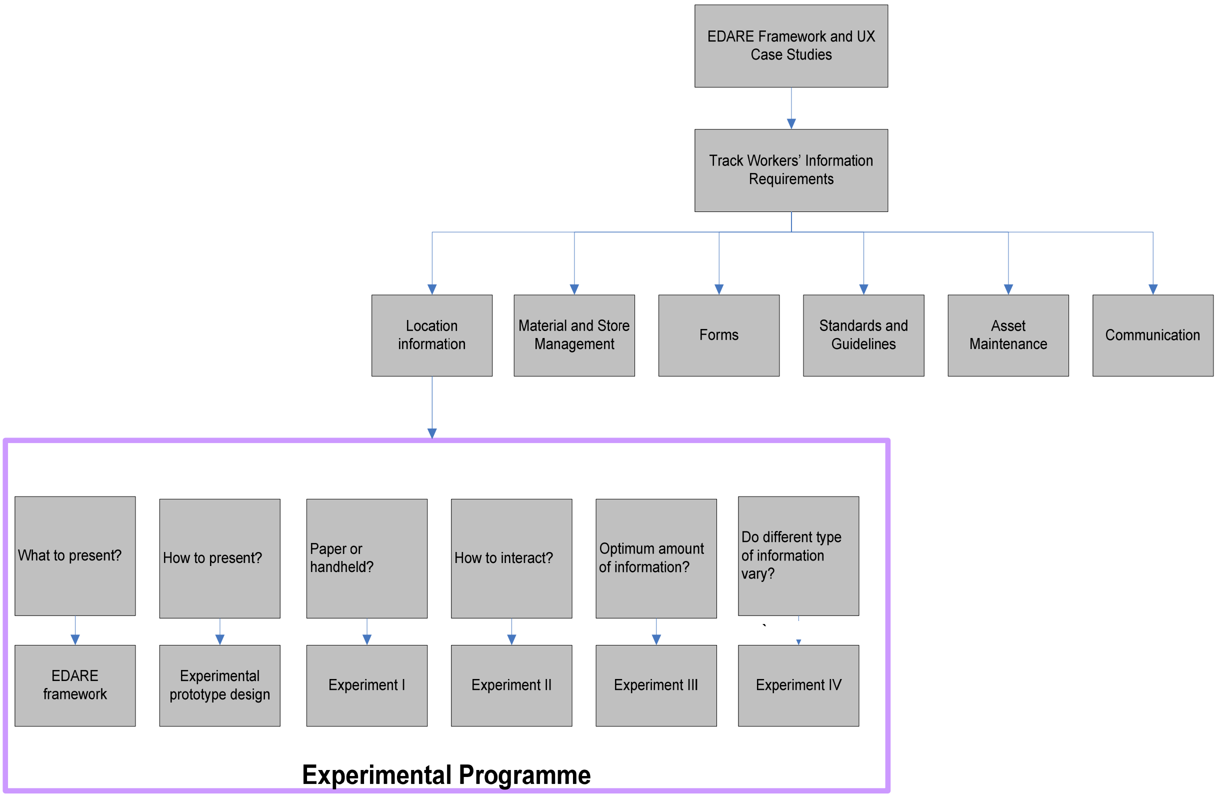

Figure 5-1 -An overview of the experimental design strategy

In sum, the experiments conducted in this research were:

1. Investigating the impact of presenting spatial information on handheld computers compared with the paper-based information on workers' performance (Experiment I, presented in chapter 5)

2. Investigating the most suitable interaction style (Experiment II, presented in chapter 6)

3. Investigating the optimum amount of information that can be presented on each screen (Experiment III, presented in chapter 7)

4. Investigating the effect of type of the information on users' performance compared with clutter on the screen (Experiment IV, presented in chapter 7)

5.1.2. Presentation of Rail Specific Spatial Information on Handheld Computers

It is clear that the content and presentation style of a mobile map should be based on users tasks, requirements, and context of work (Meng and Reichenbacher, 2005). Many factors might affect the choice of presentation style, ranging from technical issues such as display size, energy supply, memory size, to non technical issues such as constantly changing environments and user task requirements (Reichenbacher, 2004). Meng and Reichenbacher (2005) explain that it is important to keep the mobile maps simple and limited to a few key points of interests (Meng and Reichenbacher, 2005, pp. 5):

> *"Often a few points of interest (POI) floating on a skeletonised background graphic would suit the short-term memory of a mobile user better than a more detailed presentation."*

Schematisation is a method used in cartography for emphasising certain aspects while deemphasising unimportant details (Krippel et al., 2005). Research has shown that, although schematic maps provide much less information, users' performance is significantly better when they used an unambiguous schematic map for way finding (Meilinger et al., 2006).

Dillemuth et al (2007) have identified four factors that determine what information from the geographical area should be presented on the handheld computer screen (Dillemuth et al., 2007):

1. The context of the map task: the content of the map should match the context of work and users' tasks. This factor has been addressed throughout this research by matching the information which is being displayed on the screen to the data gathered in the EDARE framework (see chapter three). All of the items of information which were chosen to be displayed on the handheld computer screen had been identified by track workers and were listed in the framework.

2. The available geographic information: the display should be designed in accordance with the geographic information in the area. In the case of rail specific spatial information, the geographical area is determined by different assets and infrastructure elements.

3. The preference of and interaction capability of the users: clearly, the system should be designed so that the users can interact with the

interface and make use of its different features.

4. The spatial context: the content of the map should be a function of the environment and the symbolisations should be familiar to and understandable by the user.

These factors were considered when designing the experimental interfaces for presenting rail specific spatial information on handheld computer screens in this study. Spatial information in the rail industry is mainly displayed as schematic track diagrams. All Network Rail documents such as the Sectional Appendix, the walkout report for track inspectors and signalling diagrams are presented as schematic diagrams.

Since track workers are familiar with this presentation style, it was decided that the design of any computerised spatial information should also match their experience and expectations. Therefore, the experimental interfaces were based on the Sectional Appendix which is the Network Rail book which lists, in route order, all the running lines and provides details such as line speed, line direction, stations, mileage, and location names (Figure 6-2).

The rest of this chapter will focus on the first experiment, i.e., investigating differences between presenting rail specific spatial information on handheld computers and paper based documents. First, the background of the research is explained. The next section presents the methods employed for conducting the experiment and analysing the data and finally, the results of the experiment are reported and discussed.

Figure 5-2 - Sectional Appendix

5.2. Experiment I – Handheld Computer vs. Paper

This chapter reports on the data collection methods and the findings of the first experiment in this research. The objective of the first experiment was to investigate the difference between effectiveness of presenting spatial information on the handheld computer screen and on paper based documents and the impact of each presentation style on track workers' performance.

The results of the research in chapter three revealed that handheld computers have the potential to be used as a substitute for paper based documents. More specifically, it became clear that there is great potential for replacing the very many paper based documents used for providing general and task related spatial information with a portable solution on a mobile computing device. However, it is still important to investigate the effectiveness of using handheld computers for displaying rail specific spatial information empirically. The reason for this was that the quality of data presented on the handheld computer compared with the paper based version needs to be tested in terms of providing sufficiently detailed, comprehensive, and understandable information to track workers.

During site visits and interviews with maintenance workers, it became clear that the Sectional Appendix is workers' first point of reference for way-finding and planning purposes for trackside engineering work.

The Sectional Appendix is Network Rail's book which provides information about line speed, line direction, mileage, etc. Maintenance workers need to communicate this information to their colleagues for various purposes. For instance, in case of an incident on the trackside which needs immediate action, the Mobile Operations Manager (MOM) would use the Sectional Appendix to provide the maintenance team with information about location of the fault over the phone.

This example was used as a scenario in this experiment to compare the two different presentation devices, i.e., paper vs. handheld computer screen. It was believed that the quality and effectiveness of communicating information using each device can be measured as an indicator of the effectiveness of each method.

In this chapter, first the aim of the experiment will be defined. The next section will study the data collection and analysis methods adopted in this experiment. Finally the results of the experiment will be reported and discussed.

5.3. Aim

The aim of this experiment was to study and compare the differences between effectiveness of presenting spatial information on the handheld computer screen with paper-based documents. The objective of this experiment was to address the following questions:

1. How quickly and efficiently can the track workers communicate the necessary information using each method?

2. Which method provides more comprehensive and detailed information?

3. Which method leads to a more effortless communication?

5.4. Method

In order to achieve these objectives, an experiment was set up where pairs of participants were asked to role play in a scenario. The scenario required the participants to use the information provided to them by each method and guide their colleague to a specific location.

Table 5-1 presents the factors which were measured in this experiment to address the identified research questions.

Table 5-1 - Experimental measures

Experimental Measures	Research Question
Speed and efficiency of communication	How quickly and efficiently can the track workers communicate the necessary information using each method?
Adequacy of information	Which method provides more comprehensive and detailed information?
Ambiguities and difficulties in communication	Which method leads to a more effortless communication?

In order to gather some information about participants' experience with the handheld computer device and their opinion about the effectiveness of the device compared to the paper-based documents in a real world condition, a semi-structured interview was performed with each pair after the participants had used both methods.

5.4.1.Experimental Interface

The first stage of this experiment was development of a set of experimental interfaces. The experimental interfaces designed for all the experiments in this research are very similar. Therefore, the development process for the first experiment will be explained here in detail. Any variations in the design of the experimental interfaces for other experiments will be explained in the relevant chapter.

Different software was tested for development of the experimental interfaces. These included Microsoft Visual Studio 2003, Microsoft Visio 2003, Microsoft PowerPoint 2003 and Microsoft Publisher 2003. Eventually, it was decided to design the interfaces as html pages and display them on the handheld computer using mobile internet explorer. Therefore, Microsoft Publisher 2003 was chosen for the design of the interface.

It was important to consider the usability aspects of the interface in terms of font size and background and foreground colour combination. Reviewing the literature showed that the guidelines and standards for mobile and handheld computer interface design are usually limited to style guides developed by system developers. These style guides were consulted in order to choose the most suitable background colour and font size for the experimental interfaces.

Table 5-2 and Table 5-3 summarise the findings of studying the standards and guidelines available in the field of mobile HCI. Table 5-2 illustrates the guidance provided by some of the guidelines for an appropriate font size. As it can be seen from Table 5-2, an acceptable font size for presenting text on handheld computer screen varies between a minimum of 9 to a maximum of 16.5 points.

Table 5-2 - standards and guidelines on the appropriate text size for mobile devices

Standards and guidelines	**Source**	**Text Size**
Palm OS ® User Interface Guidelines	(Ostrem, 2002)	9 pt Or 12 pt
iPhone Human Interface Guidelines	(AppleInc., 2008)	17 to 22 pixel (12.75 to 16.5 pt)
Nokia 7710 User Interface Style Guide	(Nokia-Corporation, 2004)	22 pt (for icon labels only)

For the purpose of the experimental interfaces in this study, it was decided to use a font size of 10 points. However, considering that the interface was developed on a laptop, it was important to measure the font sizes on the handheld computer screen and ensure that a font size of 10 points is displayed.

The size of the Dell handheld computer screen used in this research is 2.9 X 4.7 inches. The width of the worksheet in Microsoft Publisher 2003 was set to be twice the width of the handheld computer screen. Since the width of the Microsoft Publisher screen was twice the width of the handheld computer screen, the size of the font on the worksheet was twice the chosen size for displaying text on the handheld screen. The only method for ensuring that the font sizes on the handheld computer screen were correct and accurate was to test them manually. For that reason, all alphabetic and numerical symbols were printed on a transparent paper in various font sizes. This paper was used as a tool for measuring the size of the fonts displayed on the handheld computer screen.

Table 5-3 displays the guidelines for suitable background colours for both desktop and handheld computer screens. The two last rows in the table present the guidelines for handheld computers. Studying these guidelines and also those generated for conventional desktop computers clearly shows that white is usually the recommended background colour for any type of computer screen. For the purposes of this experiment it was decided to choose white for the background colour and black for text and track layout.

Table 5-3 - standards and guidelines on applications of colours on computer screens

Guideline or standard	Reference	Background Colour
Apple computer, Inc. Macintosh Human Interface Guidelines	(Reading, 1992)	Natural gray, gray black, white
Palm OS User Interface Guidelines	(Ostrem, 2002)	White
SAP style guides for PDA applications	(Tairako and Cherry, 2003)	White

In this experiment, approximately four miles of track was presented on the handheld computer screen. The information presented on this experimental interface was exactly the same as the information displayed on the Sectional Appendix. On the Sectional Appendix, information is presented in four columns. The first column provides information about the location name and the second column displays mileage information. The third column, displays a schematic track diagram on which information such as line speed, line direction and identification, and platforms are shown. The fourth column provides additional information about the location. Generally, the information presented in the first three columns is used for way-finding and planning purposes and therefore on the experimental interface, only these items were displayed. Figure 5-3 displays an example of the Sectional Appendix used in this study. The figure shows the exact same location as shown on the handheld computer screen in Figure 5-4.

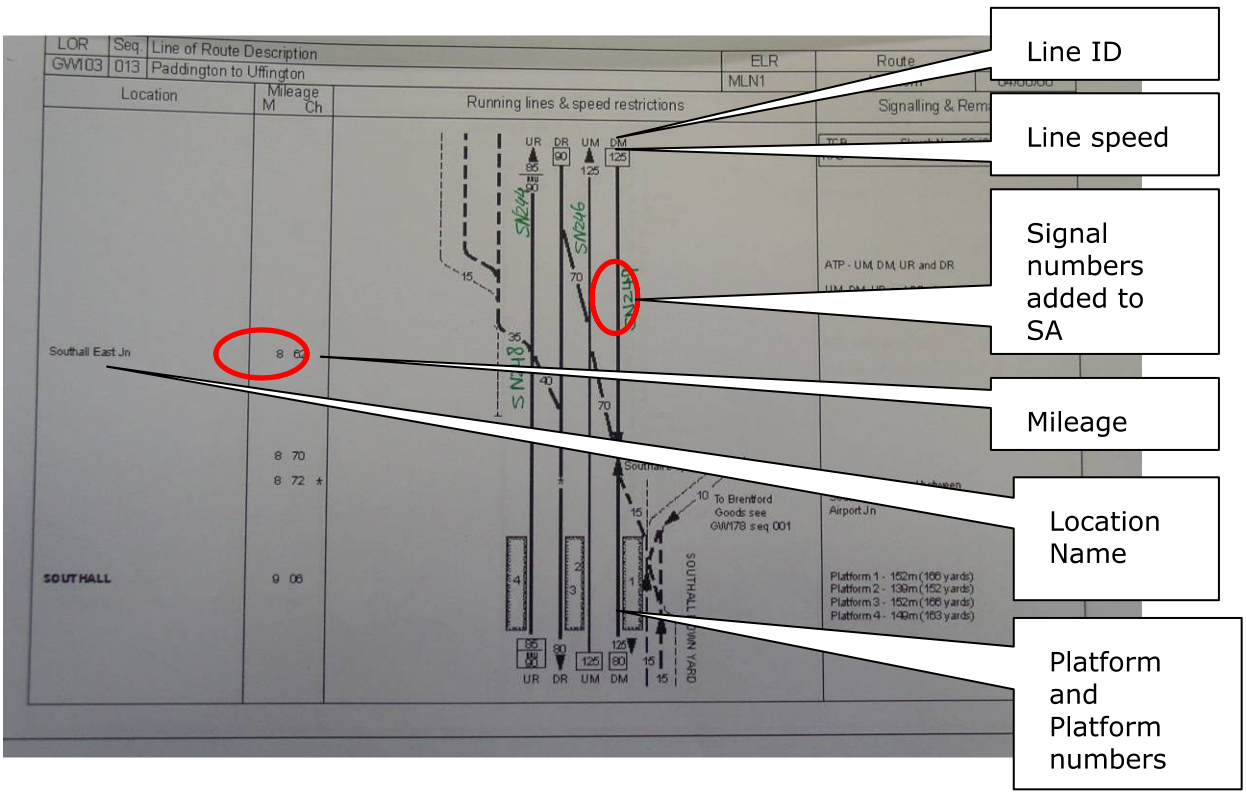

Figure 5-3 - Example of the Sectional Appendix used in the study

Six items of information were displayed on the experimental interface: 1- line direction and identification, 2- line speed, 3 – platform and platform number, 4 – signal numbers, 5 – location name, and 6 – mileage. In addition to these, displaying the track layout on the screen provided information about position of sidings and switches and crossings.

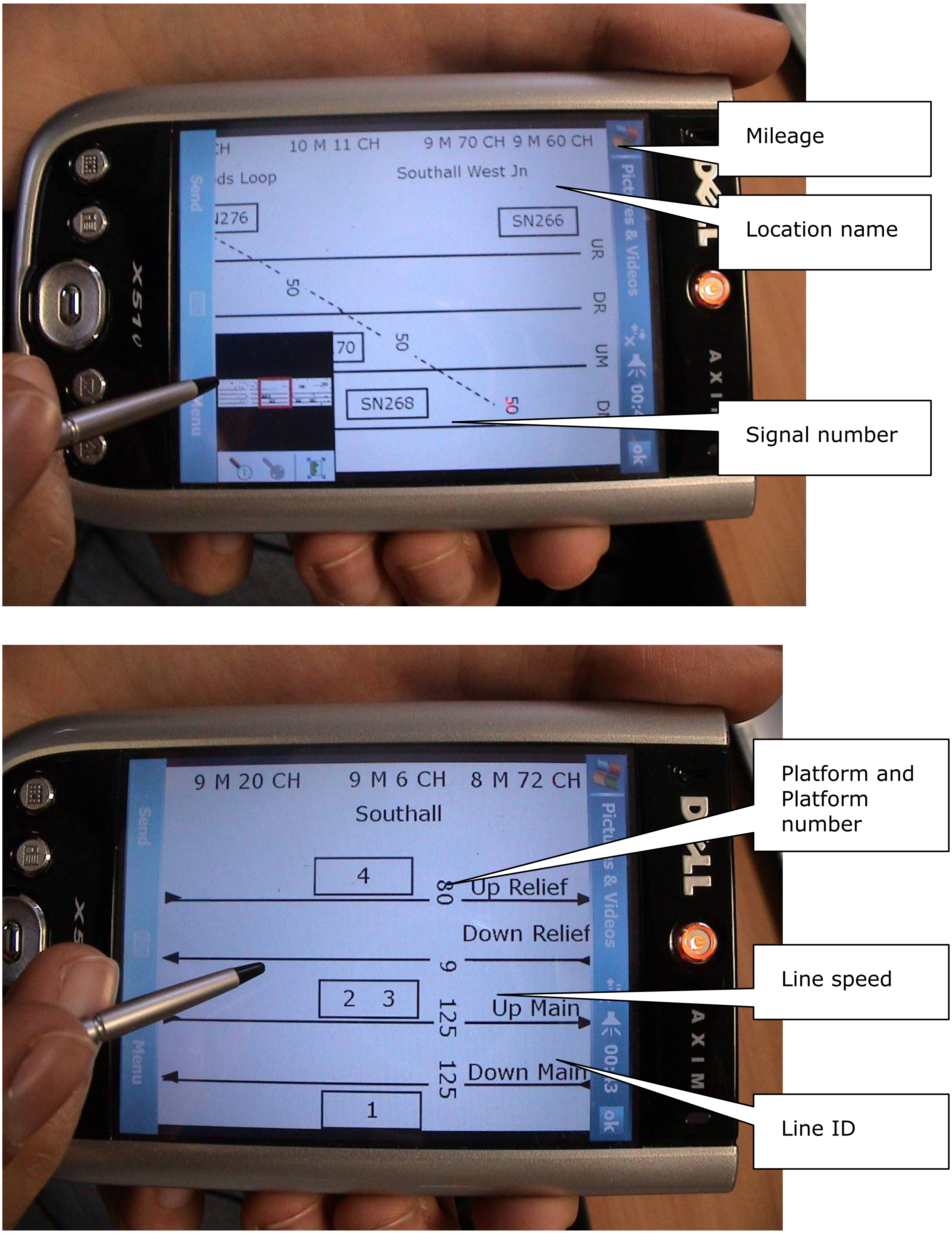

Figure 5-4 -Examples of the experimental interface used for experiment I

In order to ensure that the two interfaces, i.e., handheld computer and paper-based documents, were similar, signal numbers were added to the paper based version of the Sectional Appendix.

The layout of the information on the Sectional Appendix had to be altered so that it could be presented on the handheld computer screen. The spatial information displayed on the handheld computer were in form of schematic topological track diagrams to make them consistent with the presentation of the spatial information on the Sectional Appendix.

5.4.2. Participants

Eight track workers, i.e., four pairs, from three depots took part in the experiment. All participants were Network Rail employees and they were all male. The participants were from different parts of the maintenance function. Two were Signalling and Telecommunication (S&T) inspectors and they had used the S&T handheld computer before. The rest were from the Permanent Way (P-Way) team and had no experience of using a handheld computer for performing their tasks. S&T inspectors are responsible for inspecting and maintaining signalling and telecommunication infrastructure and P-Way team maintain the infrastructure associated with the rail track.

5.4.3. Apparatus

As mentioned earlier a range of different devices and programmes were used for designing the experimental interfaces and conducting the experiment.

5.4.3.1. Hardware

The handheld computer used in this experiment was a Dell Axim V51. Table 5-4 summarises the specifications of this PDA.

Table 5-4 - Specifications of the Dell Axim V51

Dimensions	73 x 119 x 16.9 millimetres
Operating System	Microsoft Windows Mobile 5.0 for Pocket PC Premium Edition

		(Magneto)
Memory	ROM	256 MiB (accessible: 195 MiB)
	RAM	64 MiB
Display type		colour transflective TFT , 65536 scales
Display diagonal		3.8 "
Display resolution		480 x 640
Positioning device		Touch screen

All of the experimental interfaces were designed on a Toshiba Satellite Pro laptop. Participants' conversations were recorded on an Olympus Digital Voice Reorder.

5.4.3.2. *Software*

The experimental interfaces were designed in Microsoft Publisher 2003. These were then copied and saved as jpeg files which were opened by windows mobile Image Viewer.

5.4.4.Experimental Task

As mentioned earlier, the tasks in this experiment comprised of a scenario where two track workers had to work together to perform the task. Table 5-5 displays the information provided to track workers for each of the roles.

Table 5-5 - Description of the roles for the experimental task

Roles	**Scenario**
Role A	Using the information presented on the screen, please give directions to your colleague to the following location: the set of points at Hanwell bridge sidings near SN 249 on down main line. Your colleague is sitting in a van parked at Hanwell Station on the Up relief line.
Role B	Assume that you are sitting in the van at night and you need your colleague to give you directions to the location you should get to. Please listen carefully to the directions given to you by your colleague and draw the area that is being described

to you in as much detail as you can.

In the scenario, the first participant, role A, who was at a location on the trackside had to contact his colleague, role B, who was waiting in a van at the nearest access point and required direction to get to the location where the first participant was waiting for him. The second participant was asked to draw the area that was being described to him.

The task and the scenario were verified by two subject matter experts who have several years of experience in the rail industry and work in the Ergonomics team at Network Rail.

5.4.5. Experimental Procedure

The following stages were followed for performing this experiment:

1. The researcher introduced herself and explained the background to the research and the objective of this experiment. A consent form (see appendix 5.1) and an information sheet were given to each participant for more information. Participants were informed that the conversations will be tape recorded unless they have any objections.

2. The tasks and the experimental interface were explained to the participants and both participants were given as much time as they required to familiarise themselves with the handheld computer device.

3. Participants had to decide which role they prefer to take on. Separate task sheets were handed to each participant for their role and they were asked to sit apart from each other and pretend that they are talking on the phone.

4. Once the participants were ready to start, the researcher informed the participants that she was going to start the voice recorder and they could then start the conversation.

5. The task was performed on the handheld computer and with the paper-based Sectional Appendix. The order of presenting the handheld computer or the paper-based documents was balanced

across the four pairs of participants. Figure 5-5 illustrates a typical room setup at the depot for performing the experiment.

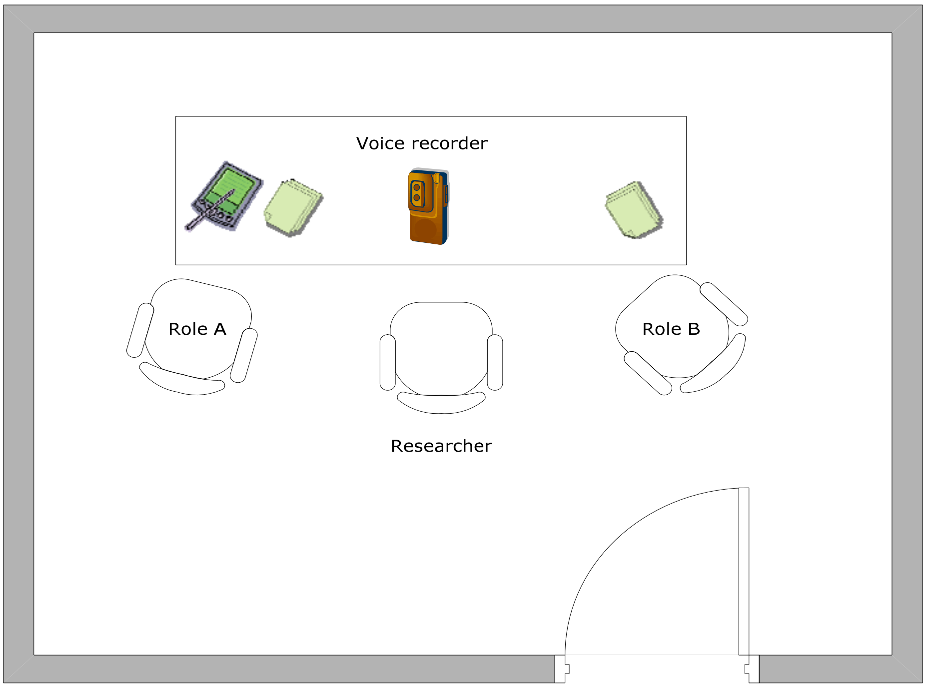

Figure 5-5 - Typical room setup for Experiment I

6. After performing the task, the participants were asked a few questions about their experience with the handheld computer device and finally they were thanked for their time.

5.4.6. Interview

The semi structured interview was designed based on the procedure recommended by Robson (2002). This procedure has been explained in detail in chapters three and four.

The key topics chosen for the interview questions mainly focused on advantages and disadvantages of each method. A list of five questions (see appendix 5.2) was drafted. These questions were used to trigger the discussions and where necessary more detailed questions were asked to elaborate the comments made by the interviewees. The fifth question asked about potential applications that users believed this device could deliver. This information was used to confirm and complement the EDARE framework. All interviews were tape recorded.

5.4.7. Analysis Method

Three measures were taken to answer the research questions raised in this research. These were: 1- speed and efficiency of the communication, 3- adequacy of information, and 2 – ambiguities and difficulties in communication.

5.4.7.1. *Speed and efficiency of the communication*

In order to measure how quickly and efficiently track workers can communicate the necessary information, three variables were measured:

1. The recorded conversations were timed for each method. The exact start and end time of each conversation was noted.

2. The conversations were transcribed and the number of words for each conversation was counted.

3. The number of words written down by role B participants on their notes and drawings was also measured.

5.4.7.2. *Adequacy of the information*

This was measured by comparing and counting the items of information mentioned by role A in the conversation (by studying the conversation transcripts) and the items captured by role B in their notes and drawings.

5.4.7.3. *Ambiguities and difficulties in communication*

Ambiguities and difficulties in communications were interpreted to include any hesitations, confusions and mistakes, or repetition of information. The frequency of occurrence of each of these behaviours was measured by analysing the transcripts of the conversations as well as listening to the conversations. The transcripts were reviewed while listening to the conversations. This way, for each of the conversations, a detailed event timeline was developed (see appendix 5.3) on which three behaviours were recorded: 1 – hesitations, 2- confusions and mistakes, and 3 – repetitions.

1. Hesitations: the frequency of pauses, mumblings, and any other signs of uncertainties displayed by role A in conveying the information to role B were recorded.

2. Confusions and mistakes: the number of times each role made a mistake or misunderstood an item of information was noted. A mistake was defined as any occasion when either role had to repeat an item of information in order to correct or emphasise the information provided to the other participant.

3. Repetitions for confirmation: the number of times that either role asked the other participant to repeat the information in order to confirm the correctness of the data obtained was noted for each conversation.

5.4.7.4. *Interview Analysis*

The interview data in this experiment was analysed using the inductive thematic analysis method (Hayes, 2000). This method has been explained in detail in chapter three. A simplified procedure was used for these interviews, since the data was mainly coded by advantages and disadvantages of each system. The following stages were pursued for analysing the interview data:

1. The recorded interview data was transcribed and printed.

2. The data was reviewed and considering the questions asked, the information was coded in terms of advantages and disadvantages of each method. The information was also reviewed in order to identify other themes and subjects pointed out by the track workers.

5.4.8. Result of the Pilot Study

This experiment was piloted with the two subject matter experts who had helped with designing the tasks. No major issues were discovered during the pilot studies.

5.5. Results and Discussions

In this section, the results of analysing the data obtained for each of the measures as well as the findings of the interviews are explained and discussed.

5.5.1. Speed and Efficiency of Communicating Information

Table 5-6 presents the results obtained from measuring the length of conversations in terms of time of conversation as well as a word count of the transcribed data. The last column in the table displays the number of words written by role B participants on their notes or drawings.

Table 5-6 - results of the conversation length (time and word count) analysis

Participant Pair No.	Paper or handheld	Conversation length (time in minutes)	Conversation length (word count)	Notes length (word count
Participant Pair 1	Paper	3′:45″	219	15
	Handheld	2′:40″	135	33
Participant pair 2	Paper	0:40″	79	6
	Handheld	2.50	203	11
Participant pair 3	Paper	12′:00	1196	8 (on the drawing)
	Handheld	8′:50″	765	15 (on the drawing)
Participant pair 4	Paper	3′:12″	306	46
	Handheld	2′:43″	211	45

This data suggests that using the handheld computer device the participants are able to communicate the information quicker compared with the paper-based documents. Apart from participant pair 3, other participants performed the task within almost similar times. This results might suggest that the quicker the length of the conversation, the more efficient the communication has been. Therefore, it might be possible to conclude that handheld computer provides a more efficient method for presenting spatial information to trackside workers. However, this conclusion, in part depends on the adequacy of the information exchanged between the two parties.

5.5.2. Adequacy of Information

One of the measures taken in this experiment was the items of information mentioned or captured by each participant. Table 5-7 summarises this information. Numbers in the parentheses show the number of items mentioned or captured using each method.

Table 5-7 - Number of items of information mentioned by Role A and items captured by Role B

Participant pair No.	Paper or handheld	Items of information mentioned by role A during the conversation	Item of information captured by role B on the notes or the drawings
Participant Pair 1	Paper	Line direction Location name Points (3)	Line direction (1)
	Handheld	Location name Points Line direction (3)	Line direction Points (2)
Participant pair 2	Paper	Location name Line direction Mileage (3)	Location name Line direction Mileage (3)
	Handheld	Location name Line direction Points (3)	Location name Line direction Points (3)

Participant pair 3	Paper	Track layout Line direction Line speed Location name Platform number Mileage (6)	on the drawing: Track layout Line direction Line speed (3)
	Handheld	Track layout Line direction Location name Line speed Platform number Signal number Mileage Points (8)	on the drawing: Track layout Line direction Line speed Platform number Signal number (5)
Participant pair 4	Paper	Location name, Line direction Platform number Mileage Signal number Points (6)	Location name Line direction Platform number Mileage Signal number Points (6)
	Handheld	Platform number Line direction Signal number Mileage Points (5)	Location name Platform number Signal number Mileage Points (5)

Although participants performing role B were asked to draw a sketch of the route that was being described to them, only one of them (participant pair 3) followed this instruction. The other participants stated that this would not be their normal practice and therefore they asked if they could take notes instead.

In terms of number of items of information mentioned by role A, there does not seem to be much difference between the two methods. However, studying the information captured by role B, the majority of the participants recorded more items of information when handheld computer was used.

This information suggests that using the handheld computer system, users are able to derive and communicate more comprehensive information. This difference might be due to difficulties and ambiguities in communicating the information. In other words, despite the fact that participant role A had mentioned the same items of information in most cases, ambiguities in communicating this information might have led to fewer items being captured by participant role B.

5.5.3. Ambiguities and Difficulties in Communicating the Information

Table 5-8 presents the results of analysing participants' behaviour with the aim of identifying any signs of ambiguities in the information communicated between the two participants. As mentioned before, this data was summarised as a timeline of the conversations. Figure 5-6 displays an example of the timelines that were developed at this stage of the study.

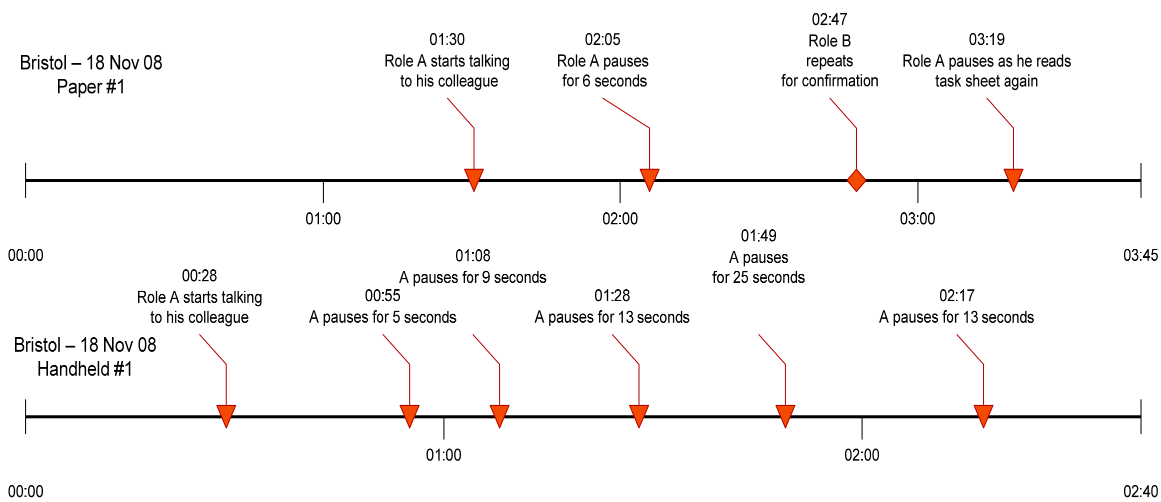

Figure 5-6 - Example of the conversation timelines

The table here presents a summary of the frequency of occurrence of each behaviour. This table also presents the results of analysing the conversation information, focusing on the number of times either participant had to repeat an item of information either to confirm that he had understood it correctly or to correct a mistake.

Looking at the information presented in this table, it seems that overall participants had fewer difficulties using the handheld computer.

Table 5-8 – Results of the communication ambiguity analysis – Hesitation and Confusion

	Paper or handheld	Hesitations	Mistakes	Repetitions
Participant Pair 1	paper	3	0	1
	Handheld	6	0	0
Participant pair 2	paper	3	0	1
	Handheld	2	1	4
Participant pair 3	paper	6	4	12
	Handheld	3	1	5
Participant pair 4	paper	0	0	6
	Handheld	0	0	5

Comparing the frequency of displaying hesitant behaviours shows that, except for participant pair 1, all other participants conveyed the information more effortlessly and with fewer hesitations using the handheld computer. In terms of mistakes made using each method, on average, using paper-based documents led to more mistakes; 4 in total on the Sectional Appendix compared with 2 on the handheld computer. Repetitions for confirmation or correction have also decreased with the handheld computer screen.

5.5.4. Interview Results

Overall the results of the interviews indicate that track workers prefer the handheld computer device mainly due to the fact that it will reduce the amount of equipment they need to carry when they go out on the trackside. The following summarises the comments made by the participants:

Less paperwork: All participants agreed that the main benefit of this system is its potential for reducing or eliminating the amount of paper work that they need to carry and manage. These comments emphasise this conclusion:

> *"this is a lot easier than flicking thorough three or four pieces of paper or going on the portal [Network Rail's intranet for different documents] and trying to find everything (interview 1, 10 October 2008)."*

> *"…and they are A4 sized for one track diagram… and it's a great big folder you have to carry with yourself as well (Interview 3, 18 November 2008)."*

Paperwork management: many of the interviewees commented about the sheer volume of paperwork printing and filing which is necessary for keeping a record of the maintenance and inspection works at each depot. Track workers believe that filing the forms takes a lot of their time and more importantly, filing cabinets take a lot of space at the depots. They believe that providing the paper-based forms and documents on handheld computers will save time and space at depots and will make the management of the archives easier and more efficient.

> *"Providing that our systems are synchronised with it [i.e., with the handheld computer], we can just put it in [a cradle], and it will get uploaded and everything will be in a central database and there is no chance for losing it (interview 1, 10 October 2008)."*

Quick and easy access to Information: interviewees believe that, if designed well, the handheld computer can provide quicker access to the necessary information for them. Partly because all of the information is integrated in one device and partly because the digital format of the information combined with a search engine might enable them to search for information instantly rather than having to browse through several pages of various paper-based documents.

> *"they [handheld computers] are something you can put in your pocket, as opposed to having to open the back of your van, get the files out and trying to find the information you are looking for…(Interview 4, 16 January 2009)"*

Working in different weather and lighting conditions: handling paperwork in different weather circumstances and under various lighting conditions introduces many difficulties. A weather-proof handheld computer might solve many of these problems. Comments given by the track workers elaborate some of the difficulties of such conditions:

> *"… [paper-based document] are not much good at night and you have to shine a light at them (interview 4, 16 January 2009)."*

> *"… whereas trying to write our paperwork when is pouring down with rain on the trackside is a bit of a pain in the neck (Interview 3, 18 November 2008)."*

Reliability of the information: one of the main concerns which was repeatedly mentioned by most of the interviewees was reliability of the information presented on the handheld computer screen. Substituting paper-based documents with handheld computer devices might solve the problem of out of date and incorrect information. Track workers believe that the digital nature of the information presented on the handheld computer devices allows for all documents to be updated efficiently and quickly.

Despite the fact that all the interviewees believe that the handheld computer system has many potentials for improving their performance, they believe that certain drawbacks and disadvantages might hinder effective use of the handheld computers.

Reliability and robustness of the hardware: robustness of the handheld computer device seemed to be a reason for concern for many track workers. Furthermore, track workers expressed some concern about the reliability of the hardware. They believe that as a potential main source of information it is essential that the handheld computer device does not fail.

> *"If it doesn't work for the first two or three years, by then everyone has lost confidence and will stop using it (Interview 3, 18 November 2008)."*

Limited screen size: rail specific spatial information comes from various sources and there are many items of information that a track worker needs for performing any typical task. Some of the interviewees believe that the small size of the handheld computer screen would not accommodate all this information which they believe is necessary for performing any task successfully.

> *"…I am not sure how much you can fit on these screens though before it becomes impossible to see anything! (Interview 1, 18 October 2008)"*

Computer capabilities of the track workers: the track workers who participated in this experiment had varying degrees of computer experience. Although, none of the participants had any difficulties with interacting with the handheld computer, they believe that increasing the complexity of the interaction might cause problems for many track workers.

Table 5-9 presents a summary of the results obtained from the interviews. The numbers in the parentheses indicate the frequency of the comments made by interviewees.

Table 5-9 - Summary of the Interview Analysis Results

Presentation Method	**Advantages**	**Disadvantages**
Paper	None was mentioned.	Paperwork management difficult in bad weather condition (1) Paperwork is often out of date (1) Poor quality photocopies (1)

		Many books to carry (2)
Handheld	Less equipment (1) Quicker information access (2) More information (3) Can speed the tasks up (1) Less time spent on managing paperwork (2) Automatic updates (2) Less paperwork (7) Integrated tool containing all necessary information (2) Portable (4)	Computer capabilities of staff (3) Fragile (4) Weather-proof (2) Small screen size (2) Need to keep the hardware up-to-date with technology (2) Battery life (3)

Studying the frequencies of the comments made shows that users' main concern is the fragility of the handheld computer device for trackside work and as mentioned before the most important advantage would be reduction or elimination of the amount of paperwork track workers need to handle while working on site.

5.6. Discussion

Comparing the results obtained from measuring the three different variables together seems to suggest that not only the handheld computer is a more efficient system for providing spatial information to track workers; it is also more effective than the current paper-based documents.

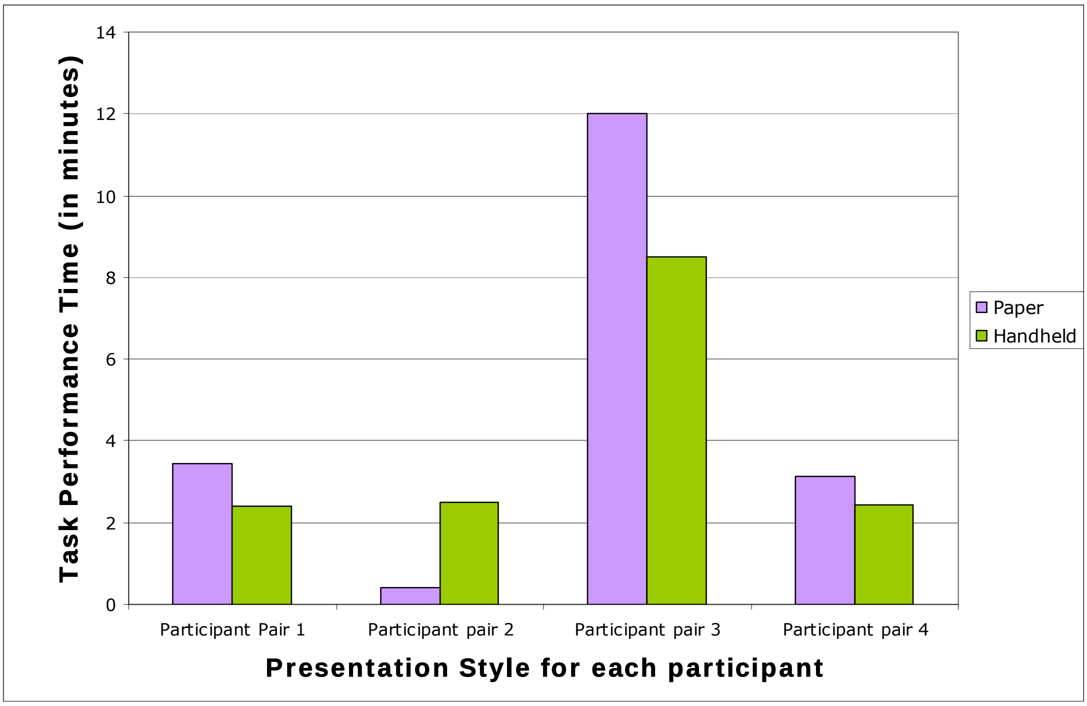

Figure 5-7 - Task performance times for each participant pair

Figure 5-7 displays time of performing the tasks, i.e., the conversation lengths, for each participant pair and Figure 5-8 summarises the difficulties and ambiguities in communicating the information by each method. This data shows that participant pair 3 performed the tasks quicker using the handheld computers. Performance times for participant pairs 1 and 2 were also shorter using the handheld computer. However, participant pair 2 performed the task quicker when using the paper-based documents.

As Figure 5-8 clearly shows, despite individual differences in difficulties experienced by track workers in communicating the information, altogether workers experienced fewer difficulties using the handheld computers. Therefore, all of the behaviours which were recorded as indicators of ambiguities and difficulties in communication occurred less frequently when the handheld computer was used.

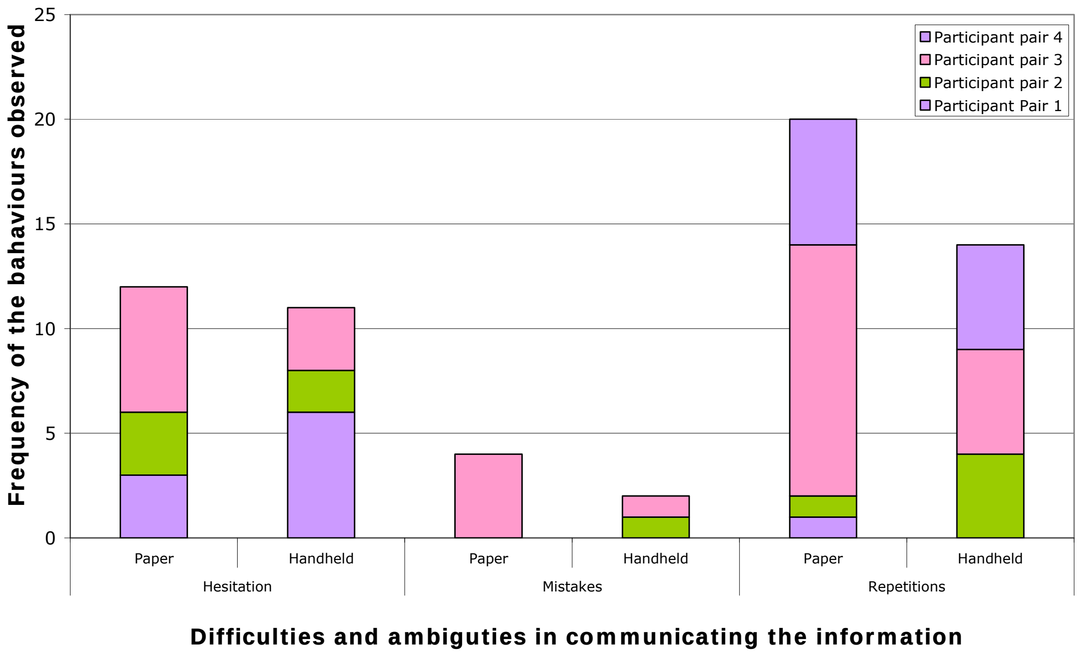

Figure 5-8 - Difficulties and Ambiguities in communication for different presentation styles

Studying the number of items of information exchanged also shows some of the advantages of handheld computers over paper-based documents. For instance, although the number of information mentioned by role A did not change for the two presentation styles, role B participants seemed to have captured more items when the handheld computer was used for obtaining the information. In addition to handheld computers providing a more effortless means of presenting spatial information, this difference could be due to the fact that the handheld computer is a more understandable means for displaying spatial information. In other words, it seems that handheld computer provides a more intuitive presentation style. Studying a comment made by one of the interviewees explains this further (interview 4, 16 January 2008):

> *"…on the Sectional Appendix, I see everything in sections, it's sections, this [the handheld computer] is continuous, I can look at it and see where I'd be going"*

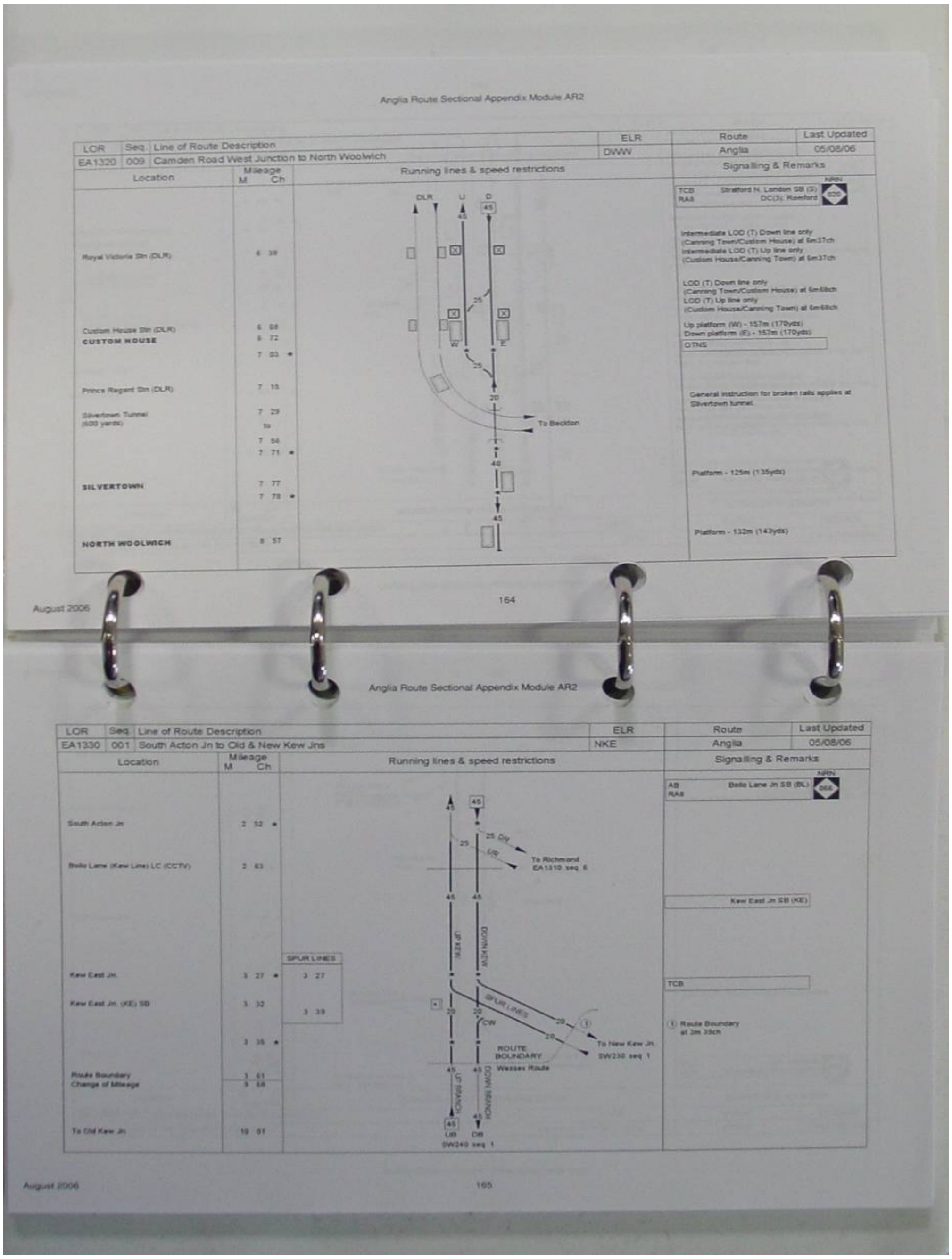

Figure 5-9 - An example of the Sectional Appendix

Figure 5-9 displays an example of the Sectional Appendix. As it can be seen, on each page, a section of the track is presented. Observing the participants during the experiment showed that role A participant tend to browse the Sectional Appendix forward and backward several times in order to form a visualisation of the route in their mind. Therefore, they had to remember how the sections on each page were connected to each other. However, using the handheld computer for presenting the spatial information, the participants could see a continuous stretch of the route and it seems that this presentation style had made the handheld computer presentation more effective than the paper-based Sectional Appendix.

Another problem seems to be the dispersed structure of the information presented on the Sectional Appendix. Using the Sectional Appendix, track workers should merge the information from the three first columns in order to locate themselves, whereas on the handheld computer screen, all this information is presented to them on a single diagram.

There is some evidence in the literature that using paper-based maps is quicker than digital maps for pedestrian way finding tasks (Nixon et al., 2007). Although in this experiment an actual way-finding task could not be tested due to safety implications of working on the trackside, the tasks performed were considered to be valid measures for comparing the effectiveness of the two systems. Therefore, it is possible to conclude that presenting rail specific spatial information on the handheld computer is an acceptable method for providing spatial information to track workers and one that is welcomed by track workers. The reason for this difference between the results of this research with previous studies might be due to the nature of the rail specific spatial information and the quality of the paper-based material used by track workers.

The next experiment in this research (chapter six) studied the effectiveness of different interaction styles for interacting with rail specific spatial information displayed on handheld computer screen.

6. Chapter 6 – Experiment II: Interaction Styles

6.1. Introduction

Presenting maps and other forms of spatial and geographical information on mobile computing devices is considered to involve principles of Graphical User Interface (GUI) design (Nivala and Sarjakoski, 2003). Interacting with geographical and spatial information on handheld computer devices has been the subject of much research in recent years (Meng and Reichenbacher, 2005). Mobile computing devices have been used extensively for wayfinding and navigation applications (see Section 2.2.6 of chapter 2) and the usage of such devices by general public on advanced mobile phones has increased dramatically in recent years.

Several studies in the literature have looked at interaction techniques for mobile and handheld computing devices (Haro et al., 2005; Jones et al., 2002; Kjeldskov, 2002; Lam et al., 2006). Mobile cartography and mobile Geographical Information Systems (GIS) have also received a great deal of attention from the scientific community in recent years (Dillemuth et al., 2007; Dillemuth, 2005; Hakala et al., 2005; Lehikoinen and Kaikkonen, 2006). Reviewing the literature in this field reveals that most of the studies focus on the difficult challenge of displaying and visualising information on the small screen of a handheld computer. Nevertheless, it would be wrong to assume that physical interaction has been ignored. There are various studies that compare different physical interaction styles for a variety of interfaces (Nicholson and Vickers, 2004; Rukzio et al., 2006a).

Displaying large scale information on small screens means that not all of the information will be visible. Handheld computer devices utilise different interaction methods for accessing large information on the screen. Up and down buttons, touch sensitive screens, a thumbwheel on the side of the device are a few examples (Yee, 2003). These techniques aim at providing users with access to off-screen content.

The second experiment in this research was conducted to address the concerns raised in previous work about difficulties of interacting with spatial information on mobile computing devices. There were three reasons for designing this experiment despite the available literature on interaction techniques:

1. The unique characteristics of the rail specific spatial information, users, their tasks and context of work necessitated studying different interaction techniques for navigating rail specific interfaces.

2. The research into interacting with mobile maps falls into two main groups: 1 - comparison between different presentation styles (Dillemuth, 2005; Nixon et al., 2007) or 2 –comparison between different multimodal interaction techniques (Guan et al., 2000; Krüger et al., 2004). Therefore, it was necessary to compare the effectiveness of conventional interaction techniques for interacting with rail specific spatial information.

3. Most of the studies investigating interaction techniques for navigating with large scale spatial information, such as maps on handheld computer screens, focus on dynamic location aware systems where interaction is assisted by the location awareness of the system (Mehra et al., 2006; Rohs and Essl, 2006; Yee, 2003). In contrast, the experimental interfaces studied in this research were static images. There were two reasons for designing the experimental interfaces with static images. The first reason was limitations in providing dynamic and location aware rail specific spatial information. The next reason which justified using static images was the fact that maintenance workers currently use paper-based documents not only for wayfinding and navigation, but also for planning purposes and therefore it was felt appropriate to provide the same functionalities on the handheld computer.

Three interaction techniques were compared in this research: scrolling, browsing, and panning.

Scrolling is perhaps the most commonly used type of interaction. Scrolling is defined as sliding text or images across a monitor or display. Scrolling is usually enabled by providing a scroll bar on the screen.

Browsing is mainly referred to the act of searching for a file within a folder and also accessing different parts of an application. In this experiment, browsing is defined as the act of navigating through the pages within the application. This function was enabled by use of two buttons on each end of the screen.

Panning is an interaction style used in many of the interfaces that present geographical and spatial information. On these interfaces, navigation is achieved by panning a moveable window over a large fixed workspace. In this experiment, the movable window was displayed in a zoom-in box on the corner of the screen and the rest of the screen displayed a detailed view of the selected section.

6.2. Aim

The objective of the second experiment was to investigate the most convenient and efficient method for interacting with rail specific spatial information on a handheld computer screen. Therefore, the hypothesis in this experiment was:

H1: Different interaction styles have an impact on time of performing a location finding task on rail specific spatial information displayed on a handheld computer screen.

6.3. Method

In order to achieve the aim of this experiment, it was decided to measure users' performance by measuring the time of performing a location finding task. Also, this experiment attempted to address the issues of physical interaction and therefore video footage of the interaction was used to study participants' physical interaction in detail. Moreover, in order to complement the result and gather some information about the participants' opinions about each interaction style, a series of short semi-structured interviews was conducted. Table 6-1 summarises the research questions investigated in this experiment and the methods adopted to address these questions.

Table 6-1 - Summary of research questions and relevant methods to address these

Research Question	Source of data
Most suitable interaction style	DV: time of performing a location finding task on the handheld computer IV: interaction techniques – browsing vs. panning vs. scrolling
Difficulties with each interaction style and number of mistakes	Video data of interaction
Participants' experience	Semi-structured interviews

6.3.1.Experimental Interface

The experimental interfaces designed for this experiment were very similar to those designed for the previous experiment with only a few changes: 1- signal aspects were displayed in colour, and 2 -station platforms were denoted by an orange rectangular. These changes were made after the researcher was shown some of the electronic versions of the sectional appendix created by track workers at one of the depots. It was believed that these changes will make features of the interface more distinguishable. In order to check the contrast between the background and foreground colours, an online contrast analysis tool was used[6] which showed that all colours have acceptable contrasts.

As mentioned before, these interfaces were designed and saved as html files and therefore, on the handheld computer, they were displayed using mobile Internet Explorer. The only exceptions were the "panning" interface. Coding the "panning" feature in html proved to be difficult.

[6] The tool is available at, http://juicystudio.com/services/luminositycontrastratio.php

Therefore, it was decided to open these files in mobile Image Viewer which provided the panning application by default.

Figure 6-2 displays a screen shot of the "panning" interface opened using the mobile Image viewer. As the figure shows, the square area on the bottom left corner of the screen provides an overview of the whole of the section which has been displayed. The rest of the screen displays a detailed view of the screen zoomed at 100%. Interaction with this interface is either through dragging the screen or by moving the moveable window on the zoom in box.

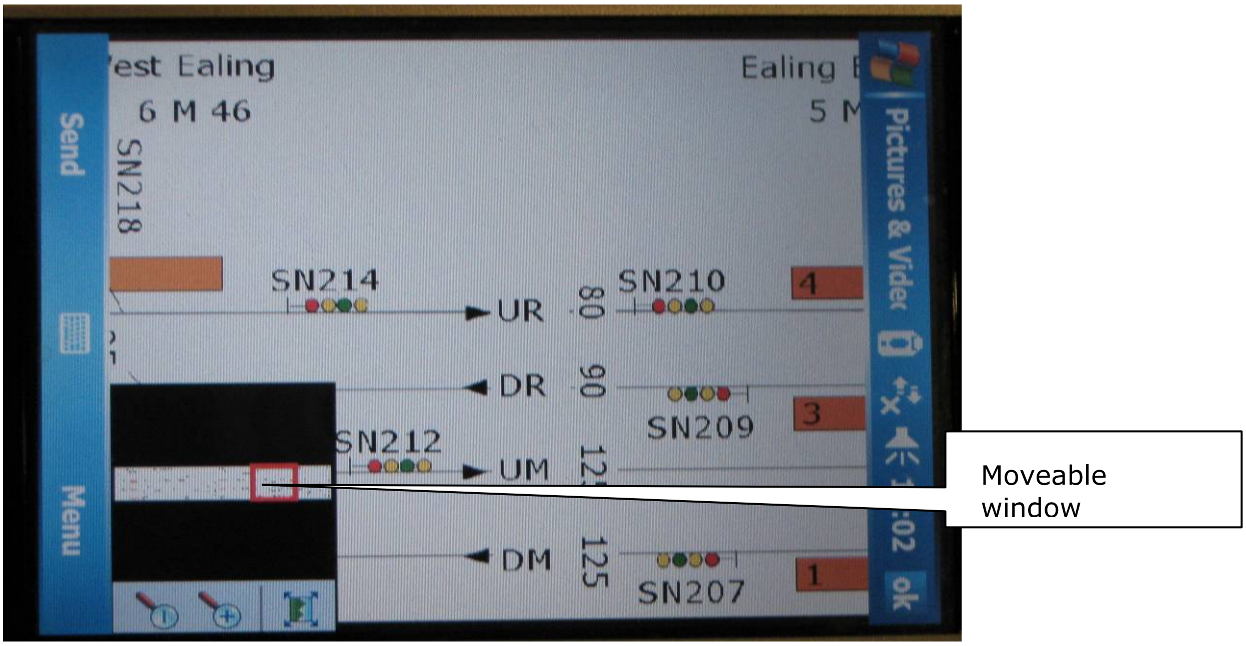

Figure 6-1 - An example of the panning experimental interface

Figure 6-2 illustrates an example of the experimental interface designed for the scrolling interaction style. As it can be seen, the scroll bar is located at the bottom of the screen.

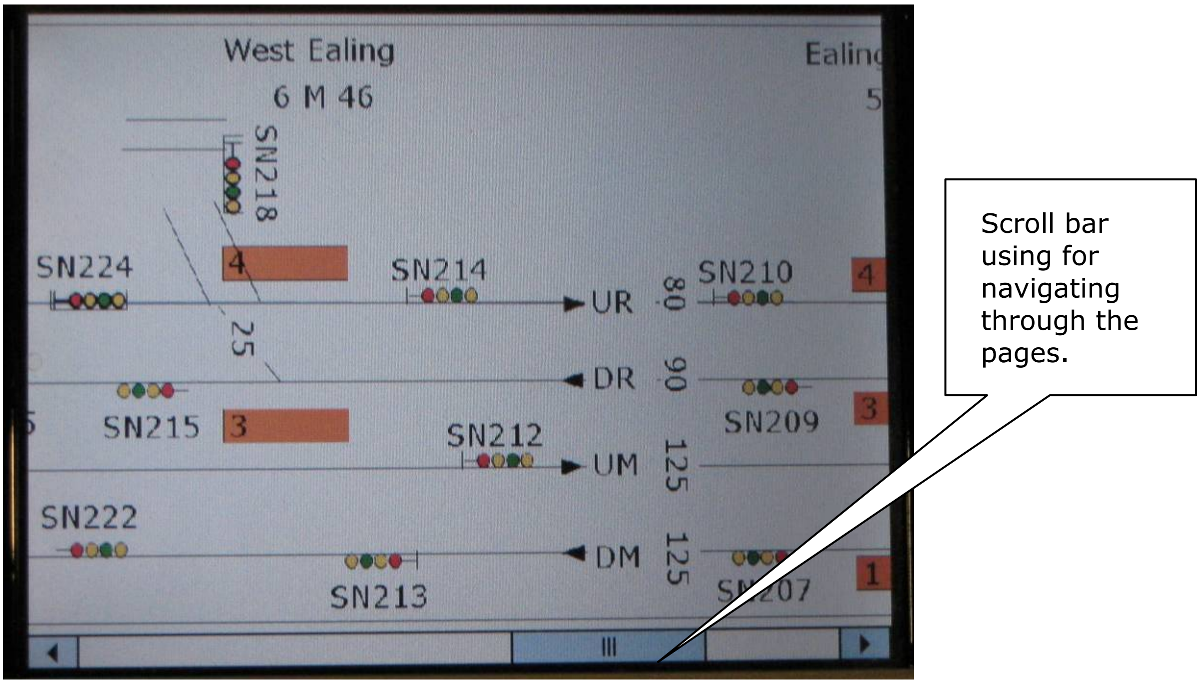

Figure 6-2 - An example of the scrolling experimental interface

An example of the browsing interface is shown in Figure 6-3. The triangular arrows on the corners of the screen are used to browse through the pages. In case of the browsing and the scrolling interfaces, the page was set to full image view. This was not possible for the panning interface.

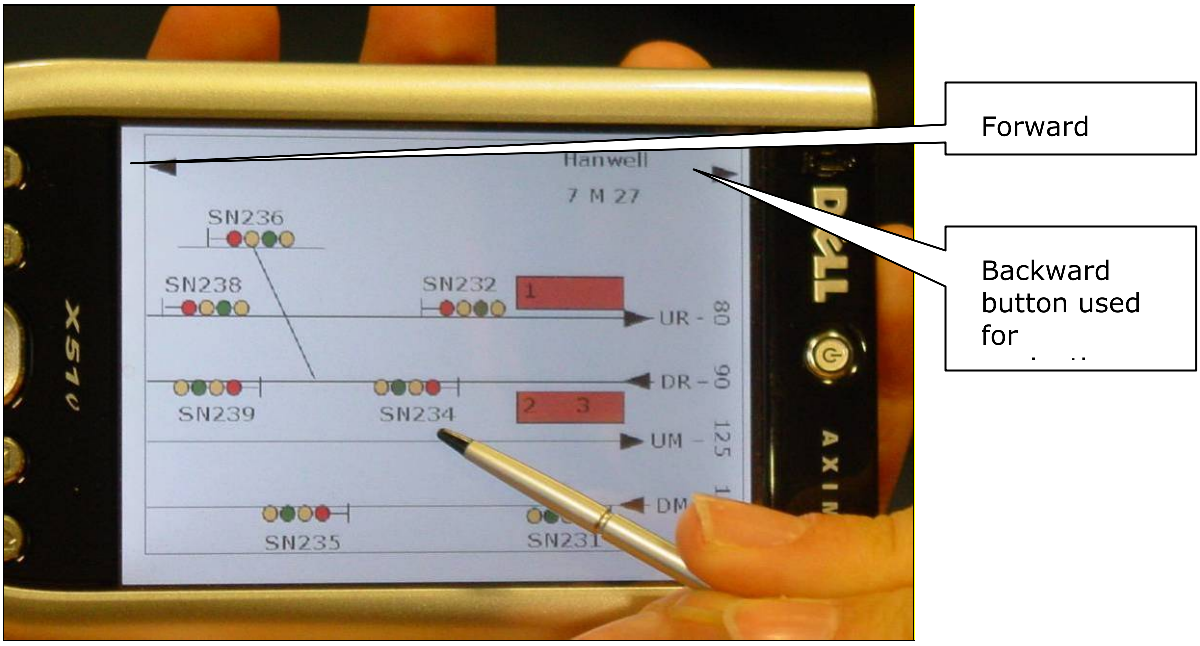

Figure 6-3 - An example of the experimental interface for browsing

Six items of information were displayed on the screen. These were: 1- line identification and direction, 2- signal type and signal numbers, 3- platform and platform number, 4- line speed, 5- location name, and 6- mileage. About five miles of the route was displayed on the screen. As mentioned before, most of the information used for designing the experimental interfaces came from the Sectional Appendix. The experimental interfaces were not scaled and displayed a schematic presentation of the track diagrams.

6.3.2. Participants

Ten staff from three Network Rail maintenance depots voluntarily took part in this experiment. All participants were Network Rail staff and they were all male with an average age of 35 years old. Four participants had between six to ten years of experience, three between one to five years, and two between 11 to 19 years. Only one participant had more than 20 years of experience in his role. The majority of the participants were Local Operations or Mobile Operations Managers, eight out of ten, and the rest were signalling inspectors. They all confirmed that they perform trackside tasks and use local knowledge regularly. None of them had ever used a task specific handheld computer; however four of the participants had used other types of PDAs such as Blackberry.

6.3.3. Apparatus

The equipment used for designing and conducting this experiment were exactly the same as for the previous experiment. A Dell Axim V51 Handheld computer was used for displaying the track diagrams. A standard stopwatch was used for measuring the time of performing the tasks. A digital camcorder was used for recording video data.

Apart from the interfaces which were designed to test panning interaction style, all other interfaces were saved as html files and therefore on the PDA they were opened using the Mobile Internet Explorer. In terms of the panning interfaces, the initial interfaces were designed in Microsoft Publisher 2003. There were then copied and saved as jpeg files which were opened by windows mobile Image Viewer.

6.3.4.Experimental Tasks

It was important to ensure that the experimental task provided an appropriate measure for testing and comparing the interaction styles. In other words, in order to test the effectiveness of different interaction styles, the task should challenge the ease with which the participants navigated through the pages. Therefore, it was decided that a way finding task would be suitable.

The task required the participants to find two locations signified by signal numbers. Once the participants found the first location, they had to navigate their way to the second location described to them. The participants were not told the signal numbers. However, the exact location of the signal posts in question was described to the participants. Table 6-2 displays an example of the experimental tasks.

Table 6-2 - Example of the experimental task

Experimental task
Assume that you have been called to attend a set of points failure incident. Once you get to the access point, you have to identify your position and also the specific set of points. To do this, please use the information presented on the handheld screen. The access point has been presented by ⊗ Please tap on the access point. From this location please find the departure signal for platform 2 located on the Up Main line at Ealing Broadway. Once you have found this location, tap on the signal number on the handheld screen. From this initial location, then find the last signal (in normal direction of travel) located on the Down Main line on the approach to Southall ladder connection and station.

This way they had to navigate through the screen and use the information given to them to locate the signal number. Table 6-3 presents location descriptions.

Table 6-3 – Locations described in the experimental Tasks

Signal number	Description
SN204	The departure signal on platform 2 on the up main line at Ealing Broadway.
SN205	The signal located in advance of the up main to down relief line crossover on approach to Ealing Broadway station
SN249	The signal located on the down main line on approach to Southall station.

These tasks were designed with the help of two Subject Matter Experts (SMEs) who have several years of experience in the rail industry.

The following flowcharts display the experimental tasks for each interaction style:

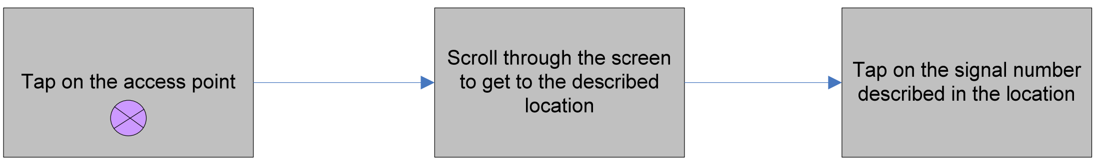

Figure 6-4 – Scrolling

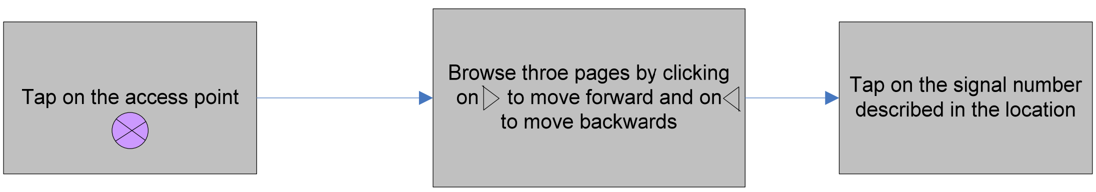

Figure 6-5 – Browsing

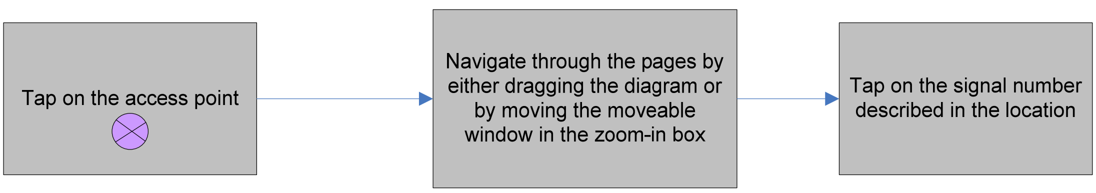

Figure 6-6 - Panning

6.3.5. Experiment Procedure

Each interaction style was tested using two tasks and the tasks were randomised in order to eliminate the order effect. In total, each participant performed six tasks. The procedure followed for running the experiment was as follows:

1. The researcher introduced herself and explained the objective of the experiment.
2. The participants were handed a consent form (see appendix 6.1) and an information sheet that explained the background to the research and the objective of this experiment and ensured the participants about the anonymity and confidentiality of the gathered information.
3. The experimental interface was shown and explained to the participants. They were given as much time as they required to familiarise themselves with the device.
4. At this stage, the researcher set up the camera to record the screen.
5. The tasks were printed on separate papers and given to participants. The participants were asked to perform the task and the researcher measured time of performing the task with a stopwatch. The data was recorded on a response sheet.
6. The participants were asked which interaction style they prefer and why, and finally, the participants were thanked for their time.

6.3.6. Analysis Methods

Information in this experiment came from three sources: 1- measuring the time of performing the task, 2- video data and 3- data from semi-structured interviews.

6.3.6.1. Time of Performing the Task

The main performance measure in this experiment was task performance time. The average time of performing the two tasks on the screens for each participant was calculated. In order to find out whether there is a significant difference between the interaction styles, i.e., to test the H_1, a one way ANOVA was performed.

6.3.6.2. *Video Analysis*

The video footage from the experiment was used to provide a better insight about the effectiveness of various interaction techniques and also to identify any mistakes that participants made with each interaction technique. The following steps were followed in order to analyse the video data:

1. The video footage was reviewed and start and end time of each task was noted,

2. Once the tasks were separated, the video data was reviewed twice:

2.1. Each participant's data was reviewed with the aim of understanding how individual user's interaction is different with each technique.

2.2. In the second review, video data for each of the interaction styles was studied in order to identify similar patterns in the interaction with the handheld computer using each technique. The main focus of this analysis was on identifying any source of confusion for users, any physical difficulties and challenges while interacting, and also any mistakes. A mistake was considered to be failing to find the location specified by the task or finding the wrong location.

6.3.6.3. *Semi – Structured Interview Analysis*

After completing the experiment tasks, the participants were asked a few questions about their preferred interaction style and their reasons for choosing the specific technique. The procedure for conducting the interviews was adopted from Robson (2002) and was consistent with the previous chapter.

In order to analyse the data, the "inductive thematic" analysis approach was selected (Hayes, 2000). The following stages were followed for analysing the interview data:

1. The recorded interviews were transcribed.

2. The transcribed data and participants' comments were reviewed. The main themes used for coding and sorting the information were "advantages" and "disadvantages" of using each technique.

3. The information gathered was used to populate a table which summarises the results of the interviews (presented later in section 6.4.3).

6.3.7. Results of the Pilot Study

This experiment was piloted with two SMEs to ensure that the tasks are representative and that the experimental procedure is smooth and flawless. The results of the pilot studies revealed the following issues:

1. Initially the interfaces were interactive providing the user with visual feedback by highlighting the signal the participant had tapped on provided that it was the right answer. However, the results of the pilot study showed that the participants found the feedback unnecessary and confusing. Moreover, proving this feedback required an extra page to be loaded and therefore, it was felt that this has had an impact on the perceived speed of the interface. Therefore, it was decided that instead of providing the visual feedback, it would be easier if the researcher confirmed that the participant has finished the task successfully.

2. There were some inconsistencies between the three interfaces. For instance, some locations were not appearing in the same place on all of the screens. This problem was rectified by amending and refining the prototypes.

3. Two of the tasks were slightly modified to ensure that all signal descriptions are equivalent and match the information presented on the screen. Furthermore, the SMEs checked to ensure that the

wording of the tasks matches the way track workers perform their tasks and the terminology they use.

Once these changes were made to the experimental interfaces and the tasks, the author started recruiting participants for conducting the experiment. The results of the second experiment are explained in the next section.

6.4. Results

The results of each section of the experiment will be reported and discussed separately here. However, in the discussion, the overall conclusions drown from this experiment will be explained.

6.4.1. Performance Measurement

As mentioned before, a one way ANOVA was performed to find out whether the interaction style has an effect on performance of participants. The results of the ANOVA test show that there is no significant difference between any of the interaction styles ($F = 0.916$, $df = 2$, $P > 0.05$).

The mean plot, presented in Figure 6-7, also shows the difference between mean times for panning and the other two interaction styles. As it can be seen, panning seems to have been more efficient than the other two interaction styles, but not significantly different.

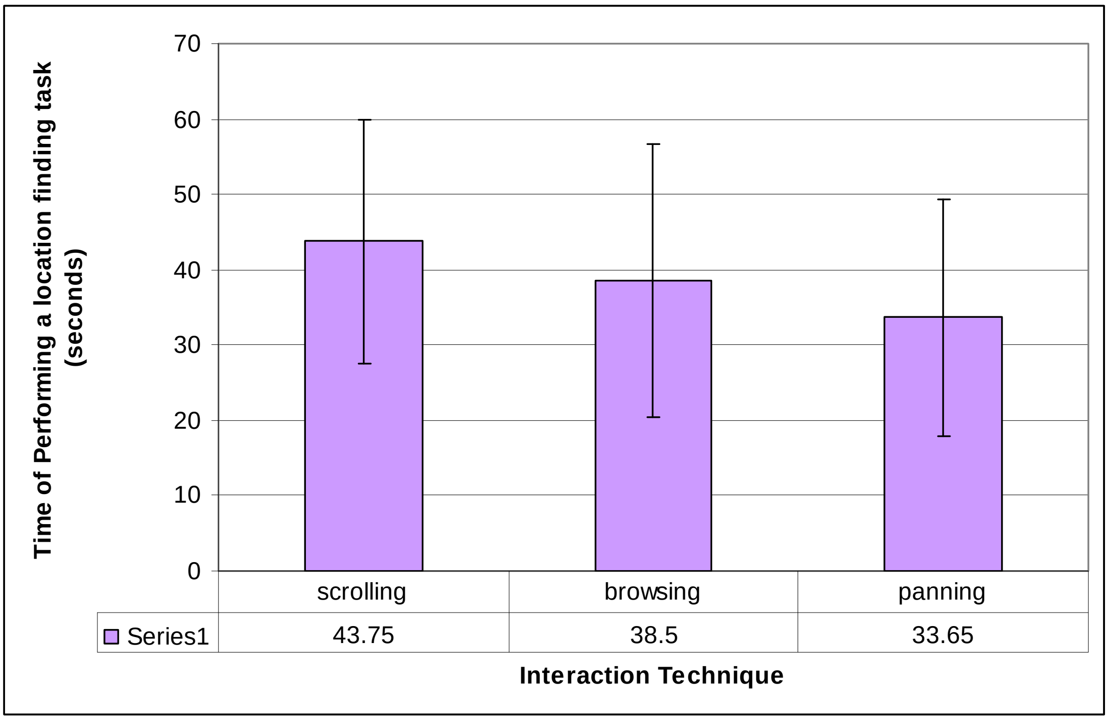

Figure 6-7 - Mean plot for the different interaction styles

Figure 6-8 displays the average performance time for each of the participants for the three interaction techniques and Table 6-4 has summarised the mean and standard deviation for each of the interaction techniques.

Table 6-4 - Mean and Standard deviation for different interaction techniques

Interaction Technique	Scrolling	Browsing	Panning
Mean and Standard Deviation (time in seconds)	43.75 (16.12)	38.5 (18.15)	33.65 (15.72)

Looking at the results obtained for individual users, it seems that there is a considerable difference between individual participants. This might explain the reason for the results obtained from the ANOVA test.

Studying this descriptive analysis and talking to track workers suggest that there might be a difference between panning and the other two interaction techniques. Looking at the performance times for each participant reveals that five participants have performed the tasks faster with panning interaction technique than with the other styles.

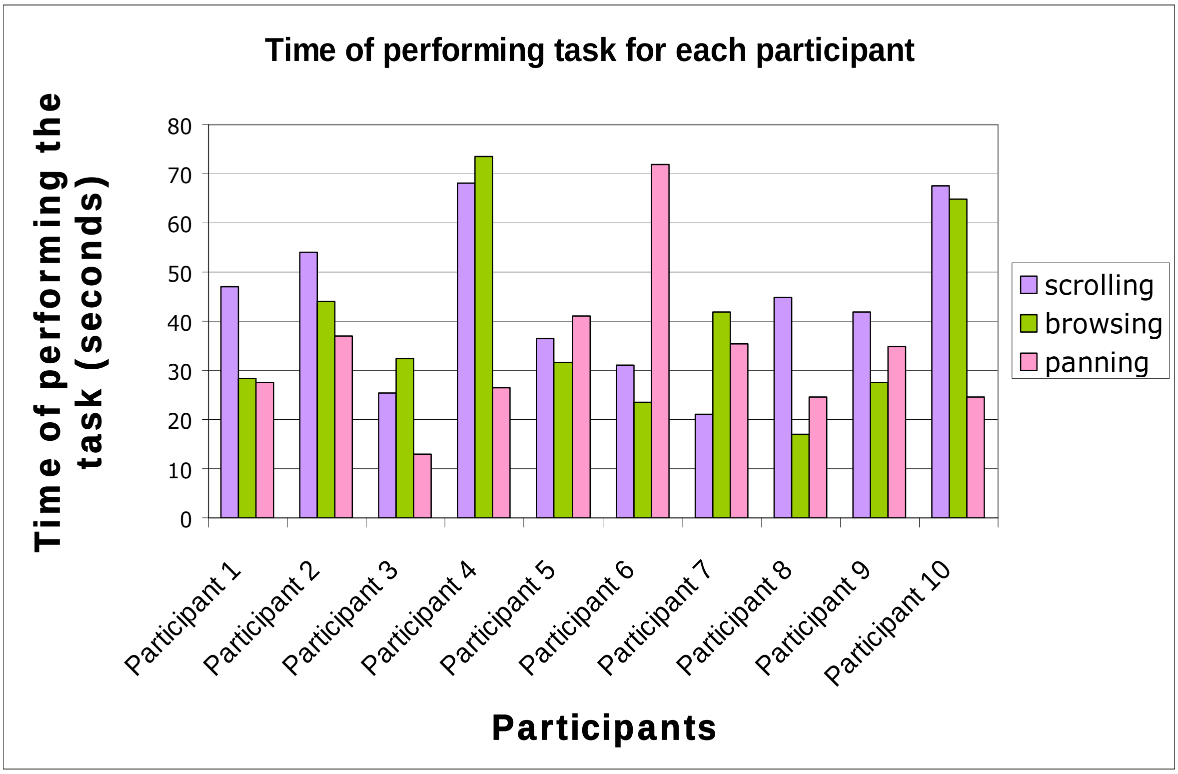

Figure 6-8 - Performance time for each participant

Furthermore, when track workers were asked which interaction techniques they prefer, five of them stated that they prefer panning to the other two methods, three preferred scrolling and only two of them chose browsing as their preferred interaction technique. Studying the findings of the video data and interviews will help explain the results of the experiment more thoroughly.

6.4.2. Video Data

In order to enable a more comprehensive analysis of the interaction techniques used, participants were videoed while performing the tasks. The video data was used to investigate physical difficulties and issues of each of the interaction styles and also identify the mistakes made by the participants.

6.4.2.1. *Scrolling*

Studying users' interaction with the handheld computer using the scrolling technique revealed some of the difficulties of this technique. The most important problem seems to be having to keep the stylus on the scroll bar constantly which seems to be difficult. Consequently, this seems to have led workers to hold the stylus with an awkward posture in order to ensure that they can effectively control the interaction.

In addition to the difficulties with the scroll bar, two of the participants failed to notice the scroll bar which led to some confusion. Overall, more users made mistakes (7/10) with the scrolling interaction style compared with the other two styles. In most cases, the users scrolled to the end of the screen without finding the location specified in the task. It seemed that the reason for this was the fact that they have to stay focused on the scroll bar for navigating. This result is also clear from the findings of the interviews, summarised in Table 6-6.

6.4.2.2. *Browsing*

The main problem with the browsing interaction technique seems to be the segmented nature of the displayed track diagrams. All of the participants browsed all the way through to the end of the route at least once before attempting to find the location. Because the route had been presented in sections, the participants had to browse backward and forward to get a view of the layout of the route.

The other problem seemed to be the small size of the hit area which led to some frustrating problems for the users when clicking on the button did not change the page. Another problem was due to the loading speed of the pages. As mentioned before, the experimental interfaces for browsing and scrolling were displayed as html files. Therefore, it took a couple of seconds for each page to load. This led most of the participants to dislike the interaction technique with only two of the participants choosing browsing as their preferred technique.

In terms of the number of mistakes made using this style, only two of the participants failed to find the location at the first attempt. However, both of them corrected their mistakes immediately and quickly.

6.4.2.3. *Panning*

This style allowed participants to navigate through the pages either by dragging the page or by moving the moveable window provided on the zoom-in box. Navigating the page using the moveable window enabled the participants to scroll through the page faster than the other two interaction techniques.

Also, some of the users commented about the usefulness of the zoom in window despite the small size of the overview provided. Nevertheless, some participants found this box to be obstructing their view which led them to scroll back and forth a few times to connect the view concealed under the box to the rest of the route.

Reviewing the video data showed that, in general, users tend to navigate through the whole screen to get an idea of the route. Therefore, the ease and speed with which users can interact with the device seems to be very important.

Panning interaction style resulted in the least number of mistakes with only one of the participants failing to identify the correct location. This might be due to the fact that the panning interface provided a clearer overview of the whole of the displayed area and therefore enables the users to identify the locations more accurately. A comparison between the speed of performing the tasks and the number of mistakes made with each interaction style (Table 6-5) confirms that the efficiency of the panning technique has not resulted in a greater number of mistakes. Therefore, not only panning seems to be a more efficient technique for interacting with rail specific spatial information, it is also more accurate.

Table 6-5 - Speed of each interaction style and number of mistakes made with each style

Interaction Style	**Speed (time in seconds)**	**Number of Mistakes**
Scrolling	43.75	7
Browsing	38.5	2

Panning	33.65	1

6.4.3. Interview Data

Analysing the interview data revealed that panning interaction technique is the preferred method by the majority of the participants.

The results of the interviews confirm the results obtained by analysing the video data. Similar advantages and disadvantages for each technique were identified. More importantly, some of the comments made by the participants either while performing the tasks (captured in video footages) or during the interviews, helped the researcher to understand the nature of interaction on the trackside better and also provided a more realistic context for the experimental data gathered. For instance, explaining the problems associated with the scrolling technique, one interviewee commented (Interview 1, 10 March 2007):

> *"you've got to think of people on site, e.g., it might be used as he is walking to the access gate and he's got to keep that pen [stylus] down on the scroll bar."*

Or talking about the advantages of having the zoom-in box for panning interface, one of the participants stated that (Interview 4, 27 March 2007):

> *"…although you couldn't see in detail, but if you know your area, you still could figure out where you are."*

Table 6-6 presents the results obtained from analysing the interview data in this research. The numbers in the parentheses indicate the frequency of the comments made by each participant.

Table 6-6 - Result of the interview data analysis

Interaction Style	Preferred by how many workers?	Advantages	Disadvantages
Scrolling	3	Easy to navigate (1)	The stylus needs to be kept on the scroll bar

		Fast (2)	constantly (1)
Browsing	2	line ID and speed information on each page very useful (1)	Very slow (3) Segmented, not a continuous view (1)
Panning	5	Easy to navigate (1) Scrolling by dragging the page very easy (1) Fast (1) Box provides some guidance about the location (3)	Little box blocks the view (2) Zoom-in box too small to provide any benefit (2)

6.5. Discussion

The main limitation[7] in this experiment, and also other experiments in this research, is the small sample size which leads to weak statistical power for the experiment. The recommended sample size, even for a large effect size, for performing a statistically powerful One-Way ANOVA is 15 subjects (Dewberry, 2004). However, this shortcoming was overcome by employing participants who had extensive domain specific knowledge and also by complementing the results obtained from the experiments with qualitative data.

The only possible way for simulating interaction with the handheld computers on trackside successfully, was using participants who can visualise using the device on the trackside. Using experts for this experiment enabled the researcher to gather rich and insightful qualitative data about the interaction of genuine end users with the handheld computer.

[7] This limitation will be discussed in more detail in chapter 10, Discussion.

In sum, the results of analysis of different data obtained in this study can be summarised as follows:

Individual differences in performing the tasks on the handheld computers is very noticeable to the extent that it seems to have masked the effects of the independent variables. However, studying the results obtained from qualitative analyses of the data shows that there is a general preference for the panning interaction style.

Considering the findings of the experiment as well the results obtained from the interviews and video analysis, it seems that it is important for track workers to be able to get to the information they require quickly. Therefore, the amount of the information displayed and the type of interaction technique used should not hinder the speed and sensitivity of the interaction.

The overview provided as part of the panning interaction was too small to offer users any real benefit. Nevertheless, some of the users commented that, even it its current form, the overview allowed them to obtain a better understanding of the whole of the area which made performing the task easier. This is also confirmed by studying the video footage of the browsing interaction technique where users tend to browse backward and forward in order to obtain a better understanding of the route.

All of the interaction styles tested in this experiment required two handed interaction. Reviewing the comments made by some of the participants reveals that a two handed interaction might not be suitable for working on the trackside. This is particularly true when the spatial information displayed on the handheld computer is being used for way finding and navigation purposes. In a risk critical environment like the rail industry where track workers' attention capabilities are already stretched in many ways, it is important to ensure that the interaction style does not impose further demands on the attention requirements of the workers. Therefore, it is believed that interaction with spatial information should be as seamless as possible. For instance, a thumbwheel can be used for scrolling which eliminates the need for two handed interaction.

The next chapter reports the results of two studies which investigated issues associated with determining the optimum amount of information to be presented on the handheld computer screen and also the type of information to be displayed.

7. Chapter 7 – Experiments III and IV: Amount and Type of Spatial Information

7.1. Introduction

Several factors need to be considered when deciding about the amount and type of information for presentation on handheld computer screens. The last two experiments in this research attempted to address the issue of optimum amount of information that can be presented on the screen and the effect of type of information on track workers' performance.

Optimisation of spatial information presented on handheld computer screens is particularly critical due to the limited size of the screen. Handheld computers not only suffer from small screen size, they are also very restricted in terms of input and output devices (Brewster, 2002). However, displaying the optimum amount of information and the type of information required by the users on the screen might reduce the impact of some of these limitations.

In order to answer some of the questions associated with determining optimum amount of information and effect of type of information, two experiments were designed and conducted:

Experiment III– what is the optimum amount of information that can be presented on the handheld computer screen?

Experiment IV – Does type of the information have an impact on users' performance?

In this chapter, first the data collection and analysis methods as well as the results obtained for each experiment will be presented and discussed. The final section of this chapter will discuss the overall results of the two experiments.

7.2. Experiment IIIA[8] – Optimum Amount of Information: Background

Presenting spatial information on a handheld computer screen in the form of schematic track diagrams introduces various human computer interaction challenges. Most importantly, it is crucial to establish how much information can be displayed on the handheld computer screen, or in other words, how much of the real world could be transferred to this small screen. Amount of information depends on two factors: 1- scale of the diagrams, and 2- clutter on the screen. These two factors should be considered simultaneously and together they determine the amount of information on the screen.

Scale in this experiment has been defined as length of track which could be displayed on each screen. Clutter can be defined in many different ways. In this research, the definition of clutter has been based on the "Feature Congestion" clutter measure which is "based on the analogy that the more cluttered a display or scene is, the more difficult it would be to add a new item that would reliably draw attention" (Rosenholtz et al., 2007). It was decided to consider the number of items of information presented on the screen as a measure for screen clutter.

The length of track determines the amount of information displayed; displaying longer lengths of track per screen means that more items of information need to be presented. The interaction between scale of the diagrams and clutter or number of items of information on the screen is important in the sense that it will determine how much information is acceptable on the screen and moreover this interaction will have an impact on the effectiveness and efficiency of performing any tasks using

[8] This experiment has subsequently extended as an experiment IIIB (see sections 7.2.4and 7.2.5) and therefore this part is labelled IIIA.

the handheld computer screen. Figure 7-1 illustrates this hypothetical relationship.

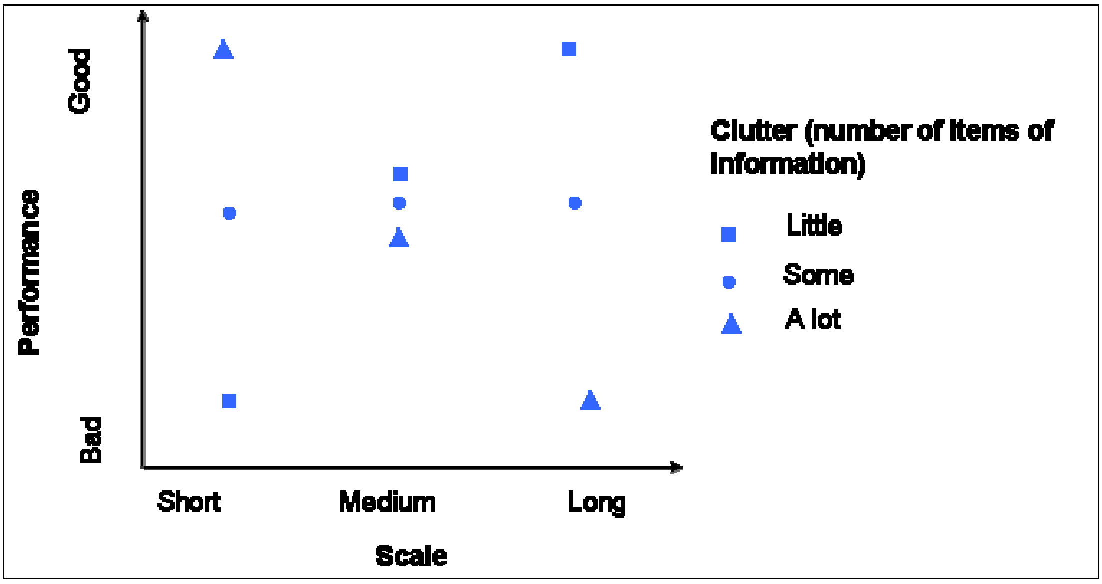

Figure 7-1 – Hypothetical interaction between clutter (number of items of information) and scale (length of track per screen) and its impact on track workers' performance

When only a short section of the track is displayed on each screen, there is more space available on the screen for different items of information. Therefore, the screen is not cluttered. But this effectively means that the user has to navigate and scroll through more pages to obtain the necessary information. Furthermore, presenting little amount of information might mean that the user is not receiving all the required data to perform the task. Therefore, it might be possible to hypothesise that the combination of short length of track and little information deteriorates performance. But, since only a small section of the track is displayed, adding other items of information will not clutter the screen. Therefore, it can be assumed that as the number of items of information displayed on a screen which presents a short length of track increases, performing the task becomes easier for the user. But this is only true when the screen clutter is at an acceptable level. Presenting longer lengths of track on the screen means that more information needs to be displayed. Considering that the font size and also size of icons and symbols need to remain constant regardless of length of the track presented on the screen, having longer lengths of track per screen means that the screen might get cluttered even with medium amounts of information. Therefore, as Figure 7-1 displays, longer lengths of track combined with more items of information leads to poor performance.

In the next sections, the methods deployed for conducting this experiment and the results obtained are discussed. This experiment is reported in two phases. After studying the results of the initial data, some changes were made to the methods and experimental tasks. These changes and the results are also explained in detail.

7.2.1. Aim

The main objective of experiment III was to determine the optimum amount of information that can be presented on the handheld computer screen. This aim was defined through the following hypotheses:

H_1: Performance of track workers is affected by clutter, i.e., number of items of information,

H_2: Performance of the track workers is affected by scale, i.e., length of track displayed per screen.

7.2.2. Method

In order to assess these hypotheses, time of performing a visual search task on the handheld computer screen using the information provided was measured. Visual search is defined as detecting or locating a target object whose position is not known (Wickens and McCarley, 2008). When track workers refer to documents that provide spatial information, they are in effect performing a visual search task and therefore, it was believed that this task will be a good representative of the effectiveness of the interfaces. The dependent variable in this experiment was time of performing the location finding task and the effect of two factors on the dependent variable was studied. These factors were:

IV 1 – Scale (length of track) – three levels: 20, 30, and 40 chains[9]

IV2 – Clutter (Number of items of information) – three levels: six items, seven items, and eight items

7.2.2.1. *Experimental Interface*

The Experimental interfaces designed for experiments III and IV are exactly the same as those designed for experiment I. Coloured signal aspects and platform symbols, added to the experimental interfaces in experiment II, were removed to ensure consistency with the Sectional Appendix.

Table 7-1 summarises the items of information displayed on the handheld computer screen for each level of the second factor, i.e., clutter.

Table 7-1 - Information displayed on the handheld computer screen for each of the conditions

		Factor I – Scale (length of track per screen)		
		20	30	40
Factor II – Clutter (Number of items of information)	6 items (little)	Track layout, line direction, line identification, line speed, stations + location name		
	7 items (some)	Track layout, line direction, line identification, line speed, stations + location name and mileage		

[9] A chain is a unit used in the railway for measuring mileage. Each chain is 72 yards.

	8 items (a lot)	Track layout, line direction, line identification, line speed, stations + location name , mileage, and signal numbers

The experimental interfaces designed for this study were based on the Sectional Appendix. Sectional Appendix is the Network Rail book which lists, in route order, all the running lines and provides details such as line speed, line direction, stations, mileage, and location names. Nine experimental interfaces were designed; one for each of the conditions of the experiment.

It was important to ensure that the information presented on the screen does not overlap and the clutter on the screen is acceptable. Figure 7-2 displays an example of the experimental interfaces designed for this study. This figure shows the interface with seven items of information and 40 chains of track per screen.

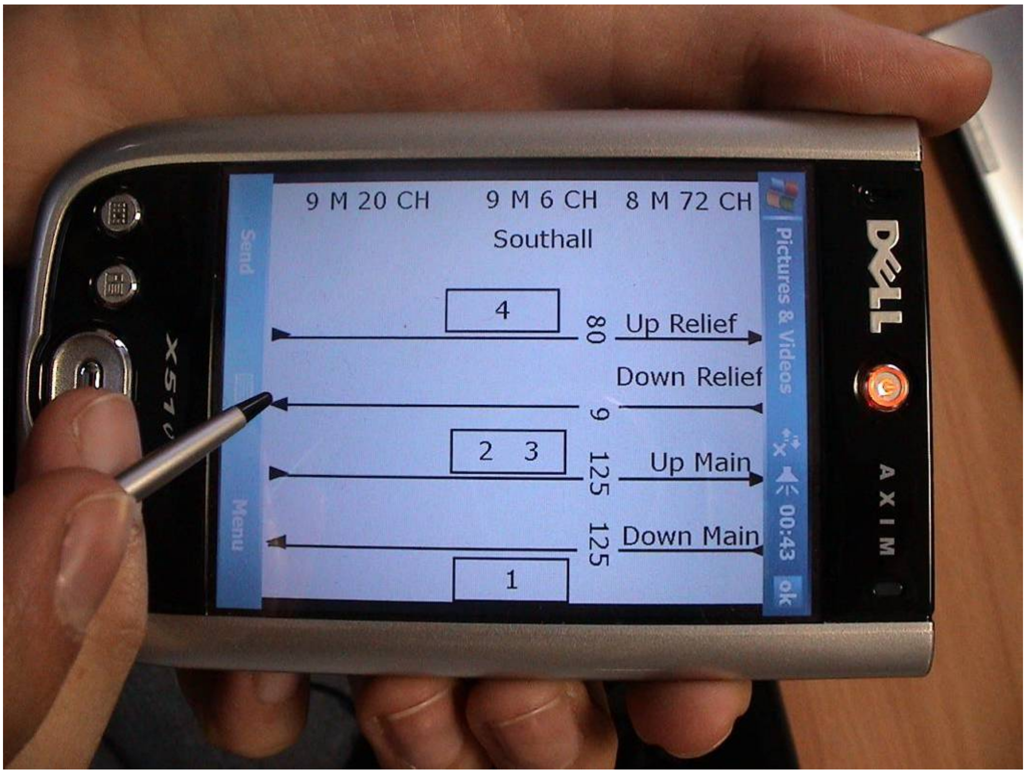

Figure 7-2 - An example of the experimental interfaces

Overall, about three miles of track was presented on the handheld computer screen. The interfaces were scaled and, as the figure illustrates, were presented as schematic track diagrams.

7.2.2.2. *Participants*

The experiment was run with six Network Rail staff from three depots. One of the participants was a Mobile Operations Manager who used a Blackberry and the rest were track workers. Only two of the track workers, who were Signalling and Telecommunication inspectors, had experience of using task related handheld computers.

7.2.2.3. *Apparatus*

The experimental interfaces were designed on a Toshiba Satellite Pro Laptop using Microsoft Publisher 2003. The handheld computer used in this experiment was a Dell Axim 51v with a screen size of 3.8 inches and display resolution of 480 by 640. A standard stopwatch was used for measuring task performance times.

Experimental interfaces were saved as jpeg files and on the handheld computer; they were displayed by Windows Mobile Image Viewer.

7.2.2.4. *Experimental Tasks*

It was decided to measure the performance of participants through a visual search task. Participants were asked to find a specific location on the handheld computer screen. For instance, participants were asked to find the location at 9 mile 66 chains (see Figure 7-2). The tasks in this experiment were derived from previous interviews with maintenance workers. In order to increase the accuracy of the tests two tasks were defined for each item of information and the average time of performing these tasks was calculated for data analysis. In total six tasks were designed; two for each of the following task groups:

1. Task 1: to find a location name on the screen
2. Task 2: to find a mileage on the screen
3. Task 3: to find a signal number on the screen

Table 7-2 - Allocation of tasks to experimental interfaces

Clutter Levels	Item of information tested in the task
Clutter Level 1 – Six items of information	Location name
Clutter Level 2 – Seven items of information	Mileage
Clutter Level 3 – Eight items of information	Signal number

It was important that all the locations appeared in the proximity of each other. In other words, the different items of information to be found were chosen so that it would take an equal amount of time to find each of them. The tasks varied depending on the type of information displayed on each interface. For instance, on the interface with six items of information, only the tasks which asked the participants to find a location name were performed, whereas on the interface with seven items, participants were asked to find both a location name and a mileage on the screen. All of the tasks were repeated for different scales. In total, each participant performed 27 tasks and each trial took between 15 to 30 minutes. The order of presenting the tasks to participants was randomised with the aim of reducing the order effect.

The tasks were designed with the help of and verified by two subject matter experts who work in the Ergonomics National Specialist team at Network Rail and have several years of experience in the rail industry. The subject matter experts verified the equivalence of the tasks in terms of their perceived meaning to the track workers (the equivalence of the tasks was statistically tested as well which will be explained later in this chapter).

7.2.2.5. *Experimental Procedure*

The following procedure was followed for running this experiment:

1. The researcher introduced herself and explained the background to the research and the objective of this experiment. The

participants were also handed a consent form (see appendix 7.1) and an information sheet which provided them with more information about the experiment and also ensured them about the confidentiality and anonymity of the gathered data.

2. The experimental interfaces were shown to the participants and they were given as much time as they required to familiarise themselves with the device.

3. Tasks were printed on separate cards. A data collection sheet was prepared which contained a randomised list of all the 27 tasks. Task cards were handed to the participant based on the order arranged on this sheet. Participants were asked to find the location described to them on the task card and tap on it on the screen.

4. The participants were asked not to put the stylus on the screen until they were ready to start the task. The researcher prompted the participants by saying “start” and started the stopwatch as soon as the participants put their stylus on the screen and stopped it as soon as they tapped on the location the task asked them to find.

7.2.2.6. *Analysis Methods*

As mentioned before, during this experiment, time of performing a visual search task was recorded. A paired sample t-test was performed to investigate the equivalence of the tasks. The t-tests were performed on the average time of performing the task for each task. In order to study the effect of different amount of information on participants’ performance and determine what the optimum amount of information is, a 3*3 repeated measures ANOVA was performed.

7.2.2.7. *Results of the Pilot Study*

Like the other two experiments, this experiment was piloted with two subject matter experts in order to discover any drawbacks and issues and ensure smooth running of the experiment. The following problems were identified and addressed:

As mentioned before, the experimental interfaces were displayed using windows Mobile Image Viewer which provides users with a panning interaction style. This style enables users to navigate through the pages using a moveable window presented in a zoom-in box in the corner of the screen. The zoom-in box, also, provides an overview of the whole of the area that is being presented. Depending on the length of track being presented, the size of the overview changed. For instance, when 20 chains of the track was displayed, the overall view was too small, whereas when 50 chains was presented, the layout of the area could be distinguished (see Figure 7-3 and Figure 7-4).

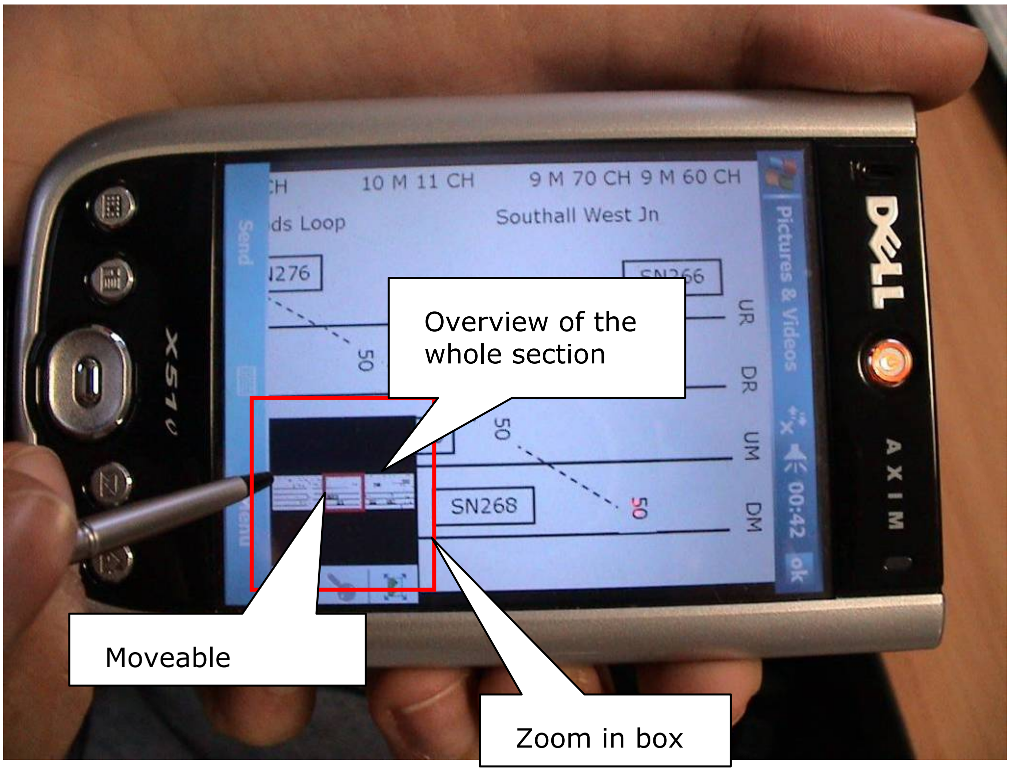

Figure 7-3 - Experimental interface with the zoom in box for 50 chains per screen

One of the SMEs commented that since the overall view in the zoom-in box offers little benefit when short lengths of track are displayed, the box should be hidden. Therefore, it was decided to display the experimental interfaces without the zoom-in box view.

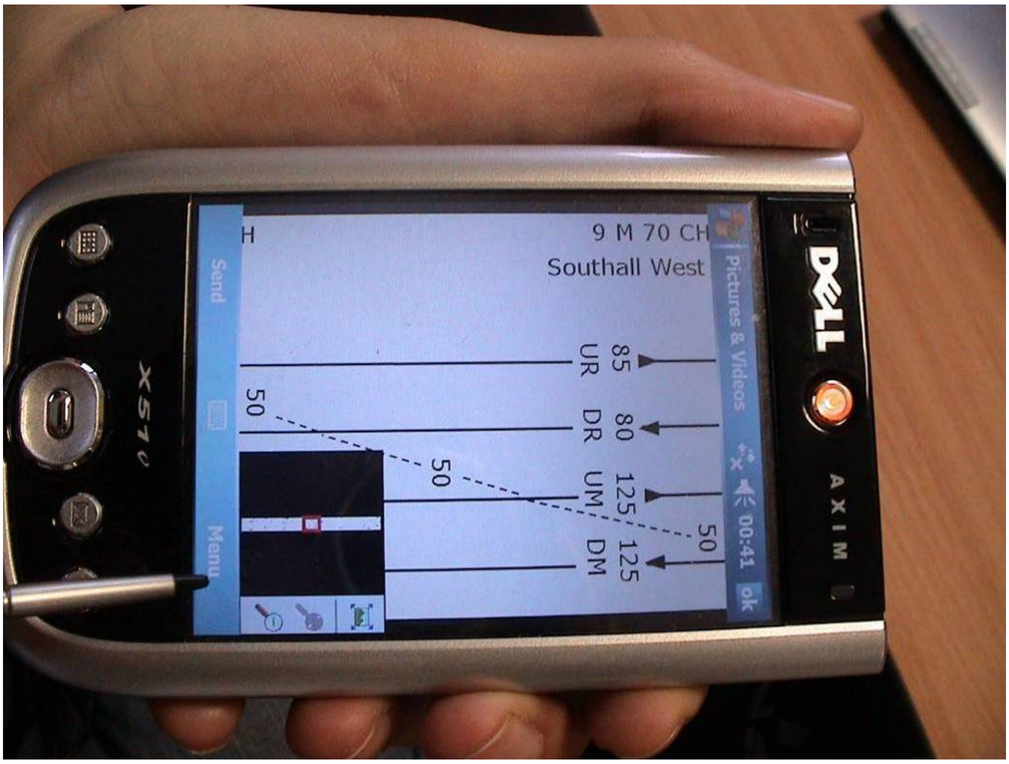

Figure 7-4 - Experimental interface with the zoom in box for 20 chains per screen

The two tasks which asked about the location name required the participant to find a set of points at that specific location. This was felt to be unnecessarily complicated and it seemed that it will lead to an increase in performance times. Therefore, it was decided to change the tasks and just ask the participants to find the specific location name.

Once these changes were made to the tasks and the procedure of running the experiments, the researcher started contacting various depots to employ volunteers for the experiment, with the design and procedure as described above.

7.2.3.Results - Experiment IIIA

The results of the paired sample t-tests confirmed the equivalence of the tasks ($P < 0.05$). In order to investigate the effect of different amount of information on the performance of the track workers, a 3*3 repeated measures ANOVA was performed. The results of the ANOVA revealed that neither length of track nor number of items of information have significant effect on the performance of the track workers ($P > 0.05$). Figure 7-5 displays the average performance time for different experimental interfaces.

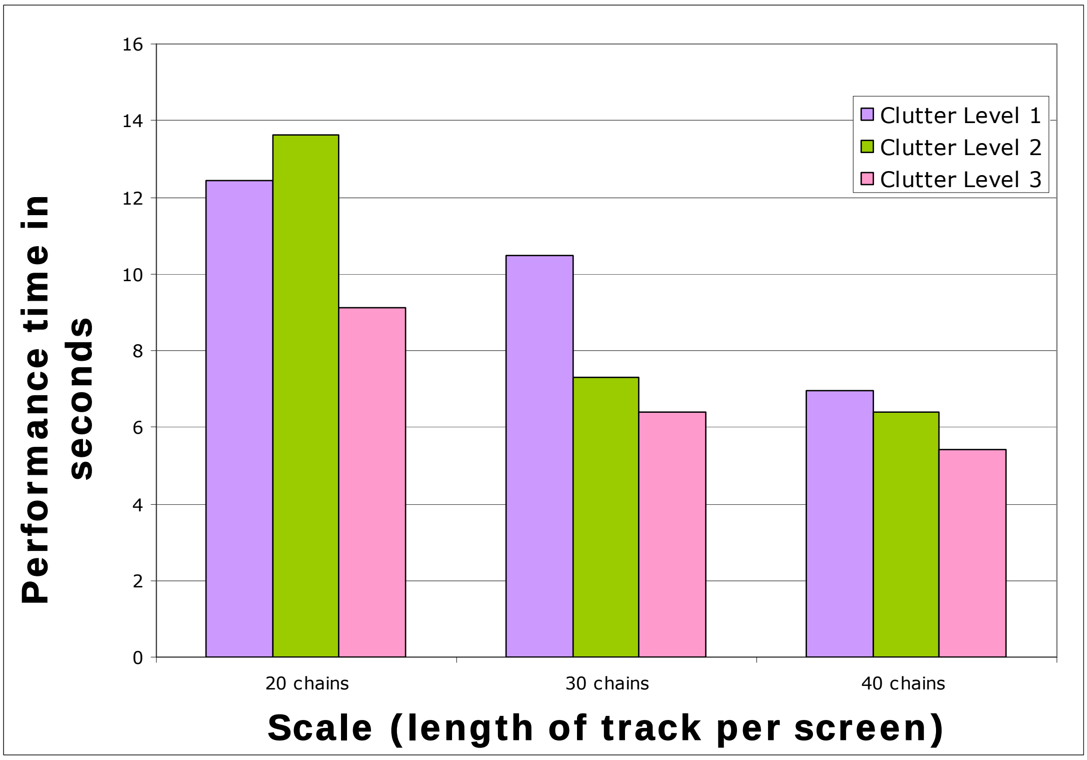

Figure 7-5 - Average performance time for experimental conditions

Studying the results obtained at this stage, it was believed that the difference between the three levels of the first factors, i.e., length of track, is not sufficiently accurate. Furthermore, it was felt that the allocation of tasks to experimental interfaces has not been accurate. In other words, the fact that certain items of information were tested on each screen seemed to have affected the results of the experiment. For instance, when signal numbers were added to the screen to display eight items of information, the task designed for this interface only asked the participants to find the signal numbers.

Due to these considerations, it was decided to investigate the effect of presenting 50 chains of track on the screen. Moreover, in order to ensure the thoroughness of the tests, it was decided to run all the three tasks, i.e., find a location, find a mileage, or find a signal number, on all of the experimental interfaces (provided that the item of information was presented).

7.2.4. Changes to Experiment IIIA Methods for Experiment IIIB

In order to address the issues explained above, some changes were made to extend the levels of the first factor, i.e., scale, and also to the experimental tasks. These changes and the new results have been explained here.

7.2.4.1. Experimental Interface

The experimental interfaces were exactly the same as before. However, three new interfaces were designed which displayed 50 chains per screen for different levels of clutter. Table 7-3 displays the information presented on each experimental interface. In total, twelve experimental interfaces were designed.

Table 7-3 - - Information displayed on the handheld computer screen for each of the conditions

		Factor I – Scale (length of track per screen)			
		20	30	40	50
Factor II – Clutter (Number of items of information)	6 items (little)	Track layout, line direction, line identification, line speed, stations + location name			
	7 items (some)	Track layout, line direction, line identification, line speed, stations + location name and mileage			
	8 items (a lot)	Track layout, line direction, line identification, line speed, stations + location name , mileage, and signal numbers			

The decision to limit the factors to a maximum of 50 chains and eight items of information was made pragmatically due to the fact that it was impossible to add any more information on the screen.

7.2.4.2. *Participants*

In total, ten participants from four depots took part in this experiment, i.e., IIIB. All participants were Network Rail employees and they were all male. Two of them were section managers who had experience of track work and the rest were track workers with various roles and responsibilities. Apart from the two Signalling and Telecommunications inspectors who had experience of using a task specific handheld computer devices, none of the participants had ever used any handheld computers for performing their tasks. Both section managers had experience of working with Blackberries.

7.2.4.3. *Experimental Tasks*

Table 7-4 illustrates the allocation of tasks to experimental interfaces after applying the changes. The tasks used at this stage were the same as the previous stage of the experiment.

Table 7-4 - Allocation of tasks to experimental interfaces

Clutter Levels	Item of information tested in the task
Clutter level 1 – six items of information	Location name
Clutter level 2 – seven items of information	Location Name + Mileage
Clutter level 3 – eight items of information	Location name + Mileage + Signal number

In total, each participant performed 48 tasks and each trial took between 30 to 45 minutes. The procedure for conducting the experiment was also exactly similar to the previous stage.

7.2.5. Results – Experiment IIIB

Track workers' performance was studied by measuring the time it took them to perform a set of visual search tasks on the handheld computer. Time of performing the tasks was recorded in seconds.

Although the SMEs had confirmed the equivalence of the tasks, it was felt necessary to investigate whether different tasks, i.e., different items of information, affect workers' performance on the handheld computer screen. As mentioned before, these tasks were:

1. Task 1: to find a location name on the screen

2. Task 2: to find a mileage on the screen

3. Task 3: to find a signal number on the screen

First, a paired sample t-test was performed in order to investigate the effect of each task on user's performance. The t-tests were performed on the average performance times on all experimental interfaces for each task. Despite the fact that the SMEs had confirmed that the tasks have equivalent meaning for track workers, the tests revealed that there is a significant difference between the performances of track workers for task 1 compared with task 3 (t_9 = 3.16 P < 0.05) and task 2 with task 3 (t_9 = 2.76 P < 0.05). These results showed that finding a signal number on the screen significantly increased the time of performing the tasks.

Looking at the average time of performing these tasks, as illustrated in Figure 7-6, also shows that locating a signal number on the screen has led to the highest task times.

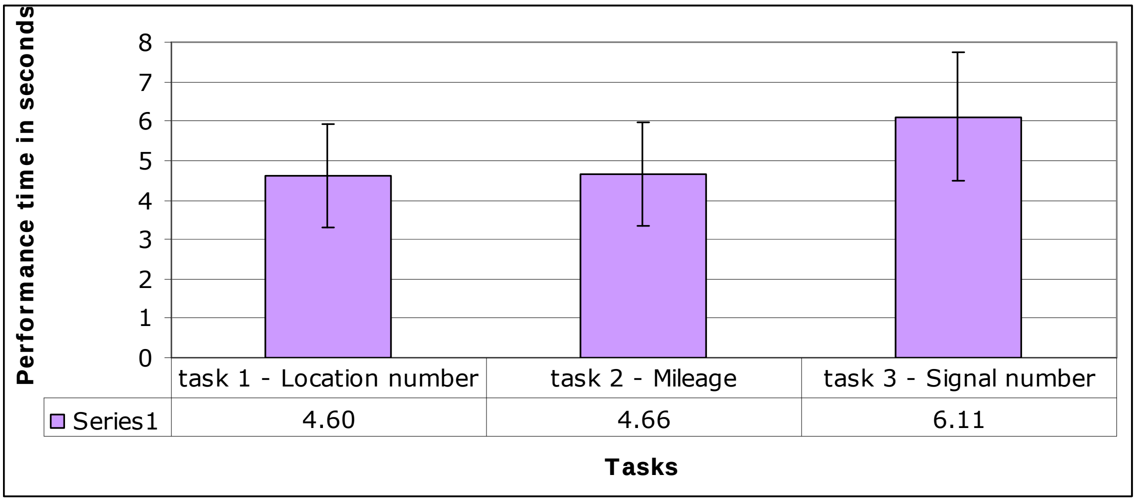

Figure 7-6 - Average time of performing tasks 1, 2, and 3

In the next stage, a 3*4 repeated measures ANOVA was conducted to investigate the effect of amount of information on the performance of track workers. Only the data obtained from tasks 1 and 2 were tested at this stage. This was due to the fact that the results of task 3 were significantly different to tasks 1 and 2. The results suggest that clutter has no significant effect on the performance of track workers. However, the length of track displayed per screen was found to have a significant effect on the performance of track workers ($F(3, 7) = 19.36$, $p < 0.01$).

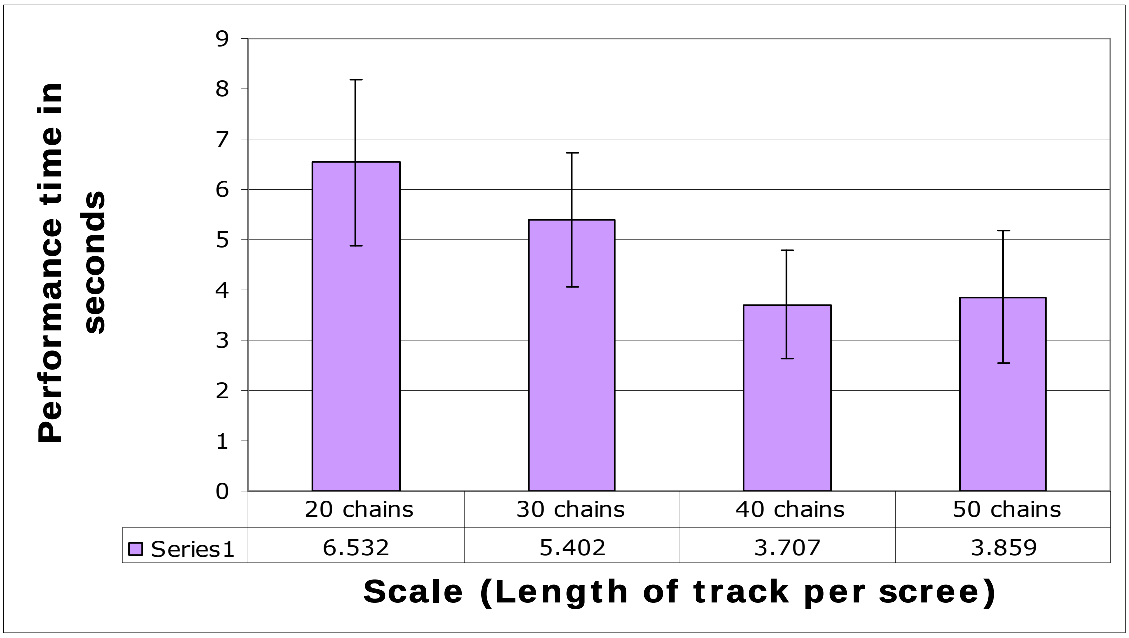

Figure 7-7 - Average time of performing tasks for different scales

In order to investigate the effect of length of track on performance further, a series of t-tests were performed. The paired sample t-tests revealed that there is a significant difference in workers' performance when 20 chains of track is displayed per screen compared with when 30 chains is displayed ($t_9 = 4.35$, $P < 0.01$). There is also a significant difference between 30 chains and 40 chains ($t_9 = 0.03$, $P < 0.01$). However, the results showed no significant difference between displaying 40 chains and 50 chains of track per screen ($P > 0.05$).

Figure 7-8 displays the mean times of performing the task for different combinations of length of track and number of information. As it can be seen in this figure, performing a task on the screen which presents 20 chains of track with fewer items of information leads to the highest performance time. The shortest average performance time was achieved on the interface with least amount of information which displayed 50 chains of track per screen.

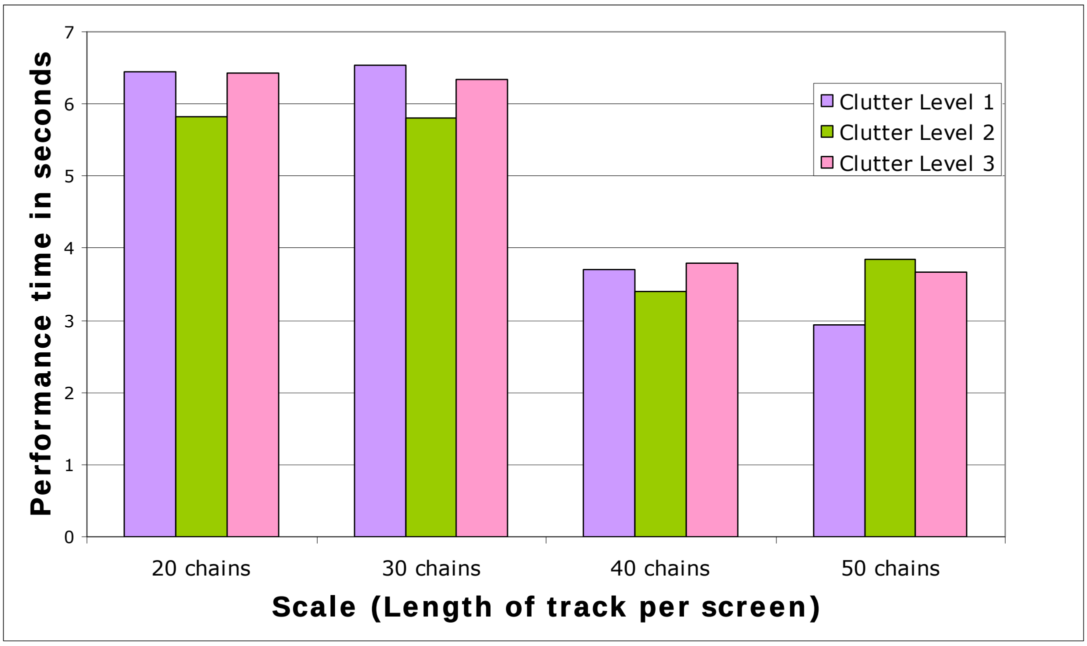

Figure 7-8 - Effect of presenting different amount of information on Track workers' performance

The result of this experiment rejects the hypothesis that amount of information has an effect on users' performance. However, comparing this information with the hypothetical interaction between clutter on the screen and length of track displayed which was proposed earlier in this chapter (Figure 7-1) reveals some relative similarities.

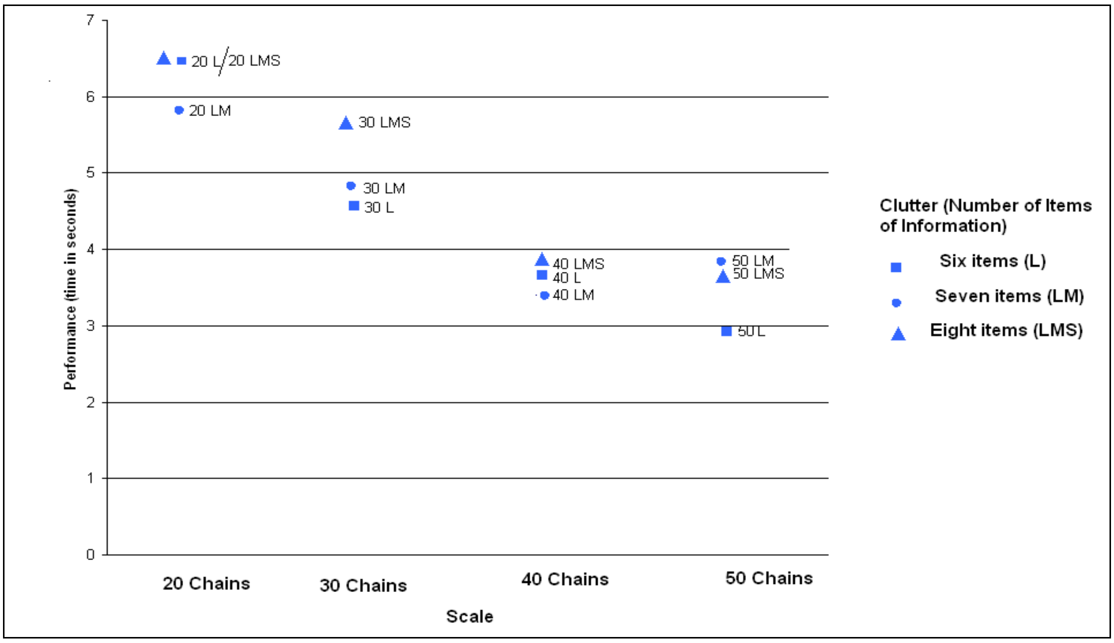

Figure 7-9 - Participants performance (tasks 1 and 2 data)

Figure 7-9 clearly shows the effect of track length on the performance of track workers. Nevertheless, as the figure shows, performance seems to stay relatively unchanged between 40 chains and 50 chains. As mentioned before, while designing the experimental interfaces, it became clear that presenting more than eight items of information on the screen when 50 chains of track is displayed is practically impossible. Therefore, it might be possible to conclude that displaying 50 chains of track per screen is the optimum meaningful length of track per screen for presenting rail specific spatial information.

Looking at the average performance times for all the three tasks shows a sharp increase in the time of performing the task when the average data of all tasks, including task 3 which asks participants to find a signal number is considered. This effect is also obvious from Figure 7-10.

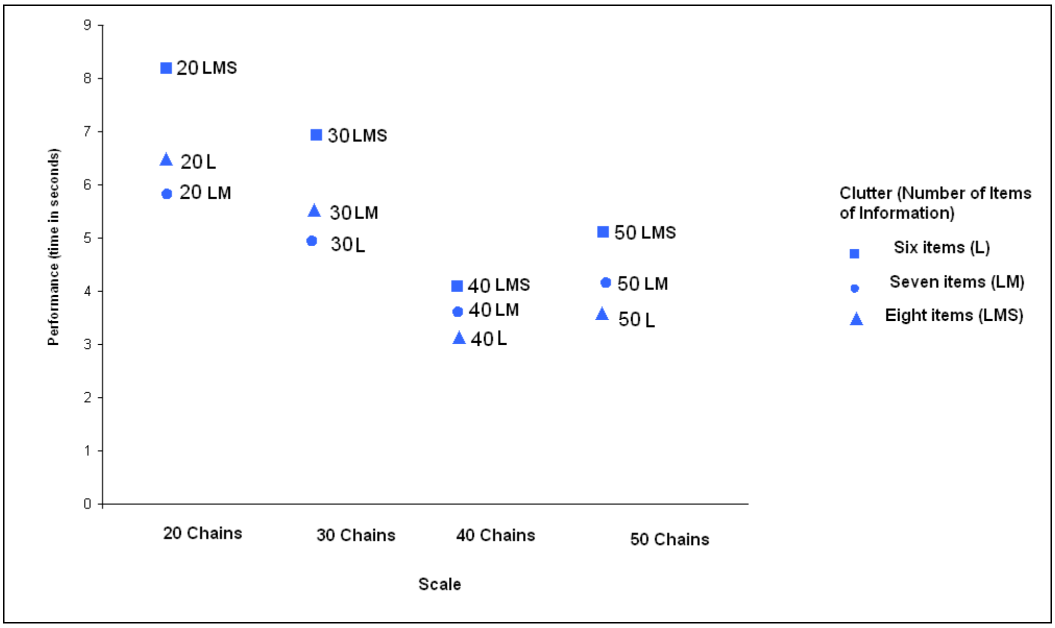

Figure 7-10 - Participants' performance (all tasks)

This shift in performance time suggests that type of information has an effect on the performance of track workers. Therefore, it was felt important to investigate the impact of type of information on track workers' performance. The fourth and last experiment in this research attempted to address the question of effect of type of information.

7.3. Experiment IV – Type of Information: Background

Although amount of information is a critical factor in determining usefulness and effectiveness of visual spatial information, type of information being displayed plays an equally important role. The results of experiment III showed that depending on the type of information presented on the screen, participants' performance times vary. Location finding on the railway is usually done using certain landmarks. For instance, depending on their role and the type of task they are performing, track workers might use location name, signal or point number, or mileage for identifying the position of an asset on the infrastructure. In terms of rail specific spatial information, results of the previous experiment and comments made by maintenance workers showed that information can hypothetically be typified by two characteristics:

1. The presentation style of the item of information displayed on the screen. In other words, whether the information is presented in a structured one dimensional way, e.g., mileage which can appear on the same part of the screen along a straight line, or whether it appears randomly on different parts of the screen, e.g., signal number.

2. The perceived or subjective value of the item of information for track workers, i.e., meaning of the information. For instance, as mentioned earlier, track workers tend to use certain items of information more often depending on their role and therefore different items of information have different subjective values for track workers in terms of their usefulness for performing trackside tasks.

The last experiment in this research was set up to investigate these hypothetical factors and their effect on users' performance. In other words, the objective was to find out if different items of information lead to different performance times and, if so, which characteristic of type of information causes this impact: the presentation style of the item of information or the perceived value of the information by the user.

Clutter on the screen was the other factor which was investigated in this experiment. Although the results of the previous experiment has shown that number of items of information does not have an effect on users' performance, it was still important to consider clutter and compare it with the type of information. This was due to the fact that comparing different types of information meant that different amount of information would be displayed on the screen and therefore it was important to determine whether any changes in the performance times are due to clutter on the screen.

The experimental design and procedure as well as the results obtained will be explained in the next section. In the last part of this chapter, the results of both experiments and the conclusions drawn will be discussed.

7.3.1. Aim

The main objective of this experiment, as explained before, was to investigate the impact of type of the item of information displayed. The following hypotheses were generated and tested in this experiment:

H_1: Type of information has an effect on maintenance worker's performance when performing a visual search task on the handheld computer screen.

$H_{2:}$ Clutter has an effect on maintenance workers' performance when performing a visual search task on the handheld computer screen.

7.3.2. Method

An experiment was designed and conducted to investigate these hypotheses. In order to understand the perceived subjective value of the information for the track workers and its impact on their performance, they were asked which item of information they rely on for performing their tasks.

Therefore, the dependent variables in this experiment were 1 – participants' preferred item of information and 2- time of performing a visual search task. The effect of two factors on the performance time was studied:

IV1 - Type of item of information– four levels: 1- point number, 2- signal number, 3- access point, and 4 - mileage

IV2 - Clutter on the screen – four levels: 1- six items, 2- seven items, 3 – eight items, and 4 – nine items.

The first stage in this experiment was designing a set of experimental interfaces.

7.3.2.1. Experimental Interfaces

The experimental interfaces designed for this experiment were similar to those designed for the previous experiment. The information was mainly based on the Sectional Appendix. 15 experimental interfaces were designed. Each interface displayed the basic items of information: 1- track layout, 2- line speed, 3- line direction, 4- location name, 5 – platforms and platform numbers. Table 7-5 summarises the information displayed on each experimental interface.

Table 7-5 - Information displayed on the handheld computer screen for each of the conditions

Clutter Group 1	**Interface 1**	**Basic data + point number**
	Interface 2	Basic data + signal number
	Interface 3	Basic data + access point
	Interface 4	Basic data + mileage
Clutter Group 2	Interface 5	Basic data + point number + signal number
	Interface 6	Basic data + point number + access point
	Interface 7	Basic data + point number + mileage
	Interface 8	Basic data + signal number + access point
	Interface 9	Basic data + signal number + mileage
	Interface 10	Basic data + access point + mileage
Clutter Group 3	Interface 11	Basic data + point number + signal number + access point
	Interface 12	Basic data + point number + signal number + mileage
	Interface 13	Basic data + signal number + mileage + access point
	Interface 14	Basic data + point number + access point + mileage
Clutter Group 4	Interface 15	Basic data + point number + signal number + mileage + access point

The interfaces were scaled and each screen displayed 40 chains of track. In total about four miles of track was displayed on each screen. Figure 7-11 displays a screen shot of the last experimental interface which displays all four types of information.

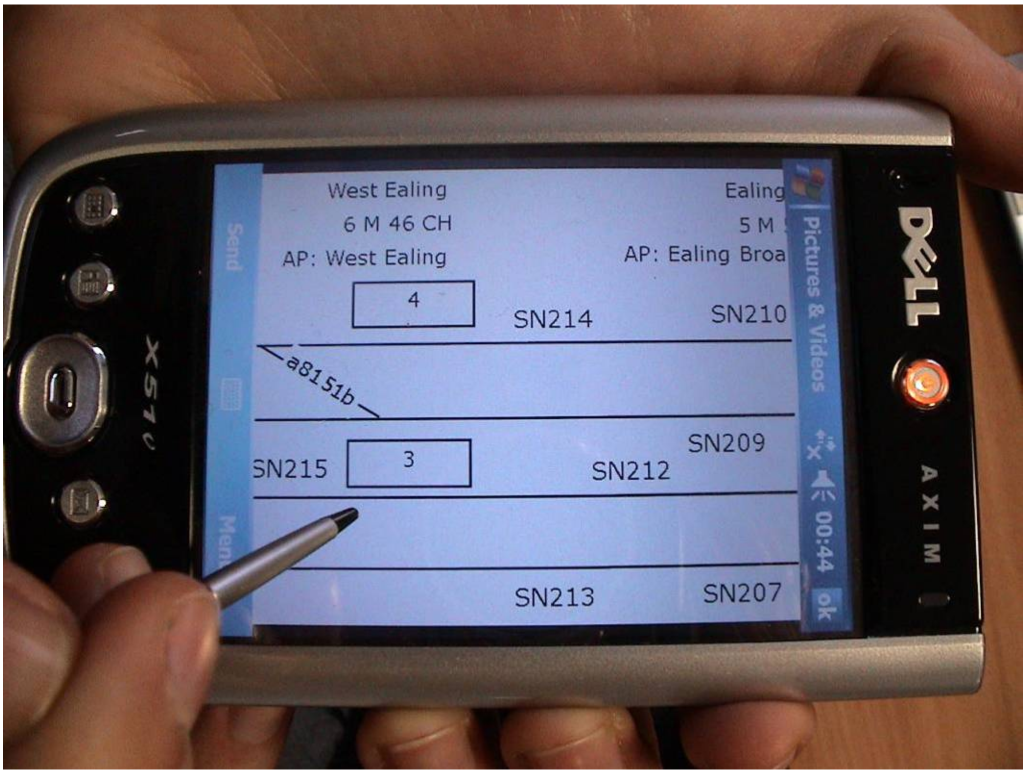

Figure 7-11 - A screen shot of interface 15

7.3.2.2. *Participants*

Eight track workers from three depots took part in this experiment. All participants were Network Rail employees and were all male. Two of the participants were track inspectors, one was a signalling and telecommunication inspector, the fourth was a point carer, two were ultrasonic rail inspectors, and the last two were novices with very little experience.

7.3.2.3. *Apparatus*

The hardware and software used for this experiment and all the equipments used were exactly similar to the previous experiments and have been explained in detail before.

7.3.2.4. *Experimental Tasks*

Like the previous experiment, it was decided to study participants' performance by measuring time of performing a visual search task on the experimental screens. These tasks were verified by two SMEs. The tasks required the participants to find a specific item of information on the screen. In order to obtain more accurate measurements, two equivalent tasks for each item of information were designed. In total, eight tasks (two groups of four identical tasks) were generated for this experiment:

1. Task 1: find a mileage on the screen
2. Task 2: find a signal number on the screen
3. Task 3: find a point number on the screen
4. Task 4: find an access point on the screen

Table 7-6 summarises the allocation of tasks to each experimental interface in this study.

Table 7-6 - Allocation of tasks to each experimental interface

Interface Group	Task allocation
Interfaces 1 to 4 (clutter level 1)	Two tasks per screen depending on the item of information
Interfaces 5 to 10 (clutter level 2)	Four tasks per screen – two for each item of information
Interfaces 11 to 14 (clutter level 3)	six tasks per screen – two for each item of information
Interface 15 (clutter level 4)	Eight tasks per screen – two for each item of information

The tasks varied depending on the item of information being displayed on the screen. The order of presentation of the tasks to the track workers was randomised to eliminate the order effect. Altogether each participant performed 64 tasks. The experiment took approximately between 60 to 75 minutes to complete.

7.3.2.5. *Experimental Procedure*

The first four stages of the experimental procedure were exactly the same as the steps followed for conducting experiment III (see section 7.2.2.5). After performing all the tasks, the participants were asked which item of information they relied on for performing their tasks. This information was also noted. This information was studied together with performance times to investigate the impact of perceived value of information on track workers' performance.

7.3.2.6. *Analysis Methods*

In order to study the effect of type of information and clutter on screen on users' performance, a 4*4 repeated measures ANOVA was performed.

In order to investigate the perceived subjective value of the information and its impact on the performance times, each individual participant's performance on the interfaces was reviewed. The performance time for each task performed on the last experimental interface, which has the highest level of clutter was considered. Since each task required the participants to search for a different item of information, performance times could be considered as a measure for the effectiveness of that specific item of information. This information was studied alongside and compared with the data gathered from participants about the item of information they use more often to perform their tasks in order to discover any consistencies between the track workers' declared preference and their performance on the handheld computer screen.

7.3.2.7. *Results of the Pilot Study*

Once again, the experiments were piloted with the SMEs. No major issues were identified and the SMEs confirmed that the tasks are representative of track workers duties.

7.3.3. Results and Discussion

As mentioned earlier, the data gathered at this experiment were analysed in two ways: an ANOVA was performed to investigate the effect of the independent variables on time of performing the tasks and additionally each participant's performance was analysed with the aim of understanding the impact of role and subjective value of the information on performance.

7.3.3.1. *ANOVA*

A 4*4 repeated measures ANOVA was performed in order to investigate the effect of the independent variables, i.e., clutter on the screen and type of item of information, on the performance of track workers.

The results of the ANOVA confirmed the result of the previous experiment that clutter has no impact on track workers' performance. However, this experiment rejected H_0 and confirmed that type of information has a significant impact on the performance of the track workers ($F(3, 5) = 13.351$, $p < 0.01$). Figure 7-12 illustrates the average performance time for each type of information.

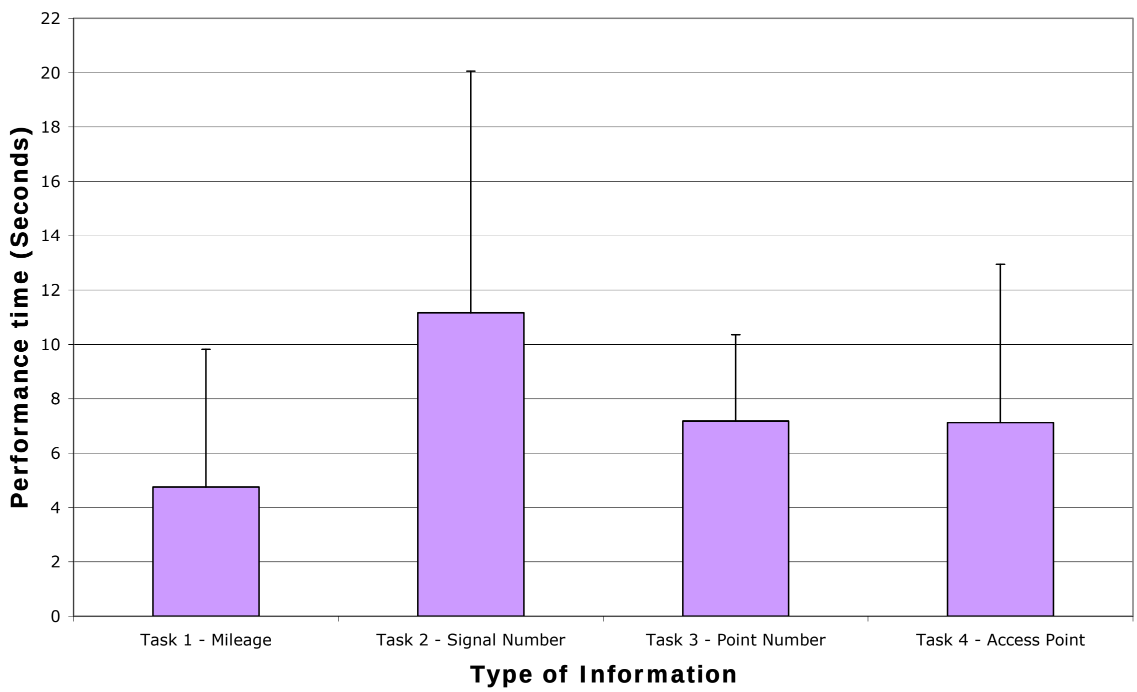

Figure 7-12 - Average performance time for each type of information

The results of the paired sample t-tests showed that there is a significant difference between performance times when searching for mileage information compared with any other type of information ($t_7 = 2.39$, P < 0.05). Also there seems to be a significant difference between performance times for finding a signal number and access point on the screen ($t_7 = 3.72$, $P < 0.05$). No other significant differences were noticed. Therefore, in sum it can be concluded that finding mileage information leads to significantly lower performance times and signal number results in significantly higher times.

Studying the results of this experiment shows that locating signal number leads to higher performance times. Many factors can have caused this effect. For instance, although signal number increases or decreases with the mileage, it can still appear anywhere on the screen whereas location name or mileage always appear in the same place on the screen.

Despite the fact that point numbers also appear randomly on the screen, studying the results of the experiment shows no significant difference in participants' performance times when searching for point numbers on the screen. This could be due to the fact that, compared with signal number, there are fewer point numbers on each section of track.

7.3.3.2. *Individual Participants' Performance*

Figure 7-13 displays the average performance time for each of the four tasks on experimental interface 15. Table 7-7 summarises the item of information that each participant declared to depend on for performing their tasks.

Table 7-7 – Participants' preferred item of information for performing their tasks

Participant No.	Job Title	Preferred item of information
Participant 1	Track inspector	Mileage
Participant 2	Track inspector	Mileage
Participant 3	Signalling and telecommunication inspector	Signal numbers
Participant 4	Point carer	Point numbers
Participant 5	Ultrasonic track inspector	Mileage

Participant 6	Ultrasonic track inspector	Mileage
Participant 7	Apprentice	NA
Participant 8	Apprentice	NA

Considering the performance times displayed in Figure 7-13 and studying this information together with the data presented in Table 7-7 shows that there seems to be no relationship between the item of information that track workers depend on and their performance on the handheld computer screen. In other words, the fact that different items of information have different subjective values for various roles does not have an impact on track workers' performance when searching for information on the handheld computer screen. Interestingly, the performance time for participants 7 and 8, who had very little experience of working on the trackside is comparable to the other participants who had several years of experience.

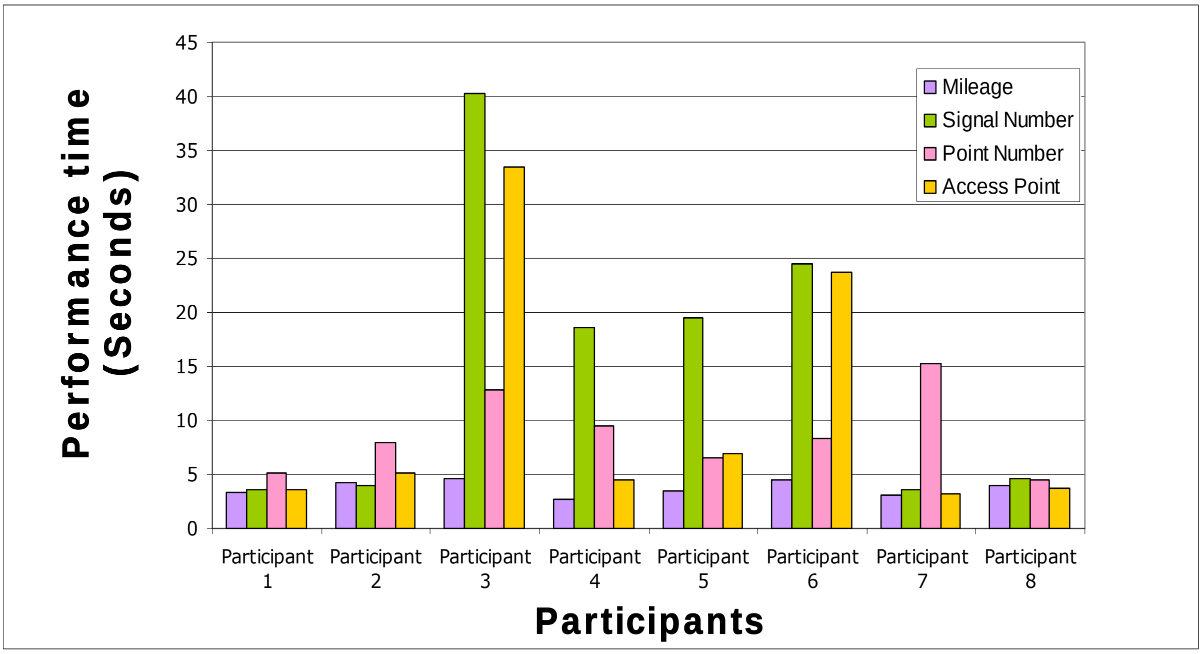

Figure 7-13 - Individual participant performance for each task on interface 15 (task 1: mileage, task 2: signal number, task 3: point number, task 4: access point)

The average performance times for individual participants for the first four interfaces (which display the lowest level of clutter) are shown in Figure 7-14. Studying and comparing the performance times for the tasks on these experimental interfaces with the experimental interfaces which displayed the highest level of clutter, i.e., interface 15, reveals that participants seem to perform almost consistently on all interfaces. For instance, studying the performance times of participants 1 and 3 shows the same fluctuations across different interfaces. This result shows the impact of individual differences on performing a visual search task on the handheld computer screen.

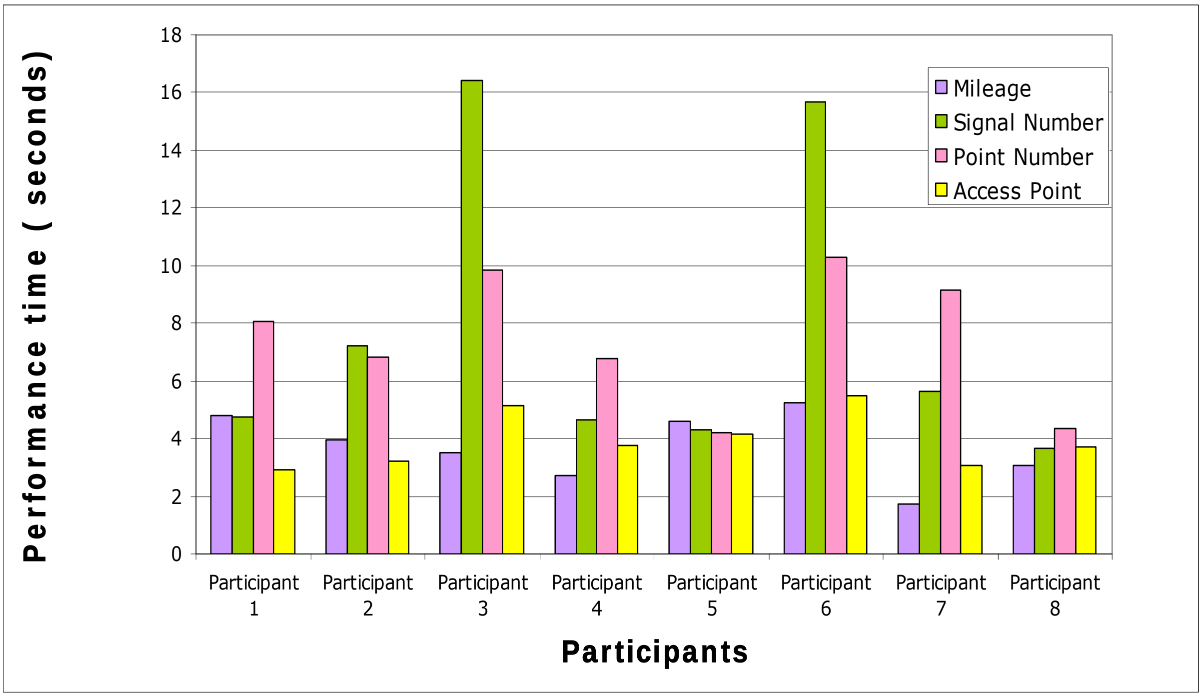

Figure 7-14 - Individual participant performance for each task on interfaces 1 to 4 (interface 1 displaying mileage, 2 displaying signal number, 3 displaying point number, and 4 displaying access point)

Furthermore, studying individual participants' performances confirms that the performance time on the screens depends on the presentation style of the item of information. The graphs clearly illustrate that the average performance time for finding a signal number or a point number is generally higher. Whereas mileage and access point information, which always appear at a specific point on the screen have generally better performance times.

7.4. Discussion

Wickens and McCarley have identified six factors that they believe have an impact on visual information access (Wickens and McCarley, 2008,, pp. 42):

1. Habit (procedural scanning)
2. Attention capture: salience
3. Information content: event rate or bandwidth
4. Information content: contextual relevance
5. Information value
6. Effort conservation

A factor which seems to be missing in their list, but nevertheless seems to have an impact on the effectiveness of the visual data presented is the structure of the information presented on the screen. In a real world setting objects are rarely scattered randomly and they are constrained to appear at predictable locations (Wickens and McCarley, 2008). This is also true for rail specific spatial information.

Rail specific spatial information is presented to track workers in the form of topological track diagrams with different items of infrastructure being mapped on the diagram. This pattern was followed in designing the experimental interfaces. For instance, location name was always displayed on the top of the screen along with mileage. Observing users performing the task showed that once users learn the structure of information on the screen, they seem to focus their visual attention only on the part of the screen where they expect to find the information.

Therefore, it might be possible to conclude that as long as information is presented in a one-dimensional structure, screen clutter does not have a significant effect on worker's performance. In a one dimensional visual field, when information is structured, it seems that users filter out any irrelevant information that is presented to them. This visual search model seems to match the theories of selective attention and in particular the "object-based" theory of selection. According to the object based theory of selection, the object and the grouping, i.e., structure, of objects in the visual field play an important role in effectiveness of the visual search tasks (Matthews et al., 2000).

The results of experiment IV indicate that user's performance is affected by the type of information. Studying the results of this experiment shows that locating signal number results in significantly slower performance times. As mentioned earlier, this result might be due to the presentation style of the information on the screen.

Considering this result in designing handheld computer applications is important since it determines what items of information can be put on the interface. All of the track workers who participated in the experiments stated that, depending on their role, they only use certain items of information. Therefore, if another item of information is to be added to the interface which is similar to signal number, i.e., it can appear on various locations on the screen, the performance might deteriorate significantly. In sum, it can be concluded that the amount of information and its impact on workers' performance is not just a factor of number of items of information and length of track; it also depends on the type of information presented on the screen.

Despite the findings of these experiments, talking to track workers after performing the experiments, revealed the importance of presenting relevant items of information for different roles. In other words, depending on the context of use and the task, the types of information might have a more important impact on accuracy of performing the tasks than other factors.

Table 7-8 presents a summary of the research questions addressed by the experiments in this research and the results obtained from each experiment.

Table 7-8 - Summary of the research questions and results of experiments in this research

Research Question	Results	What next?
Experiment I - Comparing handheld computers with paper-based documents: Which is more efficient? Which provides more comprehensive and detailed information? Which is easier?	handheld computer is more efficient and more accurate than paper maintenance workers prefer handheld computer to paper-based documents for rail specific spatial information	How should users interact with rail specific spatial information?
Experiment II – what is the most effective interaction style for interacting with rail specific spatial information?	panning is the most preferred interaction style.	What is the optimum amount of spatial information for presentation on handheld computer screens?
Experiment III A and B– Optimum amount of information: What is the impact of displaying different lengths of track per screen on maintenance workers' performance? What is the impact of clutter, when defined as number of items of information on screen, on maintenance workers performance?	Maintenance workers' performance is affected by scale, i.e., length of track per screen, but not by clutter, i.e., number of items of information It seems that type of information has an impact on maintenance workers' performance.	Does type of information has an impact on maintenance workers' performance?
Experiment IV – Type of information What is the impact of presentation style of the type of information on maintenance workers' performance? What is the impact of the perceived value of information on maintenance workers' performance?	The way information is displayed on the screen has an impact of maintenance workers' performance. Users' perceived value of the information has no impact on their performance.	

8. Chapter 8 - Discussion

8.1. Introduction

This chapter describes how the work presented in this thesis fulfilled the aims of the research and discusses the main themes and outcomes of the research. The main aims of this research were:

Research Aim I: Integrate relevant background, theory and models to develop a "theoretical framework" for human factors of handheld computers usage.

Research Aim II: Identify personal, organisational and interaction needs for successful handheld computer use in a rail industry.

Research Aim III: Explore the factors relevant to presentation of spatial and spatially orienting information on handheld computer screen.

Research Aim IV: Establish principles for design and implementation of handheld and mobile computing devices in the future railway.

Different parts of this research have contributed to different aims; Table 8-1 summarises the aims and the relevant studies in the thesis.

Table 8-1 - Research aims and relevant studies

Research Aim	Study (chapter)
Research Aim I	Literature Review and User Experience Case Studies (chapters 2, 5 and 6)
Research Aim II	User Experience Case Studies and the EDARE framework (Chapters 5 and 6)
Research Aim III	Experimental programme (chapter 7, 8, and 9)
Research Aim IV	User Experience Case Studies, EDARE framework, and Experimental Programme (chapters 5, 6, 7, 8, and 9)

Below, the significant features of the thesis are summarised. Following this, the contribution of the thesis to each of the aims is described. The limitations of the work are discussed and general recommendations for human factors of mobile applications are made.

8.2. Main themes and Outcomes of the Research

The thesis has made a unique contribution to the field in its integration of several elements. First it is situated within a real infrastructure management company, with real needs for distributed information and communication systems, and to support mobile workers and artefacts in an engineering oriented and safety critical environment. The rail industry is the perfect medium for this research as it offers a dynamic and complex socio-technical system where the infrastructure is spread across as wide a geographical area as the UK.

Second, the access of the researcher to current mobile technology users in Network Rail, and those responsible for developing the strategy for mobile technology use, has meant that the research and its outcomes can be embedded in the real functional needs of real users in real and difficult contexts. Since mobile technology has the potential to significantly change how work is organised, the design of people's jobs and the roles they fill, this field access allowed an organisational perspective to be taken rather than the largely individual artefact interaction perspective of many contributions in HCI.

Third, issues of physical, cognitive, and social ergonomics in the use of mobile computing devices were explored through use of a mixed method approach, embracing interviews, field visits, questionnaire, observations, and experiments. This mixed methods approach and the use of real world participants who brought a wealth of knowledge and experience to the research, enabled the researcher to expand her understanding and investigation of the mobile computing usage beyond the immediate issues of interacting with a user interface on a mobile device and adopt a holistic perception of different aspects of mobile HCI in the rail industry.

Fourth, the work has resulted in outcomes which support theory development, device development and selection, and work system and information choice. The EDARE framework has provided the necessary grounds for a more detailed requirements specification, in particular in relation to appropriate work system and information requirements. The recommendations generated in this research also offer the human factors principles that need to be considered for selecting and developing suitable handheld computer applications. The theoretical framework, also, provides the basis for integrating mobile HCI theories and models with an understanding of the real world issues of interacting with mobile devices to develop a hybrid model that addresses interaction more thoroughly.

8.3. Theoretical Framework

The first objective of this research was to "integrate relevant background, theory and models to develop a theoretical framework for human factors of mobile computer usage."

The aspiration was to explain and model the real world mobile computer usage in the context of rail with the available mobile HCI theories and models. The initial step for achieving this aim was to understand current theories and models in relation to mobile HCI and subsequently adapting these theories to, and integrating them with, the understanding and knowledge obtained from studying mobile computer usage in the rail industry. A review of the literature and the initial field visits showed that no single theory or model can explain the complex nature of mobile computer use in the rail engineering environment. The work on this framework has, therefore, drawn from a number of theories and models, the most important of which are Model Human Processor (MHP), Distributed Cognition and Activity Theory (Bødker 1991; Card et al., 1983; Hollan et al., 2000).

The basis of the framework presented earlier in this research is fundamental theories and models that explain human computer interaction. Nevertheless, many of the aspects illustrated by the theoretical framework are in line with the plans drafted by Network Rail for an enhanced system of asset stewardship through an intelligent infrastructure. For instance, as the framework presented in Figure 4-13 in chapter 4 suggests, assets on the infrastructure need to be embedded within the Distributed Interactive Worksystem to enable the mobile computing device to send and receive information about assets automatically by means of context aware and location based interaction.

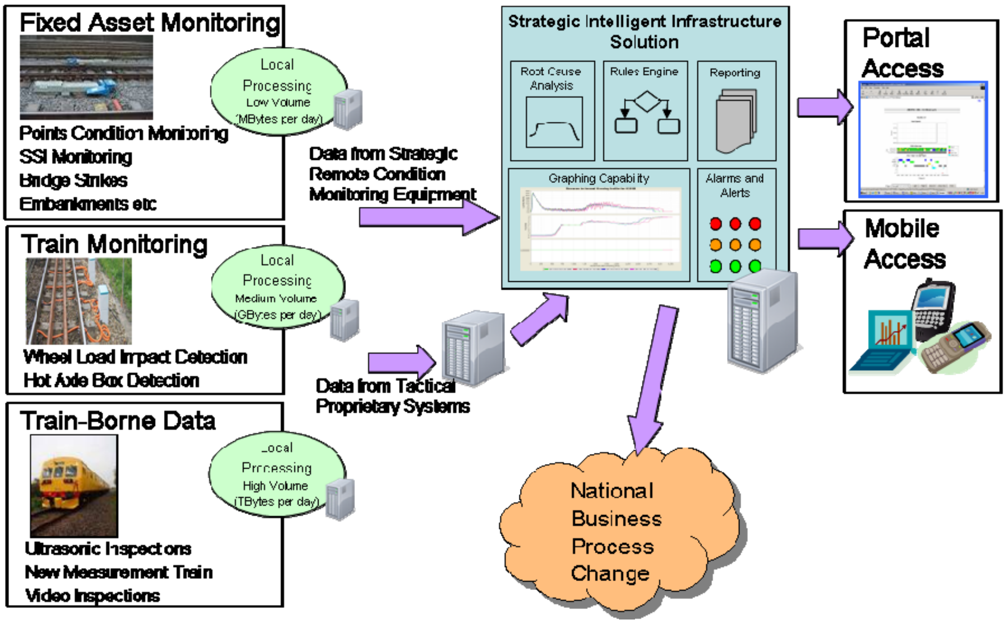

Figure 8-1 - High level model of the Remote Condition Monitoring (RCM) (Internal Network Rail communication)

This view matches the projects currently undertaken by Network Rail to realise the vision of intelligent infrastructure. One such project is Remote Condition Monitoring (RCM), see Figure 8-1. The theoretical framework can explain the immediate interaction between the workers and the handheld computer. It also illustrates the link between Fixed Asset Monitoring and the mobile application.

8.4. Applications of Handheld Computers in the Future Railway

The second aim was to "identify personal, organisational and interaction needs for successful handheld computer use in a rail industry." This aim was partly achieved by studying the results of the User Experience (UX) case studies and identifying the human factors principles that need to be considered when designing a successful handheld computer system for the rail industry. In addition to this, the EDARE framework was developed specifically to help identify functional and information requirements of mobile users in the context of rail.

8.4.1. Development of the EDARE Framework

Development of this framework was mainly accomplished by semi-structured interviews with maintenance workers and brainstorming sessions with SMEs and Human Factor researchers. Initial information gathered during the researcher's early visits to maintenance depots revealed the sheer volume of information and diversity of data in relation to workers' information requirements. The main reason for performing the brainstorming sessions was to achieve a method for structuring and guiding the process of gathering this data.

However, the structure of the framework was not the only outcome of the brainstorming sessions. Itemising the tasks using the Functional Flow Analysis method (Chapanis, 1996) proved to be a very useful practice for obtaining a deeper insight into rail maintenance work. Different levels of the analysis, i.e. level 0, level 1, etc. helped the researcher to be able to view and understand the tasks more clearly. Moreover, the Human Factors researchers who participated in the brainstorming sessions all had experience of working on research projects in the context of rail and the SMEs who helped develop and validate the framework had many years of experience of working in the rail industry in various roles. Thus, in addition to the high level information and function analysis, they were able to offer examples of more detailed information about the nature of engineering work in the rail industry.

Semi structured interviews have been used extensively in this research. The development of the EDARE framework was also greatly dependent on interviews with maintenance workers. It is believed that no other source can properly replace the information provided by participants who have domain specific knowledge and who perform the tasks on a daily basis. The findings of the interviews proved this belief. The data gathered previously during the brainstorming sessions could not have replaced the contextual examples and information gathered from the interviews.

Requirements engineering techniques offer methods and procedures for gathering and analysing requirements specifications for a new system or for changes to a current system. Nevertheless, they are usually technology driven, i.e., attempt to match the requirements of the system to technical capabilities of a potential available technology (Baber et al., 1999), and in many cases fail to take into account other aspects of a system, such as the organisational, cultural, functional, and environmental issues (Bergman et al., 2002).

User Experience case studies in this research revealed that the main reason for unsuccessful deployment of the S&T handheld computer system is the mismatch between the application on the system and the tasks that users need to perform. The significance of designing for the appropriate tasks is directly linked to, and dependent on, a thorough requirements specification analysis. However, performing a detailed requirements analysis is one of the most complicated stages of a design procedure. The reason for this complication is not the technical issues, but it is rather the problem of being able to place the application in its appropriate context. Approaches such as scenario based requirements engineering (Baber et al., 1999) attempt to address this issue.

The EDARE framework has also been developed based on the concept that in order to design a successful system, it is necessary to base the requirements analysis procedure on users' functional and information needs. Despite the diversity of the engineering and maintenance tasks, the methods used in development of the framework provided a means of structuring the requirements in different levels which meant that the identified list of six requirements are generalisable to any electronic mobile device in rail engineering.

The EDARE framework (see Table 3-6) provides a high level foundation on which system developers and designers can base their requirements analysis tasks by providing a set of "general requirements" that are applicable to any handheld computer application in rail engineering. These high level requirements can then be refined and specified for any particular rail engineering and maintenance work. Moreover, it is thought that EDARE framework may be adaptable to other infrastructure domains for mobile usage.

The last column in the framework offers potential handheld computer solutions for addressing each of the identified requirements. Reviewing the literature on applications of handheld computer devices in different industries identified three main groups of applications and the potential solutions offered in the framework are in line with these interaction categories. The solutions proposed in the framework are partially based on the affordances of the technology as it is currently used as well as potential solutions which might change the way maintenance tasks are performed by introducing devices that integrate several of the equipments that track workers require.

8.5. Recommendations for Improved Human Factors of Mobile Applications

The main outcome of achieving the last two aims of this research is a set of general and rail specific guidelines for development and implementation of handheld computer applications. The results of the experiments which were concerned with realising the third aim of this research, that is "exploring the factors relevant to presentation of spatial and spatially orienting information on handheld computer screen" provide a set of rail specific guidelines for design of mobile computing applications for presentation of track diagrams and other rail specific spatial information. The fourth aim was to "establish human factors principles for design and implementation of handheld and mobile computing devices in the future railway". The main outcome of achieving this aim is a list of recommendations for improved applications on handheld computer screens.

8.5.1. Experimental programme

Spatial information emerged as being the most important item of information for maintenance workers from the earliest stages of this research. Performing the tasks successfully and the safety of the workers depend on accurate and accessible spatial information. However, there are various human factors and HCI issues associated with presenting spatial information on the limited space offered by the screen of a handheld computer screen. The experiments in this research focused on dealing with some of these issues.

Table 8-2 summarises the experiments which were performed in this research. The methods used for all of the experiments, with the exception of Experiment III, provided for a combination of quantitative and qualitative measures.

The most important advantage for adopting a mixed methodological strategy was the ability to complement the findings of the quantitative measures. It was believed that the insight provided by qualitative methods will help understand and interpret the quantitative measures in more detail. Moreover, this research was limited in terms of number of participants who could volunteer, not due to limited access but mainly because of the limited time the researcher could spend with track workers because of the demanding nature of their job. Therefore, supplementing the quantitative data with qualitative information, gathered through interviews and observations, helped compensate for this constraint.

Table 8-2 - Experimental measures for different research questions

Experiment	Experiment Aim	Methods	Experimental Measure	Main findings
Experiment I	Speed and efficiency of communication	Communicating spatial information using the handheld computer vs. paper based	Time of conversations Number of words spoken Number of words written on notes	Handheld computers are preferred to paper based documents for displaying rail specific spatial information. Users performed the task more effectively and efficiently with the handheld computer.
	Adequacy of Information	Communicating spatial information using the handheld computer vs. paper based	Number of items of information communicated using each method	
	Ambiguities and difficulties in communication	Communicating spatial information using the handheld computer vs. paper based	Number of instances of hesitations Number of instances of confusion and mistakes Number of repetitions	
	Advantages and disadvantages of each technique	Semi structured interviews	Qualitative analysis	
Experiment II	Identify most effective interaction style	Time of performing a location finding task on the handheld	Time of performing the task	Panning is the most proffered style for interacting with rail specific spatial information. Perceived speed and responsiveness of interaction style is an important factor for users. Providing users with an overview of the whole of the
		Video footage of the interaction	Qualitative analysis	
		Semi structured interviews	Qualitative analysis	

	Advantages and disadvantages of each technique	Semi structured interviews	Qualitative analysis	
Experiment III (A and B)	Optimum amount of information displayed on the screen	Performing a visual search task on the handheld computer screen	Time of performing the task	Optimum amount of rail specific spatial information on a handheld computer screen is only affected by the scale of the geographical information displayed. Clutter on the screen does not have an impact on users' performance.
Experiment IV	Impact of type of information on performance	Performing a visual search task on the handheld computer screen	Time of performing the task	Type of information displayed on the screen has a significant impact on the performance of the users. Users' perceived value of the information does not have an impact on their performance, but structure of presenting the information has an impact on user's performance.
		Participants' preferred item of information for performing their tasks	Qualitative Analysis	

8.5.2. User Experience Case Studies

The recommendations reported in this thesis have been derived from different parts of the research, but principally this objective was achieved by studying the current handheld computer systems in Network Rail and examining user experiences to understand the issues with the current systems; hence the User Experience Case Studies.

It was important to ensure that the chosen methods for the User Experience case studies capture the human factors issues. The main methods used for acquiring this understanding were semi structured interviews and subjective measurements, i.e., the usability questionnaire. Semi structured interviews provided the researcher with a very deep insight not only into the usage of the application, but also about the task and the context of work in rail maintenance depots, and in particular about Signalling and Telecommunication and Level Crossing inspection teams.

The Usability Questionnaire for Handheld Computers has been specifically designed to attend to problems associated with interacting with handheld computers in the rail industry. Development of the questionnaire started after researchers' initial visits to maintenance depots. These initial visits were largely performed with the aim of obtaining a general understanding of the rail maintenance environment. It became apparent that due to the complex nature of rail environment, it is necessary to design and develop a questionnaire specific to the different factors that affect usage of mobile computing devices in this environment. A revised version of the questionnaire was used in a recent project to identify the usability issues of interacting with tablet PCs for displaying paper-based forms in signal boxes.

The questionnaire provided a means for comparing the perceived usability and usefulness of both S&T and LX applications more rigorously. Although the results of the questionnaire mostly confirmed and validated the findings of the interviews, they revealed other conclusions. The findings of the questionnaire showed how users' perceived value and functionality of an application influences their view about other features of the user interface, even when the statements questioned aspects of the interface that were independent of the application.

8.5.3. Rail specific and general recommendations and guidance

The recommendations listed here, in Table 8-3, form an important and vital deliverable for Network Rail and future application of handheld and mobile computing devices and the researcher is continuously working on the guidelines to produce a formal guidance note for Network Rail based on these recommendations.

These recommendations will act as a basis for Network Rail guidance or even standard. While some of the guidance provided are specific to the rail industry, in particular those about presenting rail specific spatial information, the researcher believes that the principles suggested here apply to development and implementation of any handheld and mobile computing application.

It has been attempted to verify these guidelines by applying them to the S&T and LX handheld computers and also to the experimental prototypes designed for the experiments. Table 8-4 presents this information.

Table 8-3 - Rail specific and general guidelines for human factors of handheld computers

Guideline	Rationale
Consider the match between the applications on the handheld computers and tasks and consistency with other systems and between different platforms.	In order to achieve this, it is necessary to understand users' tasks and ensure that the application is capable of accomplishing those tasks without over complicating the work. In the context of rail, using the EDARE framework will provide a starting point for identifying track workers' functional and information requirements.
Provide adaptability and customisability of the system to match user preferences.	Users need to be able to change the settings of the applications to their own preferred way of working. Although implementing handheld computers will change the normal working practices in many ways, it should not reduce the flexibility and autonomy of the workers.
Obtain evidence for the robustness of the hardware and reliability of the technology.	The importance of reliability of the technology has been repeated several times throughout this research. Any application needs to be evaluated with different hardware options to establish the most suitable device for the specific context in which it is going to be used.
Provide training and continuous support.	In order to achieve this, any application needs to be supported by a communication link between the users and IT support. Involving users early on in the design of any application can create a sense of ownership which makes implementing the system easier.
Involve end users at all stages of the development of the system.	During the development of the EDARE framework, different sources of information were used. However, despite the depth of knowledge provided by Subject Matter Experts (SMEs) and researchers involved in development of the EDARE framework, there could have not been any substitute for the rich contextual examples and information which were gathered in semi structured interviews with maintenance workers.
Use prototypes extensively throughout different stages of the design process.	Prototypes are very powerful tools in getting users to think about the system more freely; they help the users to visualise the application and mobilises their imagination. At different stages of this research, track workers were asked about the potential future handheld computer applications that they think will assist them with their tasks. Track workers generally offered more example and suggestions after having

	seen the experimental interfaces.
Balance any loss of flexibility through replacing paper-based documents by using handheld computers to provide other more important functionalities.	The limited input and output facilities offered currently by handheld computers means that using them as a substitute for paper-based documents is not necessarily the most efficient use of the opportunities offered by mobile computing devices. In the context of rail, looking at the EDARE framework shows that very few of the information requirements of track workers are paper-based documents, i.e., forms or standards and guidelines. Filling in a form on a handheld computer using the current inputting techniques is cumbersome and time consuming. However, the time spent on filling in the form on handheld computer could be compensated by developing an integrated device that provides users with other more important requirements such as location based information.
The handheld computer should be designed and developed as an integrated element of a complex multifaceted workplace.	Users normally use handheld computers as an aid to perform their primary task. In other words, the users' main tasks are "outside of the computer" (Kristoffersen and Ljungberg, 1999b). This means that users usually need to deploy other tools and equipment to perform their primary tasks. For instance, a level crossing inspector usually carries a digital camera, a mobile phone, a torch, and a measure tape, to name a few. Ideally the handheld computer should be integrated with other tools and equipment in order to provide track worker with a single device that meets many of his requirements.
Harness the potential of mobile computing devices and location based services to provide context aware spatial information.	In the context of rail, location based information forms the largest group of track workers' information requirements and it was considered by them as the most important and frequently used item of information. Perhaps the most attractive characteristic of mobile computing devices is their mobility which means that they can be carried around to different locations. Taking advantage of this characteristic of mobile computing devices as well as the technologies in the field of location based and geographical positioning services provides the necessary grounds for realising location based and context aware interaction.
The preferred style for interacting with rail specific spatial information on the handheld computer screen is panning	The reason for this seems to be the speed of interaction and the overall view of the route. Perceived speed and responsiveness of interaction style is an important factor for users. Providing users with an overview of the whole of the area enables them to obtain a better understanding of the area in which they are working.

Table 8-4 - verification of rail specific and general guidelines for human factors of handheld computers

Guideline	S&T Handheld Computer	LX Handheld Computer	Experimental Prototype
Consider the match between the applications on the handheld computers and tasks and consistency with other systems and between different platforms.	Mismatch between the application on the handheld computer and users' tasks was identified as the main reason for the failure of the S&T system. Experimental prototype:	The application on the handheld computer addresses the most important aspect of LX inspector's task which is filling in the inspection forms.	The application provides very basic spatial information, but these have been based on user requirements derived from the EDARE framework.
Provide adaptability and customisability of the system to match user preferences.	Neither of the systems provides customisability. Many users commented about usefulness of being able to customise the system to their preferred way of working.		Not applicable
Obtain evidence for the robustness of the hardware and reliability of the technology.	A technical fault with the software had led to constant failure of the system which has resulted in users' lack of trust in the application.	The hardware was considered to be robust for the rail environment and the software had a few minor bugs which did not stop the application from operating effectively.	Not applicable
Provide training and continuous support.	Lack of IT support was mentioned by many of the S&T inspectors as	Since at the time of conducting this research, the LX	Not applicable

	one of the reasons for failure of the system. Operators felt that none of the issues they raise is ever considered and therefore had lost faith in improving the system.	handheld computer was being piloted, there was a strong link between the users and the project team and this link had enabled the users to express their problems and ensure that the requested changes are applied.	
Involve end users at all stages of the development of the system.	Most of the design decisions for the S&T system were made without any end-user involvement and this had led to a gap between how users perform their tasks and how the application worked.	A strong and active link between the project link and the users who were piloting the device meant that users' voice was heard by the project and their concerns were addressed.	The application and the tasks designed for the experiment were all based on the EDARE framework and observations of users' tasks and context of work.
Use prototypes extensively throughout different stages of the design process.	No prototypes provided which meant that no significant changes to the system were possible.		Not applicable; however, using this prototype for the experiment enabled participants to visualise the application and they were able to think about the potential applications more realistically.
Balance any loss of flexibility through replacing paper-based documents by using handheld computers to provide other more	The mismatch and gap between users' preferred way of	The LX handheld computer system is a very good example for	Not applicable

important functionalities.	working and the application offered on the device meant that the loss of flexibility was not balanced and therefore users were still using paper-based document.	this guideline. Although users commented on a few of the system's shortcomings such as difficulties for entering text, they believed that the application offers so much flexibility that these issues are justified.
The handheld computer should be designed and developed as an integrated element of a complex multifaceted workplace.	The digital camera on both handheld computer systems had been disabled and many users commented about the fact that they have to carry a camera for their task and they would have liked to have the two devices integrated into one. This example shows the importance of realising this guideline and developing an integrated device that satisfies mobile users' varied needs.	Although the prototype presents a very simple application, the fact that information such as signal numbers or point numbers, which are not presented on the Sectional Appendix, were all presented on one diagram was acknowledged by many users.
Harness the potential of mobile computing devices and location based services to provide context aware spatial information.	Many of the users commented about the possibility of designing a location aware system which automatically informs the users about the assets in that area together with any information attached to these. The systems used currently in Network Rail are all static systems with no location awareness capabilities.	Not aapplicable
The preferred style for interacting with rail specific spatial information on the handheld computer screen is panning	Not applicable	Although the results of the statistical tests did not identify any differences between the three styles, observing

	the users interacting with the handheld computers and studying their comments shows the benefits of the panning interaction style.

8.6. Limitations of the Research

In conducting any research, and in particular when considering research in a real world complex system, there are some limitations. Very rarely a research plan or an experiment programme is executed without any deviations or changes. This research has been no exception.

A review of the literature on mobile HCI in chapter two revealed the many problems and complications that researchers face in conducting research in this field. These are mainly due to the special characteristics of mobile computing devices as well as the attributes of users of such devices.

However, difficulties of studying mobile computing devices were not the only source of problem in this research. Studying a complex system such as the rail industry will also impose some limitations on the research (Wilson, 2005b, P. 4):

> *"The very environmental and internal factors which generate the need for thorough human factors investigation in the railway network also provide the very issues, difficulties and challenges for such research."*

The special attributes of this research have imposed a series of limitations on the research. Many of these limitations were due to the risk critical nature of the rail industry. For instance, observing participants in the field was considered to be the most suitable method for understanding current use culture. However, this was impossible since even the least unobtrusive method meant that the researcher herself was at risk. Hence, observing users' interaction with the mobile computing device was restricted to the depot.

The other problem was identified during the interviews with track workers. After the initial interviews it became apparent that due to previous experience with unsuccessful handheld computer devices, some of the track workers have fixed ideas about the usefulness of deploying mobile computing devices for inspection and maintenance tasks. Therefore, they were very doubtful about the advantages and effectiveness of any potential system for the rail industry which led to their scepticism about the objectives of the researcher.

Another problem was difficulties in recruiting participants for different studies and in particular for the experiments. The arranged site visits and meetings had to be postponed or cancelled due to various reasons including staff shortage at certain times of the year or occurrence of an accident. Therefore, some of the studies took longer than it was originally anticipated which consequently led to delays.

More importantly, these problems led to sample size limitations. Sample size plays a significant role in determining power of the statistical tests performed. In order to address this issue, the findings of the quantitative measures were verified by adopting qualitative approaches.

There is evidence in the usability evaluation literature that suggests employing test subjects who have domain specific knowledge is more effective and provides richer data about the system than subjects without that specialised knowledge (Kjeldskov and Skov, 2003a). This research has been privileged with extensive access to real world participants. The participants for all of the experiments were maintenance workers with domain specific knowledge. Whilst it is acknowledged that the sample size for the experiments and studies conducted in this research is small, the maintenance workers who participated in this study yield rich data about the tasks and it was felt that the depth of insight that they offered could not be replaced by employing participants without the domain specific knowledge, i.e., students. Therefore, an informed decision was made to compromise for weak statistical power with strong and insightful qualitative information gathered from maintenance workers.

Currently, only two handheld computer systems are implemented within Network Rail which meant that the range of applications and tasks that could be studied were limited. More importantly, the Level Crossing handheld computer system was being trialled at five depots at the time of conducting this research. Therefore, the number of LX inspectors who could participate in the study was limited.

Network Rail is now attempting to implement mobile computing devices to more tasks within the Infrastructure Maintenance department. The researcher currently works as a Human Factors Researcher in the Ergonomics National Specialist Team in Network Rail. This association has enabled her to get involved with the projects in relation to mobile working and provide human factors guidance to the projects.

9. Chapter 9 - Conclusions and Recommendations for Future Research

9.1. Conclusions

This research was set up to study the applications of handheld computers in the rail industry and in particular for maintenance and inspection operations.

For the researcher, this project provided a unique opportunity for learning about the rail industry, in general, as well as the maintenance and inspection operations. Network Rail is entering a very exciting time. The number of passengers on the rail network has increased dramatically. Environmental considerations mean that public transport, including the rail industry, will be the focus of attention for the coming years. There are aspirations for a 24/7 railway and all this requires more efficient working arrangements and effective asset stewardship.

It is naïve and ineffective to consider handheld computers as substitutes for paper based systems. This raises the question that how substituting paper with a more expensive equivalent can increase efficiency. Instead, the handheld computer should be used to fundamentally change the way track workers perform their tasks. In order to achieve this objective, many different aspects of interacting with a mobile computing device need to be addressed ranging from traditional user interface design issues to considerations about working in a risk critical environment and also the issue of designing handheld computer applications as an integrated element of a distributed joint cognitive system.

This research has attempted to address some of these issues and to prove the basis for the much needed future work in this field. The findings of the thesis has identified ten fundamental human factors principles and guidelines that determine successful deployment of a mobile computing device in a risk critical and complex environment like the rail industry.

The EDARE framework offers designers and system developers in the industry a foundation on which they can base requirements gathering tasks. The results of the experiments have provided guidance on some of the fundamental aspects of interacting with rail specific spatial information on a mobile computing device.

The Theoretical frameworks which attempt to illustrate interacting with mobile computing devices currently and in the future railway offer a holistic and multifaceted view of mobile HCI.

The research reported in this thesis has formed the basis for continuous investigation into the applications of handheld computers in the rail industry. However, many aspects need further research and investigation before a successful handheld computer application that satisfies all the different requirements of future maintenance work could be designed.

9.2. Recommendations for Future Research

This research has been the first step towards studying the applications of handheld computers in the rail industry and has provided an insight into the challenges and opportunities that implementing such devices will introduce. Many other aspects need to be addressed before a successful system can be implemented. Mobile computing is a critical element of ubiquitous and pervasive computing. Ideally an effective mobile computing system for the rail industry should realise Weiser's vision in his 1991 seminal article stating that the computing systems need to become invisible and unobtrusive. Some of the proposed future research areas are listed here:

1. Presenting rail specific spatial information on handheld computer screens: This research has addressed only the very basic and fundamental issues of presenting spatial information on handheld computers. The field of Location Based Services and context aware interactions is growing rapidly which consequently means that the technologies supporting these systems will get stronger and more accurate in the near future. Therefore, it is necessary to investigate other aspects of presenting spatial information on handheld computers and in particular linking this information to other

applications performed by maintenance workers.

2. Appropriate hardware: The hardware currently supplied to support mobile computing does not always meet the requirements, often being big and heavy. Moreover, currently handheld computer devices are one of the many tools and equipments that maintenance workers carry to the trackside for performing their tasks. It is necessary to develop an integrated device that is capable of meeting workers' different requirements. Moreover, in order to fully realise the potentials of implicit and context aware interaction, it is important to study more effective input and output systems. The results of the UX case studies performed in this study showed the difficulties of inputting data into handheld computers which essentially impacts their potential effectiveness as data registry devices.

3. Enhanced communications: communications in the railway tend to be voice based, which is a slow and labour intensive method of communication. Using mobile computing in conjunction with more standardised communications protocols could achieve major benefits. Research into effective text based communication that is suitable to risk critical conditions of working in the railway industry would provide the necessary foundation for enhanced communication.

4. Integration with wider systems: current mobile computing systems in the railway tend to be stand-alone; supporting a single function in collection and storage of data. To realise wider benefits, mobile computing may be able to integrate with control systems and achieve major benefits in allowing maintenance staff to assure their own safety on track.

10. References

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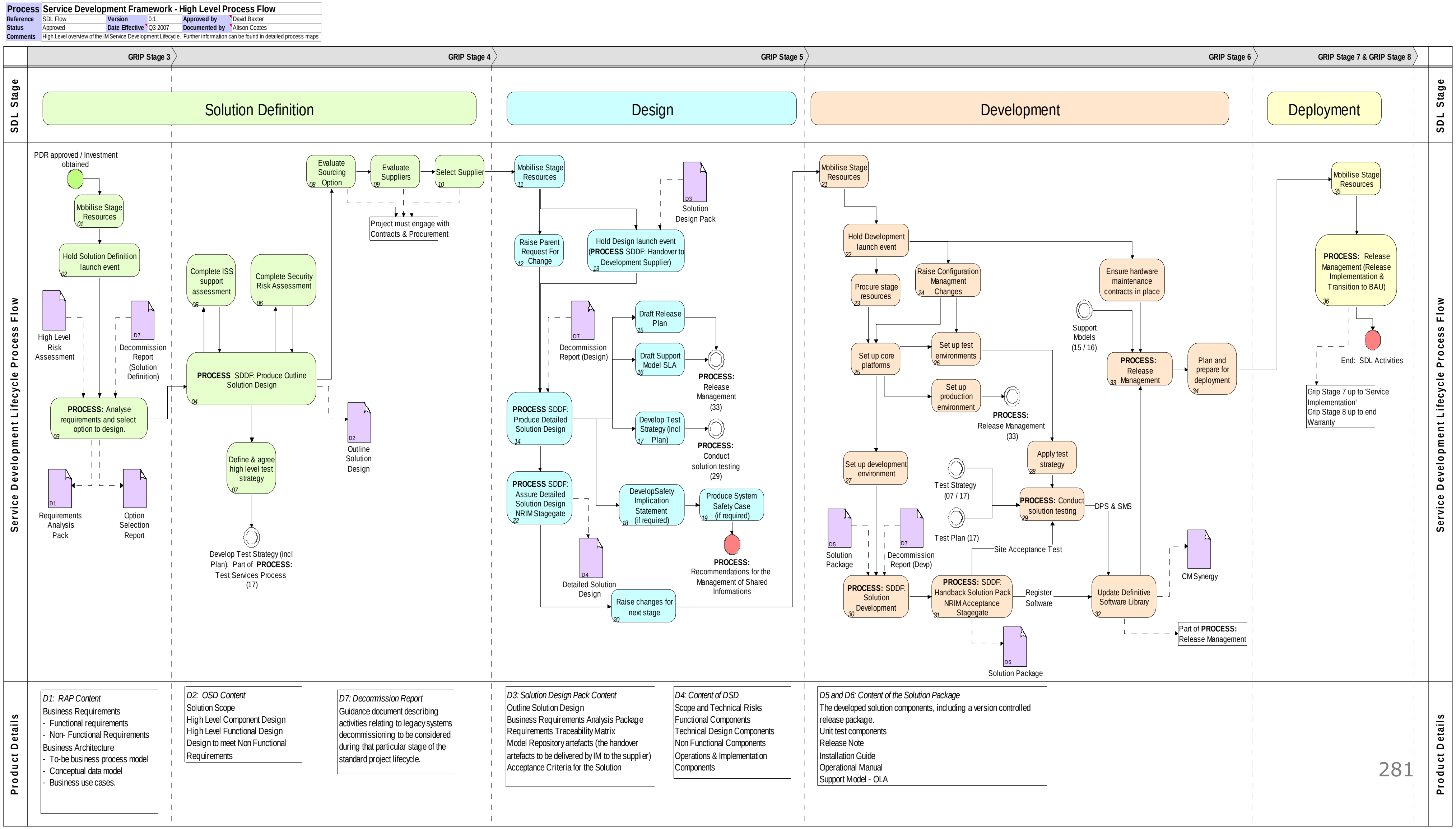
11. Appendices

11.1. Appendix 3.1 – The Service Development Lifecycle (SDL)



11.2. Appendix 3.2 – Applications Matrix (Initial Framework)

Applications Matrix				
Potential Functional Need (main categories)	Sub categories	Detailed items of information	**Source of Information** (where do track workers get the information from?)	Current Form of Information
1- Location				
2-Material and store management				
3- forms				
4- standards and guidelines				
5- Historical asset information				
6- communication				

11.3. Appendix 3.3 – Questions for the semi-structured interviews for the EDARE Framework

Section 1: Information and Functional Requirements

1. Can you please tell me about your job? What do you do on a typical day?
2. What information do you need to do your job?
3. Where do you get the information from?
4. How is the information presented/given to you?
5. Do you use any forms?
6. How do you use the forms? Can you please show me some examples of the forms you use? Can you show me how you use the forms (what information you put in the forms)?
7. What do you look at on the forms? What information do you exactly get from the forms?
8. Do you use any other types of document?
9. What other information do you use to perform your task?
10. Do you need this information on site?
11. Does performing your task depend on having this information on site?

Section 2: General Information

12. Where is your main place of work? ………………………………………………….
13. What gender are you? ☐ Female ☐ Male
14. What is your job title? ………………………………………………………………………
15. How long have you been in your current posting?

☐ Less than 1 year ☐ 1 to 5 years ☐ 6 to 10 years

☐ 11 to 19 years ☐ 20 years or more

16. Do you use a handheld computer to perform your task?

☐ Yes ☐ No

If Yes, for how long have you used the handheld system? ……….

11.4. Appendix 3.4 – Consent form for interviews for the EDARE framework

Dear participant,

Thank you for taking part in this interview. The objective of this research is to understand the information and functional requirements of performing an engineering or maintenance task on the track. In this interview, I will ask you questions about your daily tasks and the information you require to perform theses tasks.

The interview will be tape recorded in order to make any future access to the data easier. Please feel free to let me know if you would not like the interview to be recorded. This information will only be used for the purpose of the research project and therefore anonymity for all respondents and confidentiality of data are assured.

Thank you very much for your help. Please do not hesitate to ask any questions.

Yasamin Dadashi

Human Factors Researcher

Email: epxyd2@nottingham.ac.uk

Mobile: 0786 228 9497

I have read the above and am happy to take part in the study.

Participants Signatures

……………………………………………………………………..

11.5. Appendix 4.1 – Questions for the semi-structured interview for the User Experience Case Studies

1. What do you think about this system?

2. What in your opinion are the main disadvantages of the handheld computer?

3. What in your opinion are the main advantages of the handheld computer?

4. Do you think this system has changed the way you perform your tasks?

5. If you could add any other applications to this handheld computer, what would those applications be?

6. Do you use only a selection of the functions on the handheld computer or all of the functions? For instance have you ever tried to change the colour settings? What applications do you use most often?

7. Do you think the training you received has been enough?

8. Had you used any of the previous handheld computer systems? What do you think about those systems? What problems in your opinion did those systems have?

11.6. Appendix 4.2 - Usability concepts and themes gathered from the literature

Item NO.	Factor	Description	Source
1	portability	Refers to the physical device, e.g., weight, size, grip, etc.	(Pownell and Bailey, 2000)
2	accessibility	Ability for users to get the information they need instantly	(Pownell and Bailey, 2000)
3	mobility	Ability for users for greater movement	(Pownell and Bailey, 2000)
4	adaptability	Ability of user to change his or her behaviour because of the highly mobile technology	(Pownell and Bailey, 2000)
5	Dynamic user configuration	The user will want to collect data whenever and wherever they like, i.e., refers to *mobility*	(Pascoe et al., 2000)
6	Limited attention capacity	Data collection tasks are oriented around observing a subject and depending the nature of the task the user will have to pay various amounts of attention	(Pascoe et al., 2000)
7	High-speed interaction	Ability of entering high volumes of data very quickly and accurately	(Pascoe et al., 2000)
8	Context dependency	The user's activities are intimately associated with their context.	(Pascoe et al., 2000)
9	Effectiveness	The required range of tasks must be accomplished at better than some required level of performance (e.g., in terms of speed and errors) By some required percentage of the specified target range of users Within some required proportion of the range of usage environments	(Shackel, 1991), (ISO-9241-11, 1998)

10	Learnability	Within some specified time from commissioning and start of user training Based upon some specified amount of training and user support And within some specified relearning time each time for intermittent users	(ISO/IEC-9126-1, 2001; Nielsen, 1994; Shackel, 1991)
11	Flexibility	With flexibility allowing adaptation to some specified percentage variation in tasks and/or environments beyond those first specified	(Shackel, 1991)
12	Attitude	Within acceptable levels of human costs in terms of tiredness, discomfort, frustration and personal effort So that satisfaction causes continued and enhanced usage of the system	(Shackel, 1991)
13	Ease of use	Usability dimension	(ISO-9241-11, 1998)
14	Quality in use	Usability dimension	(ISO-9241-11, 1998)
15	Understandability	Usability dimension	(ISO/IEC-9126-1, 2001)
16	Operability	Usability dimension	(ISO/IEC-9126-1, 2001)
17	Attractiveness	Usability dimension	(ISO/IEC-9126-1, 2001)
18	Memorability	Usability dimension	(Nielsen, 1994)
20	Efficiency	Usability dimension	(ISO-9241-11, 1998; Nielsen, 1994)
21	Satisfaction	Usability dimension	(ISO-9241-11, 1998; Nielsen, 1994)
22	Errors	Usability dimension	(Nielsen, 1994)

23 and 24	Ease of learning and use = Learnability, Memorability, limited attention capacity, ease of use	Factors for mobile phone usability questionnaire MPUQ)	Ryu and Smith-Jackson, 2006
25 and 26	Helpfulness and problem solving capabilities = efficiency, effectiveness, quality is use,	Factors for mobile phone usability questionnaire MPUQ)	(Ryu and Smith-Jackson, 2006)
27 and 28	Affective aspect and multimedia properties	Factors for mobile phone usability questionnaire MPUQ)	(Ryu and Smith-Jackson, 2006)
29	Commands and minimal memory load = Learnability, Memorability, limited attention capacity, ease of learning	Factors for mobile phone usability questionnaire MPUQ)	(Ryu and Smith-Jackson, 2006)
30	Typical task for mobile phone	Factors for mobile phone usability questionnaire MPUQ)	(Ryu and Smith-Jackson, 2006)

31	Control	Factors for mobile phone usability questionnaire MPUQ)	(Ryu and Smith-Jackson, 2006)
32	No or little visual attention = limited attention capacity	Requirements of interaction with mobile computers	(Kristoffersen and Ljungberg, 1999b)
32	Structured, tactile input	Requirements of interaction with mobile computers	(Kristoffersen and Ljungberg, 1999b)
33	Use of audio feedback	Requirements of interaction with mobile computers	(Kristoffersen and Ljungberg, 1999b)
34	screen	Factors according to Questionnaire for User Interface Satisfaction - QUIS	(Chin et al., 1988)
35	Terminology and system information	Factors according to Questionnaire for User Interface Satisfaction - QUIS	(Chin et al., 1988)
36	Learning	Factors according to Questionnaire for User Interface Satisfaction - QUIS	(Chin et al., 1988)
37	System capabilities	Factors according to Questionnaire for User Interface Satisfaction - QUIS	(Chin et al., 1988)
38	Overall reaction to software	Factors according to Questionnaire for User Interface Satisfaction - QUIS	(Chin et al., 1988)
39	External interface	User support, accessories, supporting software	(Ketola and Röykkee, 2002)

40	User interface	Input tools, display, audio and voices, ergonomics, detachable parts, communication method, applications	(Ketola and Röykkee, 2002)
41	Service interface	Services (availability, interoperability, utility)	(Ketola and Röykkee, 2002)
42	Stability	As we rely more on technology to hold our valuable data and with the increased need for real time information on the move as consumers we will demand systems that can provide 100% stability and nothing less.	(Szuc, 2002)
43	Simplicity	The ability to access applications and data within literally a few keystrokes. This is especially important when we are on the move.	(Szuc, 2002)
44 and 45	Screen size and colour	With more dependence on applications and improved data input [?] people will demand clearer and larger screens for their mobile devices.	(Szuc, 2002)
46	Dropouts	Devices will have to look at ways to save data or auto save in case of dropouts.	(Szuc, 2002)
47	Switching applications	Easy methods for switching between applications (e.g., voice and data) and mobile platforms that can cope with more than one application being active at the same time.	(Szuc, 2002)
48	Input methods (keyboard tests)	Considering difficulties and issues with stylus, virtual keyboard, etc. Testing the speed of how a person would write an email v expected times using a pc.	(Szuc, 2002)
49	Mobility	Real ability to work on the move. This needs to be tested with users who are on the move and in different contexts to see what real problems they face.	(Szuc, 2002)

50	Voice recognition	A potential input method [?]	(Szuc, 2002)
51	Expected experience and consistency	… With the look and feel of websites and [software] on pc.	(Szuc, 2002)
52	Navigation	Access to applications and functionality in 1 or 2 steps maximum as an acceptable merit?	(Szuc, 2002)
53	Multitasking	The need to move seamlessly between applications is important. Again platform stability is a priority.	(Szuc, 2002)
54	Tough and resilient	PDAs and phones need to become tougher as we start to rely and place more data into these devices.	(Szuc, 2002)
55	Always on	Trusting that the mobile device will never break and will have a clear line to data, etc.	(Szuc, 2002)
56	Provide good guidance	Provide prompts, clues and succinct instructions to help users navigate the system; Clearly group and distinguish related and non-related items so that users are able to understand the relationships between them; Provide immediate and appropriate feedback; Ensure displays are easily readable and understood; Provide appropriate help and documentation.	Guidelines for the design of Railtrack User Interface Displays
57	Optimise user workload	Present the users with only the information they need at the time; Present users with the right information, in the way they want it; Present users with the information or content they want, in the order they want it; Minimise input requirements; Minimise the actions required to accomplish a task	Guidelines for the design of Railtrack User Interface Displays

58	Give the user control	The system should only respond to actions explicitly initiated by the user; The user, not the system, should control the pace of operations and the order in which operations are conducted; Captions should be worded as commands to the system rather than questions to the user; Users should always be able to interrupt or cancel processing operations; Users should be able to "undo" or cancel their actions restoring the system to its previous state; Every possible user action should be anticipated and an appropriate response provided;	Guidelines for the design of Railtrack User Interface Displays
59	Make the system adaptable	Provide flexibility in how tasks can be conducted and allow users to customise the interface to suit their preferred way of working; Provide different methods of working that support the needs of novice and more experienced users; Separate presentation tier coding from underlying system / database architectures.	Guidelines for the design of Railtrack User Interface Displays
60	Handle errors gracefully	Minimise the number of errors that occur and their effects; Provide appropriate error messages; Support effective and efficient user correction.	Guidelines for the design of Railtrack User Interface Displays
61	Keep in consistent		Guidelines for the design of Railtrack User Interface Displays

62	Provide significant and meaningful codes	Take account of conventions and precedents; Ensure the code will work in all contexts in which it is likely to be used; Ensure the coding system supports the tasks for which it will be used; Avoid the use of jargon and fine distinctions; Use codes that support visualisation.	Guidelines for the design of Railtrack User Interface Displays
63	Make the system compatible with user's requirements and expectations	Adhere to appropriate population stereotypes; Design data transferral forms and processes to be compatible with data input and output requirements; Use familiar terminology and language; Attune control actions and interaction processes with those of other systems that the user operates; Organize and structure user interactions; design graphics; and present information to be compatible with the user's view of the task; Follow appropriate user centred processes for deign and evaluation of usable, safe and sufficient human-computer interaction. the summarised information given at the top of the page do not stand out immediately.	Guidelines for the design of Railtrack User Interface Displays
64	Visibility of system status	Usability Heuristics	(Nielsen, 1994)
65	Match between system and real world	Usability Heuristics	(Nielsen, 1994)
66 and 67	User control and freedom	Usability Heuristics	(Nielsen, 1994)
68 and 69	Consistency and standards	Usability Heuristics	(Nielsen, 1994)

70	Error prevention	Usability Heuristics	(Nielsen, 1994)
71	Recognition rather than recall	Usability Heuristics	(Nielsen, 1994)
72	Flexibility and efficiency of use	Usability Heuristics	(Nielsen, 1994)

11.7. Appendix 4.3 – Card Sorting Protocol

Development of the Handheld Computer Usability Questionnaire

Dear Participant,

As part of my evaluative case study, I am developing a questionnaire for evaluating handheld computers. The objective of this study is to generate a set of factors that best address usability issues of interacting with a handheld computer in rail industry.

You have been provided with 73 cards which contain usability concepts derived from literature. Please follow the instructions:

Read each card carefully and try to group the similar concepts together;

Label each group with a meaningful name that best describes the concepts you have grouped together and write this title on the envelopes provided;

Rank the concepts in each group based on their importance and relevance to the title you have chosen for the group;

Compare each factor with the usability definition and characteristics of handheld computers (see page 2) and decide if each factor is a representative measurement. Record your results in the table provided;

Add any other relevant factors that describe the interaction issues of a handheld computer.

Thank you very much for your participation.

Yasamin Dadashi

Table 11-1 - the specification of the target construct for the questionnaire development

product	**Component**	**Scope of usability**
Conventional and purpose-built handheld computers	User interface	ISO 9241 – 11 definition Characteristics of handheld computers

Definition of usability (ISO 9241 – 11, 1998):

"The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use."

Four characteristics of handheld computers (Pownell and Bailey, 2000):

Portability refers to the physical device.

Accessibility refers to the ability for users to get the information they need instantly.

Mobility refers to the user who has the ability for greater movement and is not tethered to one place.

Adaptability refers to the ability of the user to change his or her behaviour because of this highly mobile technology. Handheld computers are not only an extension of the Internet and the desktop computer but also an extension of the person and his or her information environment.

11.8. Appendix 4.4 – Handheld Computer Usability Questionnaire

Dear participant,

This questionnaire aims at gathering information about the usability and interaction issues of the handheld computers.

This information will only be used for the purpose of the research project and therefore anonymity for all respondents and confidentiality of data are assured.

Please take your time, read each question carefully and answer the best you can. Please hand the completed questionnaire to Yasamin Dadashi.

Thank you for your time.

Yasamin Dadashi

Human Factors Researcher

Email: yasamin.dadashi@networkrail.co.uk

Section 1: Introductory Details

1. Where is your main place of work? …………………………………………………….

2. What gender are you? ☐ Female ☐ Male

3. Please indicate your age group:

☐ Under 25 ☐ 25 to 34 ☐ 35 to 44 ☐ 45 to 55 ☐ Over 56

4. What is your job title? ……………………………………………………………………

5. How long have you been in your current posting?

☐ Less than 1 year ☐ 1 to 5 years ☐ 6 to 10 years

☐ 11 to 19 years ☐ 20 years or more

6. How long have you been using this handheld computer system? …………………………………………………………………………..………………….

7. Have you used any of the previous handheld computer systems?

☐ Yes ☐ No

If Yes, for how long have you used the previous handheld system? …………………………………………………………………………………………………….

8. How much training have you received for using this handheld computer system? ………………………………………………………………………….

9. Do you have any supporting documentation, for example guides, training notes, own notes, etc.?

Section 2 – User Interface

2.1- Please rate to what extent you agree or disagree with the following statements.

If a statement is not relevant to the handheld system you use, please circle the not applicable (NA) box.

Factor	Statements	strongly disagree	disagree	neutral	agree	strongly agree	not applicable
Ease of Use	1.1- The handheld computer helps me to perform my tasks.	1	2	3	4	5	NA
	1.2- It is easy to learn how to use the handheld computer.	1	2	3	4	5	NA
	1.3- It is easy to remember and navigate through the menus.	1	2	3	4	5	NA
	1.4- Paper based forms and the handheld computer support are well integrated.	1	2	3	4	5	NA
	1.5- It is easy to use the handheld computer.	1	2	3	4	5	NA
	1.6- I can access the information and applications I need quickly.	1	2	3	4	5	NA

User Interface	2.1- The user interface of the handheld computer is clear and understandable.	1	2	3	4	5	NA
	2.2- The information on the handheld interface is organised so that it is easy to find any application.	1	2	3	4	5	NA
	2.3- It is easy to input text and information into the handheld computer.	1	2	3	4	5	NA
	2.4- The pictures on the handheld computer screen are of good size and quality.	1	2	3	4	5	NA
Portability	3.1- The handheld computer allows me more freedom to move around on site.	1	2	3	4	5	NA
	3.2- I can successfully perform the task on site using the handheld computer.	1	2	3	4	5	NA
	3.3- The handheld computer is usable in all weather conditions.	1	2	3	4	5	NA
	3.4- The handheld computer is usable in all light conditions.	1	2	3	4	5	NA
	3.5- Using the handheld computer I am able to perform my tasks wherever and whenever necessary.	1	2	3	4	5	NA

	3.6- The handheld computer size is convenient for transportation.	1	2	3	4	5	N A
	3.7- The handheld computer is tough and would not break easily.	1	2	3	4	5	N A
Consistency and relevancy to task	4.1- The handheld computer is similar to other handheld and PC based systems I have used.	1	2	3	4	5	N A
	4.2- The format of all data entry fields is consistent.	1	2	3	4	5	N A
	4.3- The words used within the handheld computer are consistent and understandable.	1	2	3	4	5	N A
	4.4- The words used within the handheld computer are similar to those in other handheld and PC based systems.	1	2	3	4	5	N A
	4.5- The words used are usually related to the task I am doing.	1	2	3	4	5	N A
	4.6- Design of icons and icon labels are usually related to the task I am doing.	1	2	3	4	5	N A
Feedback	5.1- The handheld computer provides immediate and appropriate feedback.	1	2	3	4	5	N A

	5.2- The handheld computer gives me information about the percentage of the task completed.	1	2	3	4	5	N A
	5.3- The handheld computer always informs me about where I am in the menus.	1	2	3	4	5	N A
	5.4- Highlighting the selected menu options on the handheld screen is useful.	1	2	3	4	5	N A
Productivity	6.1- The handheld computer usually provides correct default values.	1	2	3	4	5	N A
	6.2- Using the handheld computer I am able to perform my tasks effectively and quickly.	1	2	3	4	5	N A
	6.3- The amount of information displayed on the handheld screen is adequate.	1	2	3	4	5	N A
Adaptability	7.1- Using the handheld computer I can perform my tasks flexibly.	1	2	3	4	5	N A
	7.2- I can customise the handheld interface to match my preferred way of working.	1	2	3	4	5	N A

Affective Design	8.1- I like using the handheld computer.	1	2	3	4	5	N A
Technology	9.1- The handheld computer is reliable.	1	2	3	4	5	N A
	9.2- The handheld computer is fast enough.	1	2	3	4	5	N A
Workload	10.1- Only the information I need at the time is presented to me on the handheld screen.	1	2	3	4	5	N A
Errors	11.1- It is easy to correct any mistakes on the handheld computer.	1	2	3	4	5	N A
	11.2- The error messages are appropriate and helpful.	1	2	3	4	5	N A
	11.3- There are messages aimed at preventing me from making any mistakes.	1	2	3	4	5	N A
Help	12.1- The help information given by the handheld computer is useful.	1	2	3	4	5	N A
	12.2- The manual provided is clear and easy to understand.	1	2	3	4	5	N A

	12.3- The training that I have received has equipped me with the necessary skills to use the handheld computer.	1	2	3	4	5	N A

2.2- Are there any important issues about the handheld computer user interface that you would like to comment on?

……

……

……

……

………………………………………………………………………………………………

Thank you very much for taking time to answer the questions. Your contribution is greatly appreciated

11.9. Appendix 5.1 Consent form for Experiment I

Dear participant,

Thank you for taking part in this experiment. The procedure for these sections is explained here.

This prototype interface has been designed to test the differences between presenting rail specific spatial information on handheld computers and paper-based documents. The interfaces present the following information: 1- track layout; 2- line direction; 3- line speed; 4- platform and platform number; 5- location name; 6- mileage; and 7- signal numbers.

You will be asked to perform a short task which involves finding a location on the screen. You will be timed for performing this task. You will also be asked to use to information provided to you and guide your colleague to a specific location. Your conversations for this section of the experiment will be tape recorded. Please feel free to let me know if you would not like the conversation to be recorded.

You will be given enough time to familiarise yourself with the device before starting the tasks. This experiment should not take more than 30 to 45 minutes in total.

The information gathered in this experiment will only be used for the purpose of the research project and therefore anonymity for all respondents and confidentiality of data are assured. Thank you very much for your help. Please do not hesitate to ask any questions.

Yasamin Dadashi

Human Factors Researcher

Email: epxyd2@nottingham.ac.uk - Mobile: 0786 228 9497

I have read the above and am happy to take part in the study.

Participant's Signature

11.10. Appendix 5.2– Questions for the semi-structured interview for Experiment I

Now that you have performed both tasks, I would like to ask a few more questions.

1. What do you generally think about this system? [a general question to open the discussion]

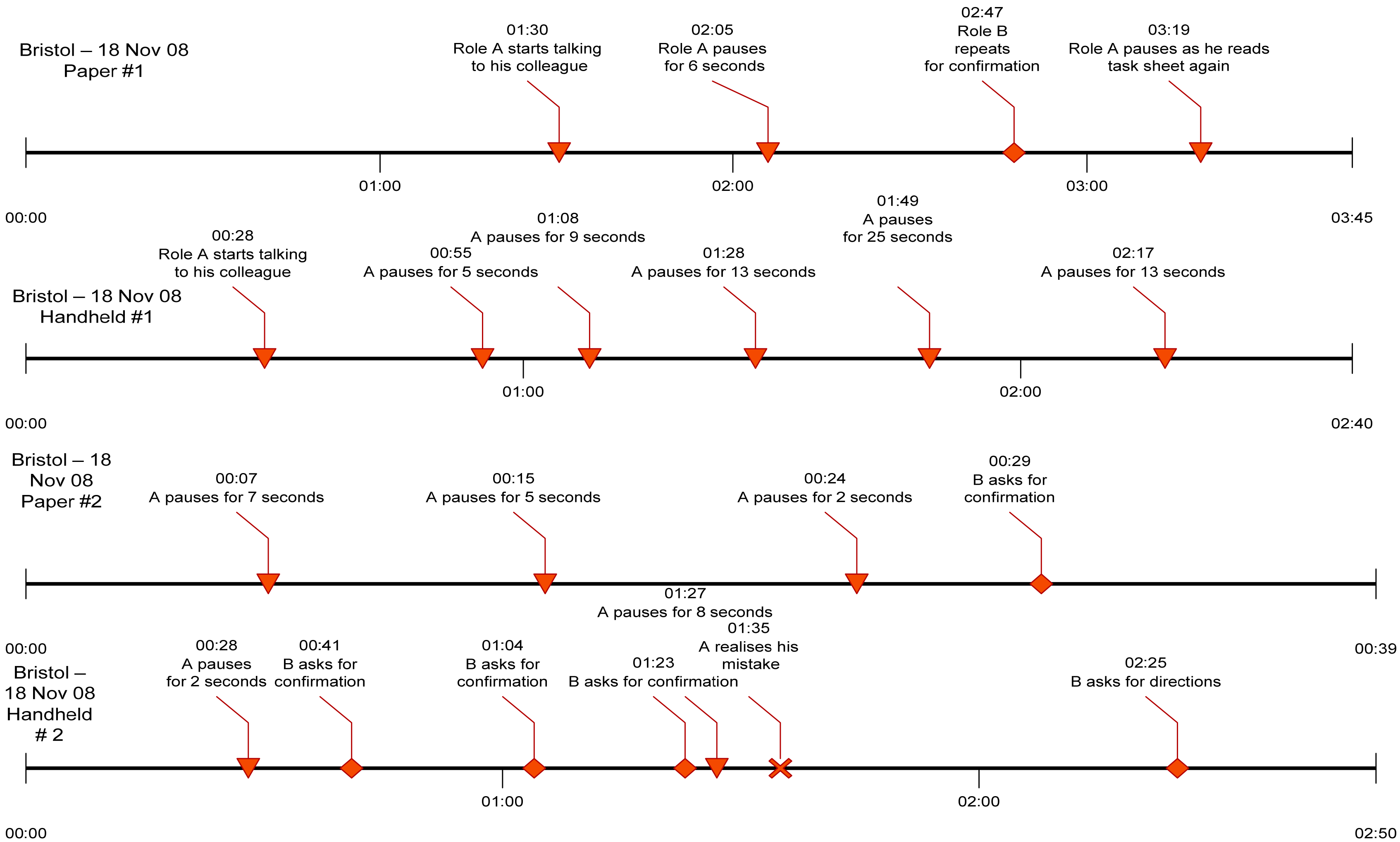
2. What, in your opinion, are the advantages of such a system for track workers? [to get a general point of view]

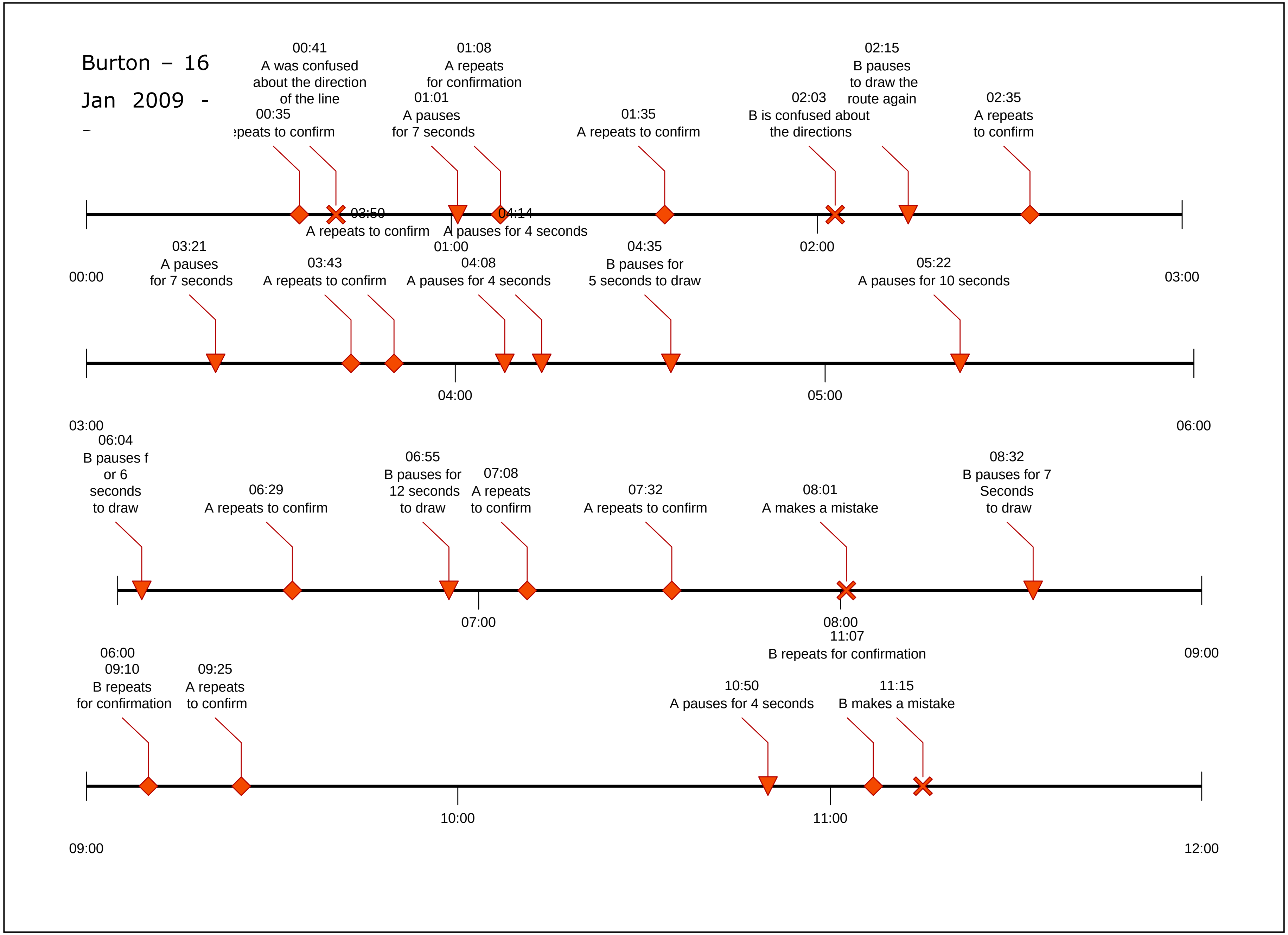
3. What, in your opinion, are the disadvantages of such a system for track workers? [to get a general point of view]

4. Which is your most preferred interaction style? Please explain your reasons.

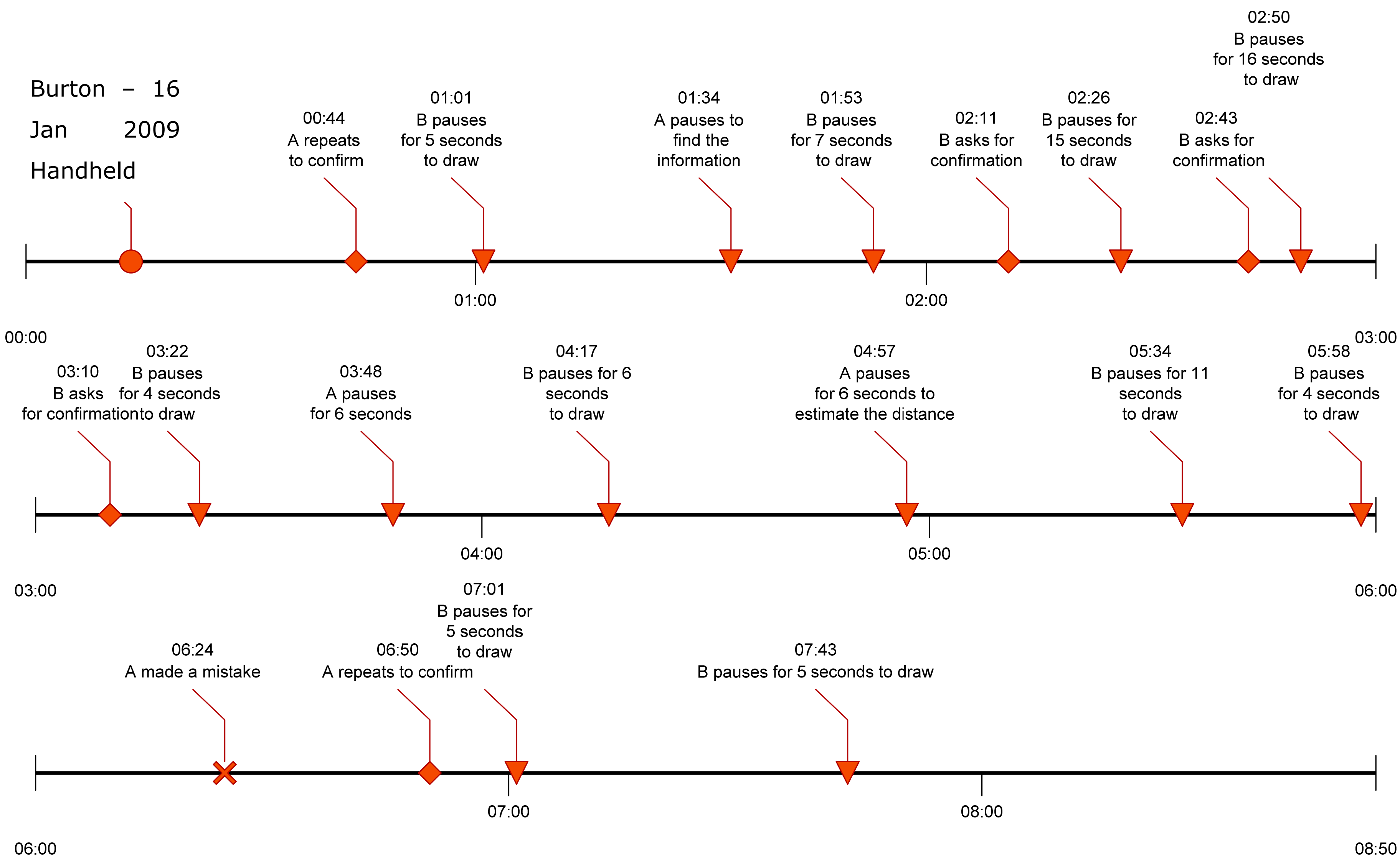
5. What other applications do you think this device could be used for?

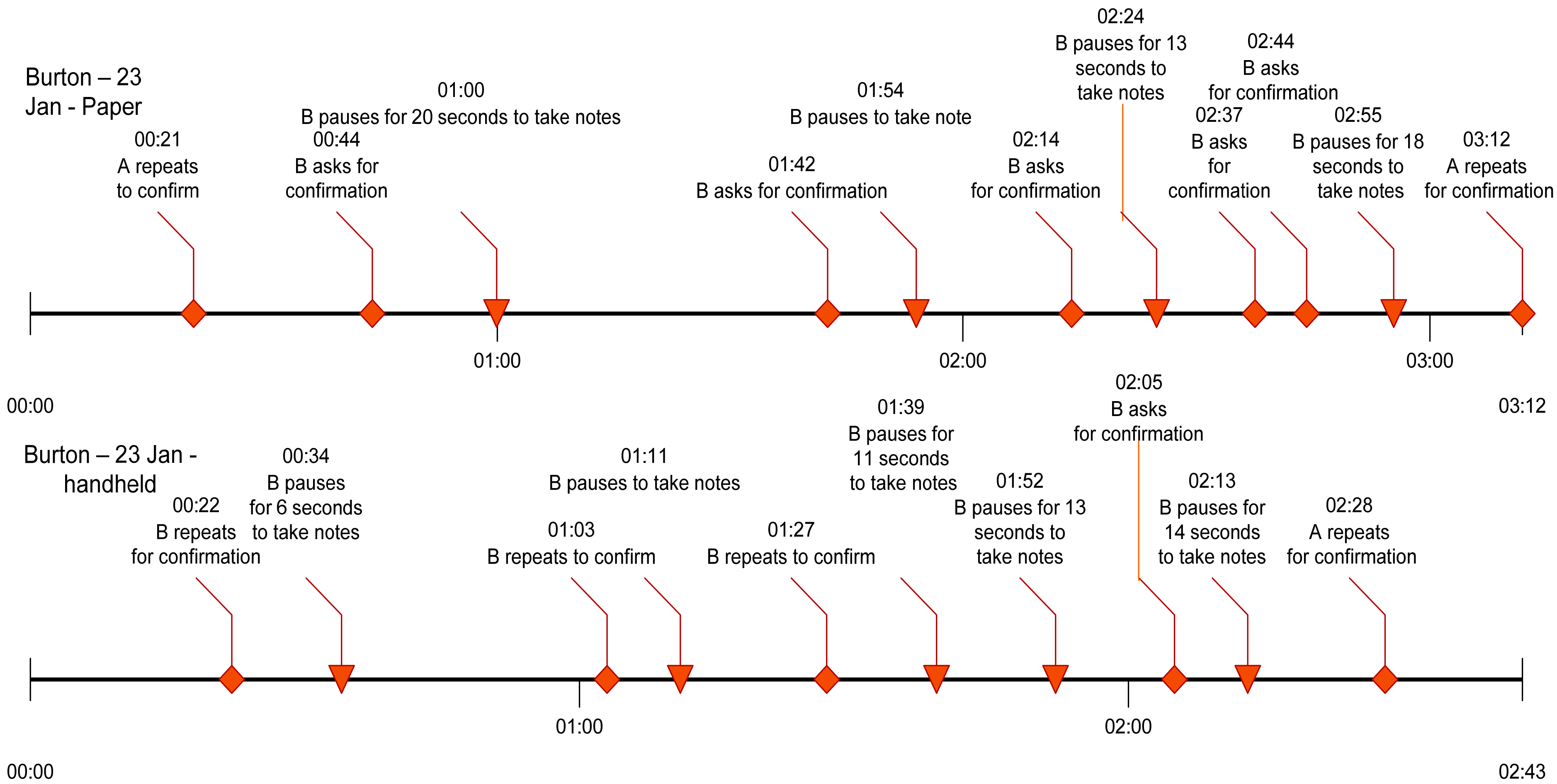
11.11. Appendix 5.3 – Conversation Timelines – Experiment I





Burton – 16 Jan 2009 – –
00:41 A was confused about the direction of the line
00:35 repeats to confirm
01:08 A repeats for confirmation
01:01 A pauses for 7 seconds
01:35 A repeats to confirm
02:03 B is confused about the directions
02:15 B pauses to draw the route again
02:35 A repeats to confirm
03:50 A repeats to confirm
04:14 A pauses for 4 seconds
00:00
01:00
02:00
03:00
03:21 A pauses for 7 seconds
03:43 A repeats to confirm
04:08 A pauses for 4 seconds
04:35 B pauses for 5 seconds to draw
05:22 A pauses for 10 seconds
03:00
04:00
05:00
06:00
06:04 B pauses f or 6 seconds to draw
06:29 A repeats to confirm
06:55 B pauses for 12 seconds to draw
07:08 A repeats to confirm
07:32 A repeats to confirm
08:01 A makes a mistake
08:32 B pauses for 7 Seconds to draw
06:00
07:00
08:00
09:00
11:07 B repeats for confirmation
09:10 B repeats for confirmation
09:25 A repeats to confirm
10:50 A pauses for 4 seconds
11:15 B makes a mistake
09:00
10:00
11:00
12:00


Burton – 16
Jan 2009
Handheld
00:44
A repeats
to confirm
01:01
B pauses
for 5 seconds
to draw
01:34
A pauses to
find the
information
01:53
B pauses
for 7 seconds
to draw
02:11
B asks for
confirmation
02:26
B pauses for
15 seconds
to draw
02:43
B asks for
confirmation
02:50
B pauses
for 16 seconds
to draw
01:00
02:00
00:00
03:00
03:10
B asks
for confirmation
03:22
B pauses
for 4 seconds
to draw
03:48
A pauses
for 6 seconds
04:17
B pauses for 6
seconds
to draw
04:57
A pauses
for 6 seconds to
estimate the distance
05:34
B pauses for 11
seconds
to draw
05:58
B pauses
for 4 seconds
to draw
04:00
05:00
03:00
06:00
06:24
A made a mistake
06:50
A repeats to confirm
07:01
B pauses for
5 seconds
to draw
07:43
B pauses for 5 seconds to draw
07:00
08:00
06:00
08:50


Burton – 23 Jan - Paper
00:21
A repeats to confirm
00:44
B asks for confirmation
01:00
B pauses for 20 seconds to take notes
01:42
B asks for confirmation
01:54
B pauses to take note
02:14
B asks for confirmation
02:24
B pauses for 13 seconds to take notes
02:37
B asks for confirmation
02:44
B asks for confirmation
02:55
B pauses for 18 seconds to take notes
03:12
A repeats for confirmation
00:00
01:00
02:00
03:00
03:12
Burton – 23 Jan - handheld
00:22
B repeats for confirmation
00:34
B pauses for 6 seconds to take notes
01:03
B repeats to confirm
01:11
B pauses to take notes
01:27
B repeats to confirm
01:39
B pauses for 11 seconds to take notes
01:52
B pauses for 13 seconds to take notes
02:05
B asks for confirmation
02:13
B pauses for 14 seconds to take notes
02:28
A repeats for confirmation
00:00
01:00
02:00
02:43

11.12. Appendix 6.1 – Consent form for Experiment II

Dear participant,

Thank you for taking part in this experiment. The procedure for this experiment is explained in this document.

This prototype system has been designed to test methods of presenting track diagrams and local information on handheld computers. The interfaces present the following information: 1- track layout; 2- line direction; 3- line speed; 4- platform and platform number; 5- location name; 6- mileage; and 7- signal numbers.

You will be asked to perform two short tasks. After performing these tasks, I will ask a few more questions about your experience. You will be given enough time to familiarise yourself with the device before starting the tasks. This experiment should not take more than 45 minutes in total.

The interview will be tape recorded in order to make any future access to the data easier. Please feel free to let me know if you would not like the interview to be recorded. This information will only be used for the purpose of the research project and therefore anonymity for all respondents and confidentiality of data are assured.

Thank you very much for your help. Please do not hesitate to ask any questions.

Yasamin Dadashi

Human Factors Researcher

Email: epxyd2@nottingham.ac.uk

Mobile: 0786 228 9497

I have read the above and am happy to take part in the study.

Participant’s signature …………………………………………………………..

11.13. Appendix 7.1 – Consent form for Experiment III

Dear participant,

Thank you for taking part in this experiment. The procedure for these sections is explained here.

This experiment will test the relationship between presenting different lengths of track and various amount of information on the screen. A set of interfaces will be displayed each containing different combinations of length of track and amount of information. You will be asked to find a specific location on the screen and you will be times for this task.

You will be given enough time to familiarise yourself with the device before starting the tasks. This experiment should not take more than 45 minutes in total.

The information gathered in this experiment will only be used for the purpose of the research project and therefore anonymity for all respondents and confidentiality of data are assured.

Thank you very much for your help. Please do not hesitate to ask any questions.

Yasamin Dadashi

Human Factors Researcher

Email: epxyd2@nottingham.ac.uk - Mobile: 0786 228 9497

I have read the above and am happy to take part in the study.

Participant's signature ……………………………………………………………..

11.14. Appendix 7.2 – Consent form for Experiment IV

Dear participant,

This experiment will test the relationship between presenting different types of information and various amount of information on the screen. A set of interfaces will be displayed each containing different combinations of length of track and amount of information. You will be asked to find a specific location on the screen and you will be times for this task.

You will be given enough time to familiarise yourself with the device before starting the tasks. This experiment should not take more than 45 minutes in total.

The information gathered in this experiment will only be used for the purpose of the research project and therefore <u>anonymity for all respondents and confidentiality of data are assured</u>.

Thank you very much for your help. Please do not hesitate to ask any questions.

Yasamin Dadashi

Human Factors Researcher

Email: epxyd2@nottingham.ac.uk - Mobile: 0786 228 9497

I have read the above and am happy to take part in the study.

Participant's signature …………………………………………………………..