USING COGNITIVE ARTEFACTS TO AID DECISION-MAKING IN RAILWAY SIGNALLING OPERATIONS

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ABSTRACT

This thesis presents work undertaken in conjunction with Network Rail in the area of planning and re-planning in railway environments. It aimed to study a real world signalling environment in order to understand the strategies signallers use when re-planning and how decision tools can be designed and integrated into existing signalling environments to support proactive planning. As Network Rail moves into the future and considers the consequences of minimising many hundred signal boxes down to a small number of centres, new systems and automation play a large part. As new centres are introduced, the impact of such systems in terms of forward planning, decision making and workload need to be considered. By studying artefacts already in use in the railway industry today, and how these affect the strategies signallers use when making decisions and planning, the impact of new artefacts can begin to be understood.

This research study was carried out in a real-world environment and the research methods used were adapted to suit the environment. The main research focused on two case studies: The graphical "Docker" tool developed by signallers to assist in managing station areas; and the rollout and uptake of "Train Graph", a graphical time based planning tool. The first part of the first case study consisted of interviews and observations investigating how signallers currently plan (specifically in and around station areas) and what existing tools and artefacts are used and how these influence the strategies. The main findings of this part of the case study was that signallers who were using a graphical based tool to assist in managing station areas were able to create plans and manage disruption more easily than signallers using a list based tool. These findings then fed into the design of a new electronic tool that could be used to manage station areas, for which subject matter experts and focus groups were used to develop the requirements.

The second part to the first case study involved a lab based experiment to compare the effectiveness of three different types of tool when re-planning in station areas. The experiment used participants with no previous signalling knowledge in order to fully identify the effects of each tool without the input of knowledge and experience. The experiment demonstrated that participants using the electronic tool with automation manage the station area more efficiently than those using the list representation. However participants using the list based representation had a better overall understanding of the task.

The second case study investigated an existing electronic tool called the Train Graph that had already been implemented on one area of the railway. Interviews, observations and questionnaires were used to gather data on the opinions and general uptake of the Train Graph. An existing, well established Technology Acceptance Model was extended so that it considered the safety critical nature of railway signalling operations. This found experience and prior knowledge to be a vital component when signallers are assessing whether they find the tool relevant their job and whether it will be advantageous to them. Trust was also found to be an important input into whether users perceive the new tool as being useful or easy to use. This subsequently was a significant driver of end user behaviour and uptake of the technology.

One key output of this research was a tangible framework that can be used by Network Rail to guide design and implementation of future decision support tools and artefacts. The framework considers the artefact design and various inputs including task characteristics and organisational context as an indicator of performance. If used at an early stage of product development the framework and associated guidelines can be used to influence system design and establish how key implementation considerations impact upon user uptake and trust of the design.

List of Publications

Anderson-Palmer, R., Wilson, J.R., Sharples, S., & Clarke, T. (2010). The use of artefacts for the management of train movements in station areas. Paper presented at the International Control-room Design Conference, Paris, France, October 2010.

Anderson-Palmer, R., Balfe, N., Wilson, J.R., Sharples, S., & Clarke, T. (2011). User Trust and acceptance of real time rail planning tools. Paper presented at the Human Factors and Ergonomics Society Europe Conference, Leeds, UK, October 2011.

Anderson-Palmer, R., Balfe, N., Wilson, J.R., Sharples, S., & Clarke, T. (2012). Active planning requires appropriate graphical support tools: the case of scheduling trains at stations. Paper presented at the 4th International Conference on Applied Ergonomics and Human Factors, San Francisco, USA, July 2012.

Charles, R., Balfe, N., Wilson, J.R., Sharples, S., & Carey, M. (2013). Using graphical support tools to encourage active planning at stations. Rail Human Factors: Supporting Reliability, Safety and Cost Reduction, Publisher: Taylor & Francis, Editors: Nastaran Dadashi, A. Scott, J.R. Wilson, A. Mills, pp.427-434

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John - I think a little bit of your confidence might have finally rubbed off; and there isn’t a Dictaphone in sight...!

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GLOSSARY

AB	Absolute Block – a method of signalling control
ARS	Automatic Route Setting
ASWAT	Adapted Subjective Workload Assessment Technique
CBI	Computer Based Interlocking – a signalling safety system
CCF	Control Centre of the Future – a system giving information on train delays
CIS	Customer Information Service
CCTV	Closed Circuit Television
CSR	Cab Secure Radio – a radio system between signallers and train drivers
CTRL	Channel Tunnel Rail Link – railway linking the UK to Europe
ECRO	Electrical Control Room Operator – a job role responsible for controlling electrical power to the railway
DOS	Disk Operating System
EPSRC	Engineering and Physical Sciences Research Council
FCFS	First Come First Serve – a method of signalling control
FOC	Freight Operating Company
GP Screen	General Purpose screen – an ARS display giving information on alarms and train paths
ICT	Information and Communication Technology
IECC	Integrated Electronic Control Centre – a type of signalling system
IWS	Integrated Workload Scale – a signalling workload measurement tool
LOA	Level of Automation
LOM	Local Operations Manager – a job role responsible for managing signal boxes
MOM	Mobile Operations Manager – a job role responsible for trackside management of incidents on the railway
NX	eNtry-eXit Panel – a type of signalling system
OCS	One Common Switch – a type of signalling system
ODEC	Operational Demand Evaluation Checklist – a signalling workload measurement tool
OLE	Overhead Line Equipment – a method of delivering electrical power to trains
ORR	Office of Rail Regulation
PICOP	Person In Charge Of Possession – a job role responsible for managing engineering and maintenance work on the railway
PPM	Public Performance Measure – a railway performance measure
RRI	Route Relay Interlocking – a signalling safety system
RSSB	Railway Safety and Standards Board
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
SART	Situation Awareness Rating Technique
SD	Standard Deviation
SME	Subject Matter Expert
SPAD	Signal Passed At Danger
SPAM	Situation Present Assessment Measure
SPT	Signal Post Telephones
SSI	Solid State Interlocking – a signalling safety system
SSM	Shift Signalling Manager
STP	Special Timing Pattern – a control mechanism within ARS
SWAT	Subjective Workload Assessment Technique
T12	Form of protection for track workers
T2	Form of protection for track workers
T3	Possession of the line by track workers
TC	Track Circuit
TCB	Track Circuit Block – a method of signalling control
TD	Train Describer – unique identifier for trains

TOC	Train Operating Company
TOPS	Total Operating Processing System – a system giving information on train movements
TORR	Train Operated Route Release – a signalling support system
TRB	Train Record Book – a manual recording system
TRC	Train Running Controller
TRUST	Train Running System on TOPS – a system giving information on train movements and delays
TSDB	Timetable Services Database – a system holding the railway timetable
TTO	Timetable Order - a method of signalling control
TTP	Timetable Processor – a method of changing train timetables in ARS
UK	United Kingdom
VDU	Visual Display Unit
VSTP	Very Short Term Plan
WON	Weekly Operating Notice – a publication giving details of planned railway operations

1. INTRODUCTION

This thesis describes research carried out in conjunction with Network Rail in the area of planning (for future events) and re-planning (reacting to events) in railway environments and the use of tools to aid the user with this task. Every day, signallers make critical decisions on how to operate and manage the rail network that have significant impact on the train service as a whole. This in itself is a complex cognitive task for the signaller to manage and it is done so with the aid of a variety of paper-based and electronic tools. The research presented here studies how this process is carried out with a special focus on the use of planning tools and their development. This is all placed in the context of the current modernisation plans for signalling and the proposed increases in capacity and reliability required for the future of the railway network.

Focusing on two real world case studies, the research takes a mixed method, real world research approach to develop hypotheses. These are derived from qualitative data collected within these case studies based on existing theories and methods and the larger experience within Network Rail. This in turn led to a controlled experiment and the application of structured quantitative methods to establish the effectiveness and usage of tools to aid planning and their acceptance by users. The goal in this thesis is to bring together this research to provide recommendations to Network Rail on the development of planning tools as the modernisation of signalling is implemented.

This research fits into the wider field of cognitive ergonomics, as the research shown here is an example of a cognitive ergonomics challenge in designing systems that can effectively support cognitive tasks, carried out in a safety critical environment. It will also contribute to an understanding (and suggest methodological approaches) of how to carry out cognitive research within rail environments. The railway industry provides many cognitive ergonomics challenges and is a rich source of research.

The majority of the research presented in this thesis was carried out in the real world environment of an operating railway network. It is useful to provide a brief history and background of the signalling environment before proceeding to the research motivation, research aims and objectives and an outline of the research methodology.

1.1 Signalling environment

The main goal of the signalling task is to maintain a safe and efficient running of the railway. The signaller does this by maintaining a safe distance between trains and managing any problems as they occur. Signalling as we know it today first appeared as a concept in 1841, when the first semaphore signal was erected by the South Eastern Railway. The main principle behind signalling is that a train is not allowed to enter a section of railway until the train before it has left. By dividing the track into blocks (sections of track) a higher level of safety was able to be achieved. This marked the birth of absolute block signalling and by the second half of the 19th century the absolute block system was installed throughout Britain. The principle is still used today.

The process of maintaining a safe distance between the trains by managing disruption and conflicts is known as regulating. It can be summarised as utilising the infrastructure in order to optimise the train service.

Lever frame signal boxes operate a small section of railway via mechanical levers. These boxes communicate with each other via a simple bell ringing system which uses a code to make signallers aware of whether or not there is a train in the preceding or proceeding section of track. Lever operation was the only way to remotely signal trains until the 1950s when NX (eNtry and eXit) technology was developed. Instead of the signaller moving the points manually with levers attached to the points by cables, the NX panels allowed trains to be signalled using button presses. Later, VDU (Visible Display Unit) technology in IECCs (Integrated Electronic Control Centres) was introduced. These use the same principle as the NX panel, but are computer based and incorporate a much higher level of automation, including ARS (Automatic Route Setting). As a result, it is important to understand the effects that this change will have on the decision-making, planning and re-planning that the signaller currently carries out.

Generally the signallers work to a predetermined timetable which is developed by a team of timetable planners to make most efficient use of the track and the platforms at any one time. All signallers have access to current timetable information via an electronic system called TRUST (Train Running System). TRUST details every train in the timetable and signallers can look up specific attributes such as what route the train is on, where it has been, and what its maintenance schedule is. Signallers also increasingly have access to CCF (Control Centre of the Future) which provides real-time information regarding train running. CCF uses an overview display similar to those seen on IECC systems that displays a track layout and all the trains. The trains are then colour-coded depending on whether they are on time or running late. This colour-coding allows the signallers to be able to determine the state of the railway at a glance.

In addition to electronic information, signallers are also required to process paper-based and verbal communication in order to manage the railway. Every signaller has access to a paper simplifier which will detail all of the trains running through their area that day. Typically they have a different simplifier for weekday and weekend running. This simplifier will contain all of the information about the train plus route specific information. Signallers use the simplifier to identify the route of the train and to set the route for that train. In some complex stations, they may also have access to a similar paper format which may be called a “Docker” or an arrivals and departures book. This will detail all of the trains in arrival order that are due to go into the station that day. As well as this static information, the signallers will receive up-to-date information from various third parties such as the Train Operating Companies (TOCs), train drivers and other signallers. This may not only be up-to-date information about the state of the railway such as the train driver calling in to report a track defect, but may also be additional requests such as a TOC calling up to request a route for an extra service. Another large part of the signaller’s job is to grant track access for maintenance work: however this is not covered within this research. Chapter 2 provides a more thorough description of signalling operations.

Station areas are one particular area that require frequent intervention from the signaller to maintain the smooth running of the railway and as a result provide key pinch points in the regulation of the network as a whole. Stations can vary in complexity from very simple (two lines and two platforms), to very complex which could be around 20 lines (some bi-directional) with a mixture of terminus and through platforms. Terminus platforms are platforms that only have one way in and out. The drivers will change ends and leave the platform the same way that they arrived. Through platforms are generally used en route, so trains will be stopped for a few minutes and then the driver will then continue the journey in the same direction. Terminus platforms are most commonly used to terminate services. A train (the physical rolling stock) will come in assigned to one head code (a unique identifier) which indicates what train service is assigned to that rolling stock, and will leave assigned to another head code, i.e. a new train service. This signalling task not only involves ensuring that the train can get in and out of the platform without obstruction (more than one service may be ‘stacked’ in the same platform) but may also involve the coordination of train crew, drivers and passengers.

When the railway is running to plan the signaller’s workload should be fairly manageable as they will mainly be setting routes and monitoring. The signaller’s demands increase considerably when there is disruption. Disruption can be anything from a late running train to a fatality and will involve the signaller re-planning to some degree. A considerable amount of workload in station areas, specifically terminus platforms, can arise from late running trains. Due to the nature of the operation of terminus platforms any deviation from the timetable could potentially impact other services.

Increasingly, trains are being signalled using automated systems such as Automatic Route Setting (ARS) which automatically sets routes for trains using information held in a central timetable database requiring no signaller intervention to run. ARS operates using an algorithm that regulates trains based on their lateness. The signaller often finds ARS difficult to work within the station area due to the complexity of the station area and the number of options available. This makes it difficult for the signaller to predict the regulating decisions ARS may make in a station area. The signaller can manually override ARS for an individual train or a particular area or set of train routes (called an ARS subarea). In some complex station areas, where ARS is used on the route, ARS is often not used in station areas. This is due to the problems that can arise from the predictability issue, so the signaller maintains greater control over the station area by manually signalling trains.

1.2 Research Motivation

Currently, the rail network is controlled by signallers placed in over 800 signal boxes around the country. This ranges from mechanical lever boxes controlling a short section of the railway (of the order of tens of miles) to IECCs controlling much larger sections of railway (of the order of hundreds of miles) using computer systems and technology to interact with the signals as described above. The main difference between these two extremes is the visibility of the rest of the network (in terms of what the staff know about what is happening on the rest of the network) and the proximity of other signallers. In an IECC, there are many signallers working together in the same space controlling larger sections of railway by VDU based systems (Figure 1).

Figure 1 - A typical IECC interior

When the signaller is controlling their section of railway, their main goal is to keep the railway running to timetable and to resolve any problems as quickly and efficiently as possible. In order to do this effectively they must consider the impact of their decisions on both a local and a national level. Having access to the correct information at the right time and in the right format is therefore vital. Many different tools and decision aids are currently used by the signallers to assist when making decisions and planning around abnormal events. The type, format and delivery of this information can impact upon the decisions signallers are able to make.

The station area is key when making these regulating decisions as it is one location where there is the opportunity to get extra staff, swap staff, or move passengers to alternative trains. The station area can be used to halt trains, swap trains, or carry out repairs on trains that have failed. For these reasons, the station area specifically is the focus for this research. Stations can vary considerably in size, complexity and capacity. These factors and many others can influence the signallers' ability to make changes, plan and reorganise the train service during disruption. Currently, issues such as late running services, cancelled trains and track closures are dealt with largely on a reactive basis, dealing with problems as and when they occur. Despite these issues and strategies being apparent for many years, there has been little research approaching this problem in a holistic manner, specific to the rail domain exploring the strategies, decisions, and artefacts that signallers utilise when re-planning in station areas. There have been some good studies approaching scheduling in station areas in a very technical manner, applying algorithms to improve scheduling (Carey and Carville (2003), Carey and Crawford (2007)) and some thorough analysis of the signalling task (Roth et al., 2001). However, there appears to be a gap in the literature regarding short term planning in rail and the use of cognitive artefacts to aid decision making. This thesis aims to fill that gap and provide an understanding of these activities and if support can be provided to decision making in safety critical environments, and the impact this will have on the user, and the technology.

Network Rail (NR) are currently involved in a major programme of work that will include reducing the 800+ current signal boxes to 14 National Operating Centres (NOC). As part of this process all of the older types of signal box will be closed and signalling will be carried out at the NOC using a new generation of VDU systems. This is alongside plans to increase the capacity on the network considerably over the coming years (without increasing the size of the network). With this as a key focus, it is vital that signallers are able to utilise information efficiently in order to move from reactive to proactive planning (planning in this case referring to the management of station areas to ensure trains are running on time), which will become increasingly important as the capacity increases. Understanding how stations are managed currently and how aids can be designed to interface with new technology is an important consideration when looking at how signalling tasks are carried out and how they are supported when NR transfer their control to the NOCs.

This shift from reactive to proactive planning has been a key driver for this work. An outcome of the research will be recommendations for the design of decision support tools to aid these planning processes in the future, fitting within the wider spectrum of cognitive ergonomics by understanding the implications of introducing new tools to the user and the effect this has on decision making and planning.

1.3 Aims and objectives

The aim of this research study is to **study a real world signalling environment in order to understand the strategies signallers use when re-planning and how decision support tools can be designed and integrated into existing signalling environments to support pro-active planning.** In order to achieve this aim, the following objectives were developed:

1. To understand the existing strategies used by signallers to regulate and re-plan; exploring the notion of computational offloading and the use of artefacts in rail
2. Evaluate existing decision support tools and their use and integration into signalling environments; exploring the design constraints and supporting decision making
3. Explore the implications of introducing new tools into signalling environments to support proactive control and how existing models can be used to study these concepts
4. Develop recommendations and rail specific models for the development, integration and acceptance of decision support tools into existing and future rail signalling systems.

1.4 Research approach

This research was carried out in close collaboration with Network Rail, with the researcher embedded within the Ergonomics Team at Network Rail throughout the period of study. From day one the researcher was considered as part of the ergonomics team at Network Rail. Through integration with the ergonomics team the researcher gained knowledge about rail operations from shadowing other members of the team on site visits initially, through to conversations with SMEs, and latterly working on projects for the ergonomics team. This led to an understanding of not only rail operations, but also how ergonomics as a discipline fitted into the structure of Network Rail as a corporation, and how academic theories can be incorporated into a business environment and aid development. It allowed the researcher to gain hands-on experience at administering Network Rail tools, and gathering data to be used for business purposes. This enabled the researcher to identify how the aims of the research could be fulfilled in order to provide benefit to Network Rail.

Many other indirectly associated projects were also worked on as part of this close association. This formed the basis of the background and context work for this PhD, and helped in developing a rich and thorough understanding of general railway operations, and more specific signalling operations. All of the research was carried out in the field, and the researcher had no knowledge of rail operations prior to commencing the research.

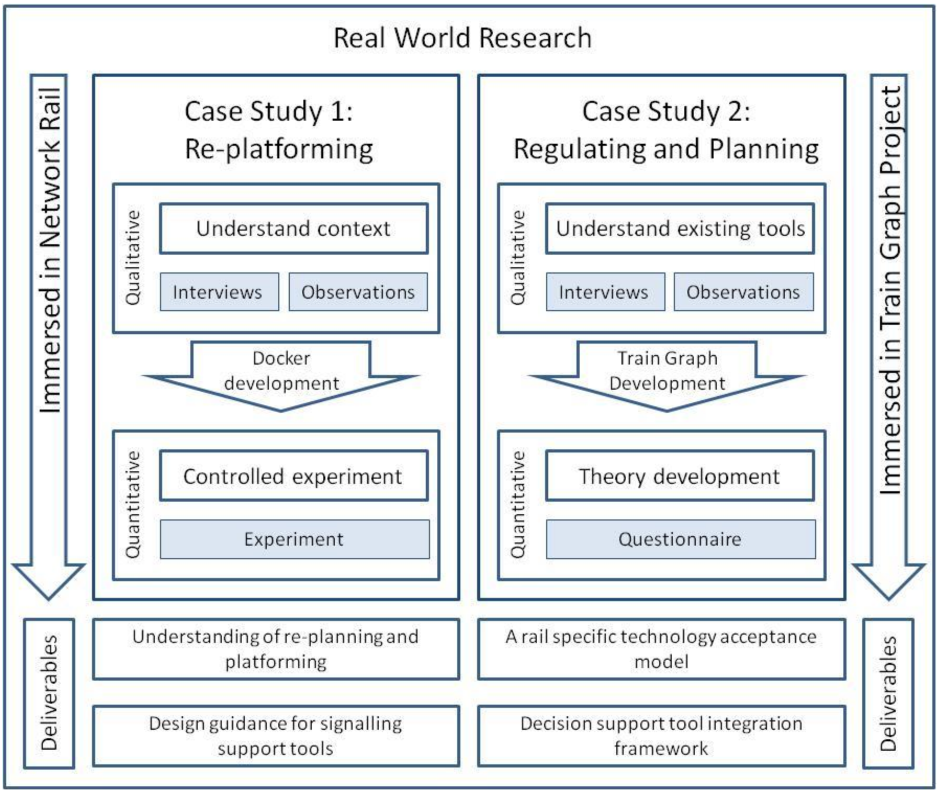


Figure 2 - Research Framework

Figure 2 illustrates the research approach taken to support the aim of the thesis and address the objectives given in the previous section. A mixed method approach was used to account for the fact that this environment was not able to be controlled and so a more flexible approach was required. By using many different methods the researcher was able to utilise and adapt each method to suit the situation rather than engineer the situation to suit the method (Robson, 2002).

The research was underpinned by one main approach: real-world research. Two of the most relevant case studies were selected from the projects that the researcher worked on in order to focus the research for this thesis. The two case studies build on existing work. Case study one looking at re-platforming utilises work by Roth et al (2001) building on the robust methodology to explore the notion of re-platforming. Case study 2 builds on existing theories of technology acceptance (Venkatesh and Davis, 2000) with a relevance to rail. These theories were utilised and built on by supporting them with data collection. Due to the nature of the domain data collection opportunities were often opportunistic and were unable to be manipulated. Each data collection opportunity was taken as it arose, and the data were analysed and coded after each visit or small group of visits to inform the next visits. More structured approaches were developed from the initial studies to quantify and enrich the qualitative findings, and to address the research objectives of this thesis.

Case Study 1 looked at the “Docker” tool that is used to aid planning and decision-making at Glasgow and Edinburgh stations. Initial work was spent understanding the background and context of this complex station operation. Semi-structured interviews and observations made at the location over a four month period of time were used to study the planning processes that are carried out, and how the Docker tool is currently used. Analysis of the qualitative data led to the development of an electronic version of the Docker tool and a controlled experiment. The development of the electronic Docker included the supervision of an undergraduate student to develop the software, generating software requirements from the analysis of how the current Docker tool is used, and focus groups with potential users to close the development loop. The controlled experiment used the electronic Docker tool (alongside existing tools used for station area planning) over a number of typical scenarios based on the experience at Glasgow. The quantitative results of this experiment provided insight into the decision processes made during re-planning and how tools may be used to aid this.

Case Study 2 looked at the “Train Graph” project that has developed and rolled out a graphical based planning tool used to aid regulation over a flexible region of the network. The research was carried out while immersed in the project providing ergonomics support on the user interface design of the tool. Observations and semi-structured interviews carried out at the signal boxes and control centres during the development and rollout of the software were used to develop a questionnaire to obtain quantitative data on how effective and useful the users found the tool to be in aiding their planning. The questionnaires were administered during a later phase of the national rollout of the tool, when new users were taking a one day course on the new software. Inferences on re-planning and dealing with disruption were taken from the qualitative work in this case study, but the main output was focussed around the technology acceptance and what influences the user’s trust and confidence in the tool and its successful use.

The results from both case studies were then brought together to establish a framework of how tools can be successfully used to aid planning and regulation, particularly with a view to disruption, and the key issues involved in successfully developing and achieving acceptance of the tools in a real world environment such as Network Rail.

All of the research methodology described above was underpinned by a thorough understanding of existing work and research within the area via a literature review, enabling key themes to be identified in order to keep the focus throughout the research. This also meant that the research would be able to maintain a focus on input into the academic domain in terms of adding to the cognitive ergonomics literature. This is expanded in more detail in the literature review chapter, and all of the methods used will be explained in more detail in the relevant chapter. However, a summary of all of the methods used throughout the thesis can be seen in table 1.

Table 1 – Summary of research methods

Method	Chapter	Time	Sample size	Description	Date
Embedding within the organisation	All	4 years		Working within the organisation to gain an understanding of the research domain	2009 - 2013
Operational observation / box visits	All	3 years	60 box visits	Visiting different signal boxes as an observer / researcher to gain an insight into railway operations	2009 - 2012
Semi structured interviews	5	100 hours	25 participants	Semi structured interviews using CWA techniques to understand the process of re-docking trains. Carried out at workstations	Jan – April 2010
Direct observations	5	20 hours	8 sites	Alongside the interviews to observe signallers docking trains and general box operations	Jan – April 2010
Requirements development for electronic Docker	6	4 hours	3 SME's	Utilising results from chapter 5 to develop requirements for an electronic Docker tool, using SME's	Sept 2010
Development of electronic Docker	6	8 weeks	1 student	Development of an electronic Docker tool. Involved supervising an undergraduate student to complete his undergraduate project in computer programming	Sept 2011
Focus group	6	4 Hours	3 SME's	A focus group with 3 SME's to refine the electronic Docker tool	Nov 2011
Docking experiment	6	2 months	60 participants	An experiment to compare the techniques used to re-dock trains when using different tools - list, graph, and electronic	March – May 2012

Method	Chapter	Time	Sample size	Description	Date
Ergonomics lead for Train Graph project	7	17 months		Taking on the responsibilities of leading the Train Graph project. Involved attending regular meetings and inputting into design decisions and providing ergonomics guidance.	Feb 2011 - June 2012
Semi-structured interviews	7	60 hours	20 participants	Semi structured interviews utilising TAM and IDT theories to obtain information about the uptake of the Train Graph	Oct 2011 Jan 2012
Questionnaire	7		138 participants	A questionnaire utilising TAM and IDT concepts to investigate attitudes towards Train Graph for new and existing users	Jan 2012 May 2012

1.5 Thesis structure

- Chapter 2 covers the description and overview of the railway environment that this research encompasses.
- Chapter 3 covers a review of the current human factors literature relevant to this research, in particular distributed cognition, situation awareness, planning and cognitive artefacts.
- Chapter 4 covers a review of the current human factors literature relevant to this research, in particular technology adoption.
- Chapter 5 covers the method, results and discussion of signalling interviews and observations carried out at eight signal boxes, focussing on managing station areas (i.e. qualitative data for case study 1 – "Docker" tool)
- Chapter 6 details the method, results and discussion of a controlled experiment carried out to compare three different data presentation methods used to aid signallers with managing station areas (i.e. the quantitative data for case study 1 – "Docker" tool)
- Chapter 7 covers signaller interviews, observations and questionnaire study for case study 2, the "Train Graph" project. This chapter presents the method, results and discussion of looking at the integration and acceptance of a computerised tool to aid signallers with regulating running lines.
- Chapter 8 is a general discussion chapter. Signaller strategies used when re-planning are discussed in light of the findings from the thesis. The findings from the two case studies are brought together to address the research objectives described earlier in this chapter.
- Chapter 9 presents the conclusions, recommendations and suggestions for future work.

Figure 3 shows how each chapter maps to the relevant objectives.

Chapter		Objective
1	Introduction	
2	Rail environment	1, 2
3	Cognitive ergonomics and artefacts	4
4	Technology adoption	4
5	A qualitative study of re-platforming	1, 2
6	Quantitative re-platforming experiment	1, 2
7	Regulating and Planning	1, 2, 3, 4
8	General discussion	4
9	Conclusions	

1. To understand the existing strategies used by signallers to regulate and re-plan.
2. Evaluate existing decision support tools and their use and integration into signalling environments.
3. Explore the implications of introducing new tools into signalling environments to support proactive control.
4. Develop recommendations for the development, integration and acceptance of decision support tools into existing and future rail signalling systems

Figure 3 - Objectives mapped to relevant chapters

2. RAIL ENVIRONMENT

This chapter describes the rail environment in which the research was conducted. It gives an introduction to the history of the railway, the development of modern signalling, and the roles, functions and technology that is used to run the railway. The chapter is intended to provide an introduction to the context of the research.

2.1 History of the railway

The UK railway was nationalised by British Rail in 1948 (Ottley et al., 1988). Prior to this, railways had been operated as separate lines which slowly became amalgamated through the introduction of more railway companies. British Rail was a government owned company which centralised the running of the railway. At this time many tracks and stations were modernised and electrification was introduced. However during the 1960s it became apparent that the railway was not profitable and as a result there were many line closures. The British railway continued to decline and lines continued to be closed until 1997 when the industry was privatised. This meant British Rail was divided into several different companies. Railtrack was given responsibility for the maintenance and day-to-day operation of the infrastructure. Railtrack invested money in the railway to try and reverse the decline leading up to this time. As a result of privatisation, a number of Train Operating Companies (TOCs) and Freight Operating Companies (FOCs) franchises were created to run services. In 2001 Railtrack went into administration.

From 2002, Network Rail (2004) was responsible for running, maintaining and continually improving the UK rail infrastructure. Network Rail then effectively sell routes to the TOCs and FOCs who bid for the franchises run by the government. The responsibility of developing a timetable falls with Network Rail, with an amount of TOC negotiation, so if a delay is incurred by an operating company for which Network Rail are found responsible (this may be due to timetabling or infrastructure issues) Network Rail are subject to a penalty. These changes have influenced the way TOCs and Network Rail communicate and has led to closer working relationships. All operations that Network Rail carries out are overseen by the Office of Rail Regulation (ORR) and the Railway Safety and Standards Board (RSSB) also have input into how the railway is managed.

2.2 Infrastructure

Network Rail owns, maintains and continually improves over 20,000 miles of track, 40,000 bridges and tunnels, and 2500 stations. These 2500 stations are divided into six categories known as A to F. A ‘category A’ station would be a national hub such as Euston, and a 'category F' station would be a small unmanned station such as Rhosneigr (see table 2).

Table 2 - station categories

Category	Number	Description	Trips per annum	Example
A	28	National hub	over 2 million	Blackfriars
B	67	Regional interchange	over 2 million	Barking
C	248	Important feeder	0.5–2 million	Andover
D	298	Medium staffed	0.25–0.5 million	Abergavenny
E	679	Small staffed	under 0.25 million	Crowthorne
F	1,200	Small unstaffed	under 0.25 million	Aldermaston
Total	2520			

2.3 Railway Operations

Railway operations are illustrated in Figure 4. From the bottom of the diagram, trains are controlled by train drivers, who work for the TOCs and FOCs and are out of the scope of this research. The routing for each train is directly controlled by the signallers who refer to the working timetable and also receive instruction from the TOCs and FOCs via the Shift Signalling Manager (SSM). Each of these is discussed in more detail in the following sections.

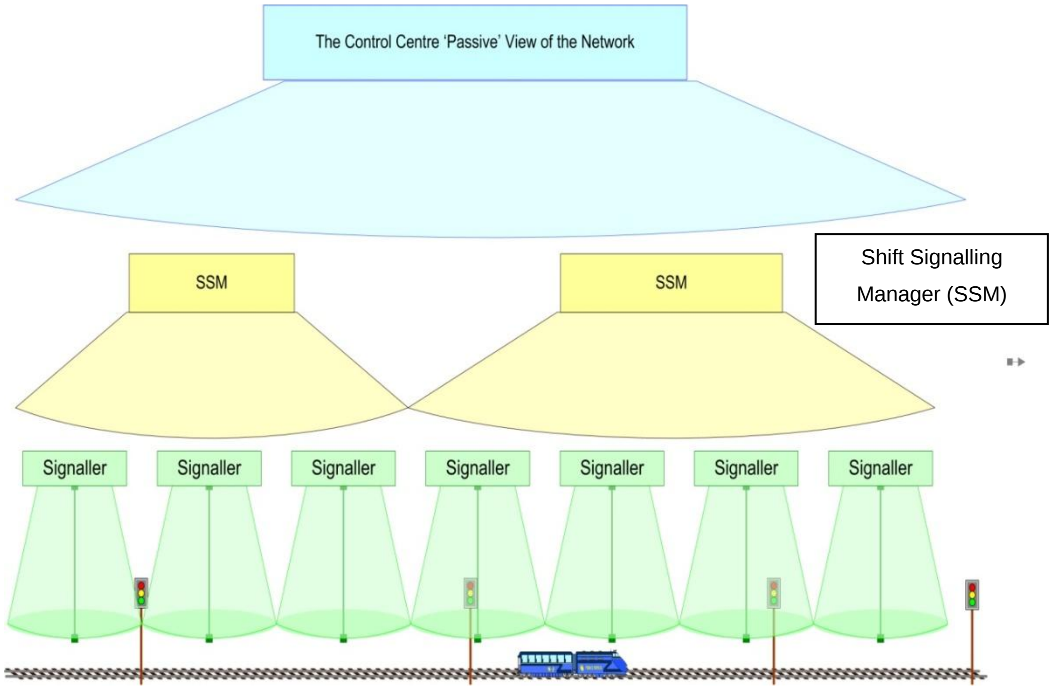


Figure 4 – illustrative control of the railway (not to scale)

The controllers are located in a control centre, and the SSMs and signallers are located together in a signalling centre. Currently ‘control’ is usually located away from signalling, however the introduction of Integrated Control Centres (ICCs) are seeing control and signalling being co-located more frequently. This is discussed in more depth in the following section.

2.4 Railway control

2.4.1 Organisation

Network Rail Control is organised by route. There are currently 10 routes within the UK. These are:

- Anglia
- East Midlands
- Kent
- LNE
- LNW
- Scotland
- Sussex
- Wales
- Wessex
- Western

Each one of these routes contains a number of signalling locations and types of signalling technology. These may be one IECC, or several small lever frame boxes, or a combination of all types of signal box.

2.4.2 Functions

‘Control’ is responsible for overseeing signalling operations. They have a wider view of the railway and often operate on a national level, rather than signallers who operate on a more local level. Signallers take a tactical view of the railway, whereas control take a more strategic view and typically only get involved in larger incidents or delays and tend to be involved in the longer term planning. They may contact signallers on a regular basis about any incidents or irregular occurrences on the railway and it is the signallers responsibility to re-plan the railway whilst taking guidance from control who have a wider view. Control may consist of not only Network Rail staff but also staff belonging to a TOC.

2.4.3 Roles

Control staff will often operate from a dedicated control centre, although there are instances where control and signalling are integrated. The main roles within control are as follows:

- Route Control Manager (RCM) - responsible for overseeing the whole of control
- Train Running Controllers (TRC) - responsible for ensuring the efficient running of trains in their area
- Incident Controllers (IC) – responsible for logging and actioning any incidents on the railway; often working closely with the TRCs managing incidents within their area of control but are also the main link to maintenance staff.
- Delay Attribution - responsible for ensuring all delay is accounted for.

Train Operating Companies will focus more on the running and management of rolling stock and also ensuring messages regarding delay and disruption are communicated in a timely manner to passengers.

2.4.4 TOCs and FOCs

The TOCs and FOCs communicate with control regularly. The TOC and FOC controllers communicate with the Train Running Controllers in Network Rail control in order to maintain a smooth service. Dependent on the individual TOC and FOC, they may have to interface with several different control routes if they cover a large area. Each TOC and FOC may have different rules and procedures on how to deal with incidents and how to manage their train service. This adds an extra layer of complexity to the control task.

2.5 Signalling

Signalling systems are required to move trains through the infrastructure and their main goal is to maintain safe separation between trains. Signalling systems have developed over time as the increasing speed, capacity and availability of trains has put new requirements on the network. Where a slower train could rely upon adequate braking power to stop a potential collision, as trains increased in weight and speed this stopping ability could not be guaranteed. Therefore train drivers required a system to inform them if the track in front of them was clear of other trains and it was safe to proceed.

2.5.1 Signalling theory

The first step towards the modern signalling systems we have in place today was a system known as Absolute Block (AB). In basic terms this system prevented a train leaving the station until it was known that the previous train had arrived safely at the next station. The line was divided into a series of sections, known as blocks, and bells were used to communicate with other sections. This became achievable due to the invention of the electric telegraph. Signals were fixed to a signal post and operated from the foot of it, but it was soon realised that it would be more efficient to operate the signals from a distance by pulling a wire. This invention allowed points and signals to be operated from one place known as the signal box.

Absolute Block was installed throughout Britain during the second half of the 19th century and continues to be refined. Due to primitive braking systems when trains were getting faster and heavier it was becoming increasingly difficult to stop safely if the signals were at danger. To mitigate this, a warning signal (or an auxiliary signal) was placed before the signal at danger to pre-warn the driver that he would have to stop at the next signal. However this additional signal still did not mitigate from drivers being able to stop in time and collisions into rolling stock or vehicles standing just beyond the station signal were common. This prompted the notion of the "quarter of a mile clearance". This basically meant that the signalman would not send a "train out of section" message until the rear end of the train had passed a quarter of a mile beyond the end of the section. This was known as the overlap.

The safety that absolute block provided was used mainly for passenger trains on double and multiple track lines. Goods lines used exclusively by freight would use the system known as permissive block. This effectively allowed more than one train in a section at any one time. The drivers would be informed of this verbally and will travel sufficiently slowly to be able to stop for any obstruction they may come across ahead of them. This permissive block system was then eventually used on occasion by passenger trains in larger stations, allowing trains to double dock in platforms.

The development of interlocking was an extra layer of safety in the signalling system. Initially interlocking was mechanical in nature and worked by metal bars being attached to the levers in the signal box. When a route is set the metal bar blocks the levers of conflicting routes meaning they cannot be pulled and the signals cannot be set. Further technical developments between the wars led to the application of safety devices such as track circuits, multiple light signals and interlocking. The development of route relay interlocking was a turning point for signalling operations. This meant that signals were automatic and would turn to red as soon as the train passed them. As the train travelled further the signal would turn to yellow meaning caution, two yellows preliminary caution, and was then taken to green indicating that it was safe for the next train to enter that section. Colour light signals will be described in more detail further on in the chapter.

2.5.2 The signalling task

The signallers' main goal is to maintain safe operation of the railway. This involves using the signalling equipment correctly but it also means ensuring all of the trains run to their planned path. These passages are determined by the timetable. This is a straightforward task when the railway is running to plan. If there is any level of disruption the signaller must then work to get back on plan as quickly as possible. This means he must regulate trains. Regulation may be defined as:

> "the planning and implementation of trains paths over the available infrastructure in order to optimise the train service, mitigate the effects of disruption, and support recovery from disruption" (Balfe, 2010)

In basic terms this means the signaller must manage the train service in the most efficient way possible at the time. The signaller will be required to make decisions about delaying trains and placing certain trains in front of other ones. The signaller will need to take a variety of things into account when making regulating decisions.

These may include:

- The infrastructure - possible passing locations (regulation locations, or regulation points) and route and platform availability
- Train attributes - the class of train (class one being express passenger trains, class two being ordinary passenger trains, and class three, four, and six being different types of freight), the train speed (it would not be prudent to route a slow train in front of a fast train, for example) and train routing information. For example an express service may not stop at as many stations as a local service, so placing a stopping train in front of an express service may not be the most effective regulating decision.
- Delay attribution - when delay is attributed to Network Rail, this costs Network Rail money. Typically, delay for express services costs more than for regular services. This may influence the way signallers regulate trains, and they may prioritise express services over other services. Also, if a train has already accumulated an amount of delay, the signaller may choose to delay this train further rather than delay another train that would otherwise be on time.

The signaller may regulate trains at regulating points. These are junctions or crossovers. Their availability will depend upon the route. Therefore the amount of regulation the signaller is able to do is very dependent upon the route and the availability of regulating locations. When regulating trains the signallers have to take into account the impact of their decisions on the future running of those trains: although they are only directly concerned with trains in their area of control, these decisions have the potential to impact upon the entire journey of the train.

2.5.3 The Signalling Systems

There are three main ways that the signalling system is operated today on the railway. These are lever frame operation, NX panel operation and VDU operation. These will be described in separate sections below.

2.5.3.1 Lever frame

This was the earliest way that signallers were able to operate more than one set of signals and points from one location. These consist of a row of levers physically attached to the signals and points via wires. Each of the levers is numbered and colour coded (see figure 5). They are often grouped for convenience. The signaller would also be able to see a map of the area he is controlling placed above the levers. There are currently around 450 lever frame boxes in operation today (Minnis, 2012).

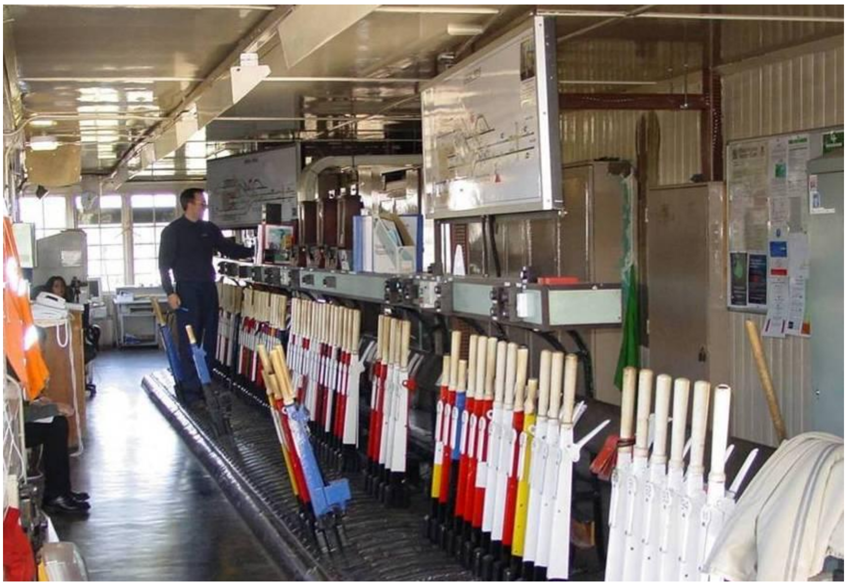


Figure 5 - Lever frame box

From the lever box the signaller operates stop signals and distant signals. A signal called the semaphore signal (see figure 6) is operated by the levers which is mechanically set to either horizontal or at 45° to the ground. When the signal is horizontal this indicates stop, and when at 45° this indicates to the driver that he may proceed. For distant signals a 45° angle indicates that the driver that the next signal (stop signal) will be set to proceed. If this signal is set to a horizontal position, it is indicating to the driver to be prepared to stop at the next signal.

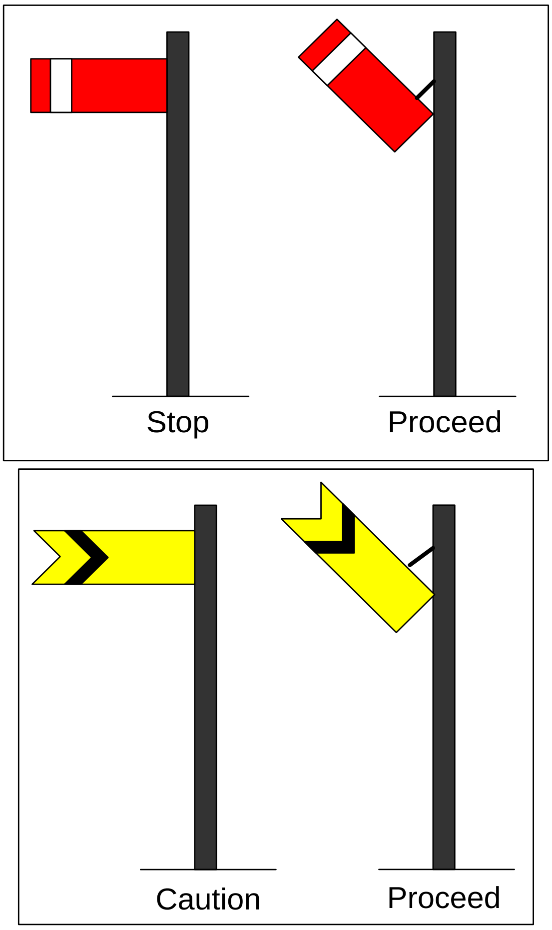


Figure 6 - semaphore signals (top) and distant semaphore signals

In order for a signaller to operate signals effectively he needs to be able to communicate with the signaller in the next signal box. Signallers in a lever frame box use a Block Bell to send coded messages to the next signal box. This communication equipment consists of a Block Bell, and a Block instrument (see figure 8). The block instruments show the status of a section of railway. They have three settings:

- Normal - indicating no trains in the area
- Train on line - indicating an obstruction is present in the section
- Train accepted - a train may proceed as the line is clear

Only when the Block instrument is set to train accepted will the signalling system (the interlocking) allow the signaller to set the route.

If the signaller did not want to be able to set a route, for example if there were track workers on the line or a section of line was damaged the signaller could set a reminder on the signal that was in the form of a metal collar that fit over the lever preventing the lever from being pulled (Figure 7). Reminders could also be set on points in the same way.

Figure 7 - Lever Frame Reminder

By using the absolute block method (see figure 9) the signaller would receive a request from the preceding signaller to allow a train into their section and request a route the train.

Only when the line is clear will the signaller set the Block instrument to train accepted. This signaller must then do the same thing to the next signal along; he must send a message to the signaller to let him know that train is on its way. Only when this next signaller turns his Block Instrument to train accepted will this release the interlocking and allow the signaller to set the route into the next section. When the train has left the section the signaller then turns his Block instrument to normal.

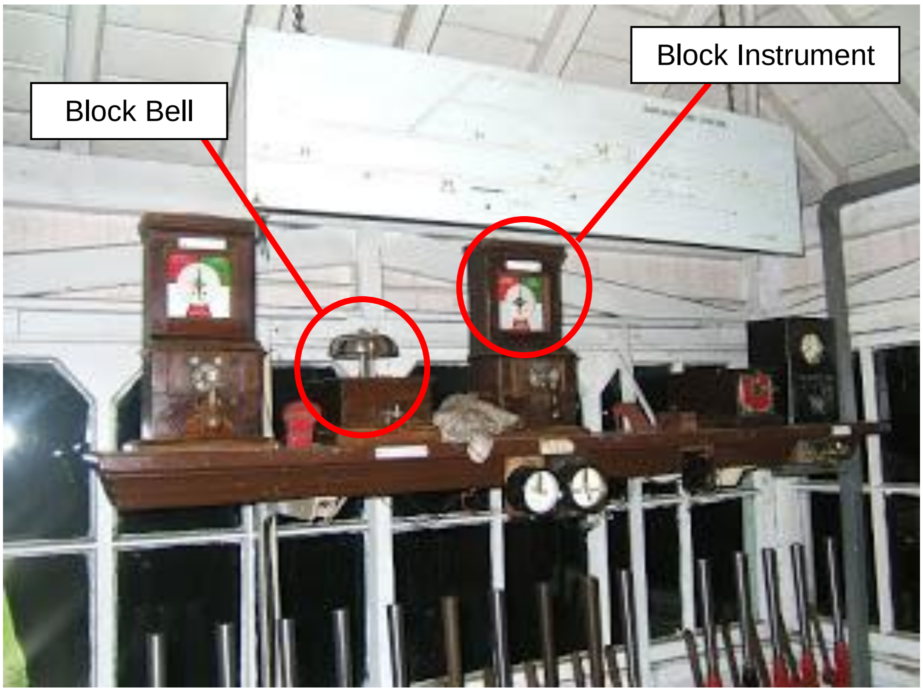


Figure 8 - lever frame block shelf showing block Bells and instruments

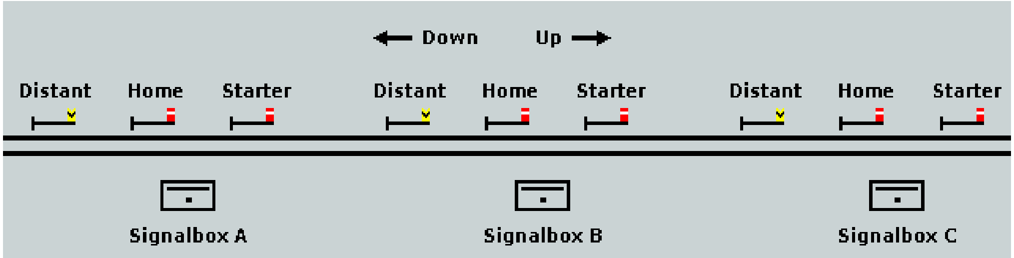


Figure 9 - absolute block signalling

2.5.3.2 <u>NX panel</u>

NX stands for eNtry and eXit. Through the introduction of track circuit and electronic controls, signallers were able to control a larger area than was possible by using physical wires connected to point and signals (figure 10).

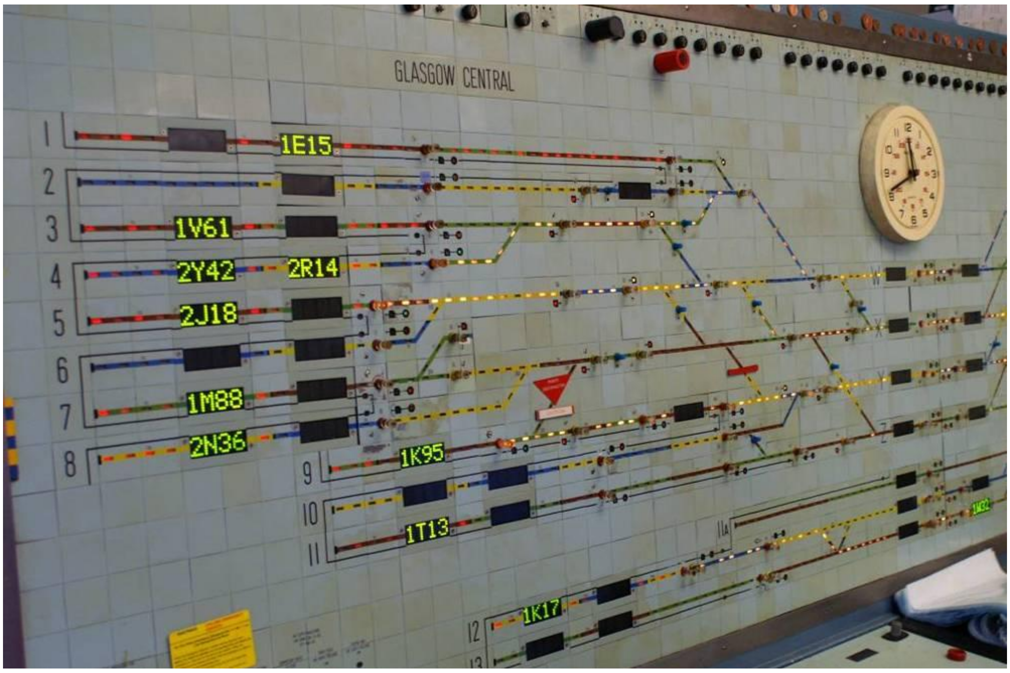


Figure 10 - NX Panel

The concept is similar to the lever frame operation, the main difference being electrical rather than mechanical control. The system still works on the same concept of block signalling, except instead of levers, signals and points are operated via buttons. Reminders can still be applied to signals in a similar way as at lever boxes. In NX panel boxes these plastic collars that fit over the buttons that physically prevent them from being pressed.

The introduction of four aspect signalling added an extra safety layer to signalling operations. Figure 11 shows four aspect signalling relative to train movements. Working on the same basis of traffic lights, red means stop, yellow means caution (the next signal is red) and green means go. Double yellow indicates that the next signal will be a yellow. Using a double aspect yellow means that block sections can be shorter.

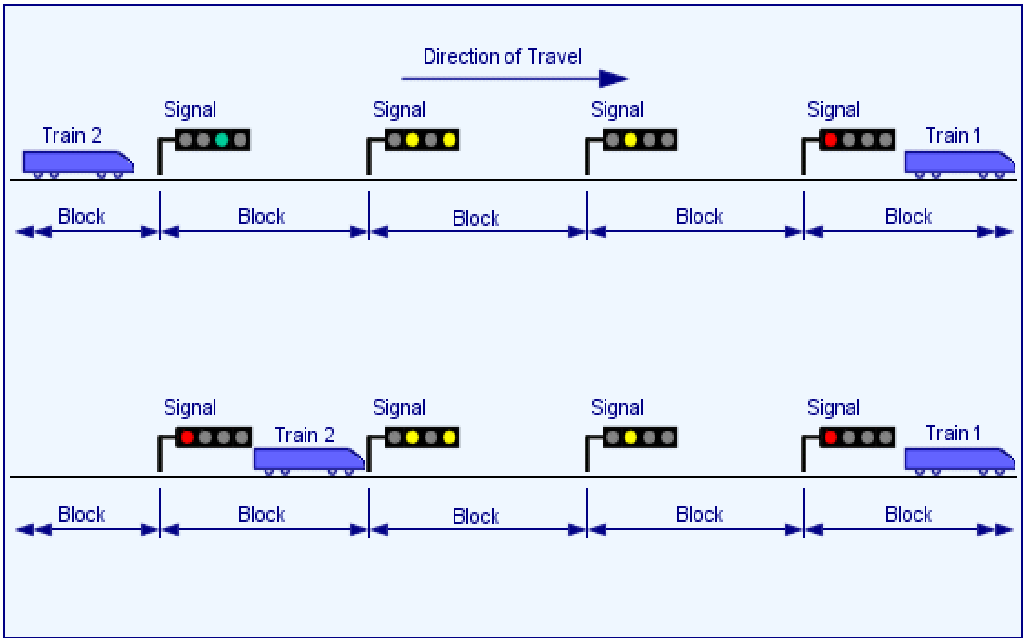


Figure 11 - Four aspect signalling

The interlocking in use follows the same principle as mechanical interlocking but is electronic rather than mechanical. The introduction of electronic interlocking also saw the introduction of Train Operated Route Release (TORR) which automatically releases the signal when the train has left the section. This again increased the amount of track that one signaller could manage.

Track circuits are an incredibly simple yet effective way of ensuring safety on the railway. By using a simple electronic current, the train on a track short-circuits the track circuit. This means that signallers are able to locate a train without having to physically see it. This meant signallers' capacities could be increased.

On an NX panel (figure 10) the signaller is able to easily see where trains are as the track circuits will be displayed on the panel as red lights. When a route is set these are shown as white lights. The panel also has train describer bays that display the head code (a unique identifier) of the train. By being able to see the identity of the train the signaller is then able to use the buttons on the panel to set the route for the train. The fact that everything was now controlled by an electronic signalling rather than mechanical signalling mitigated the need for the Block Bell.

2.5.3.3 <u>VDU</u>

Integrated Electronic Control Centres (IECCs) were introduced in the 1980s.These had the exact same concept as an NX panel but on VDU screens (see figures 12 and 13). Instead of controlling the area with buttons, the signaller controls the area with a trackerball and keyboard on VDU screens.

Figure 12 - an IECC signalling system

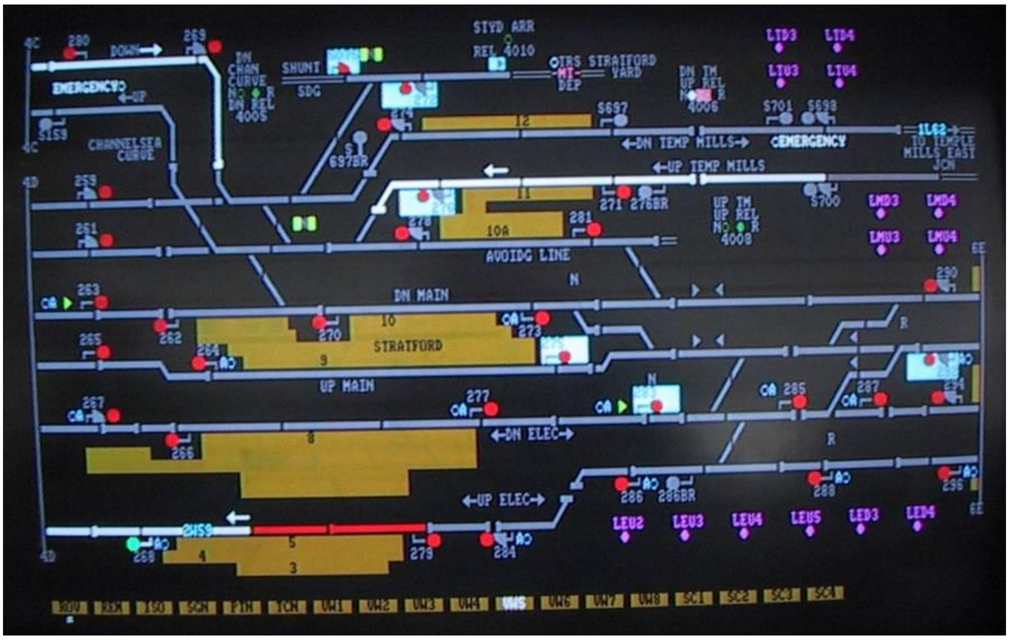


Figure 13 - IECC screen

One significant addition to the IECC is Automatic Route Setting (ARS):

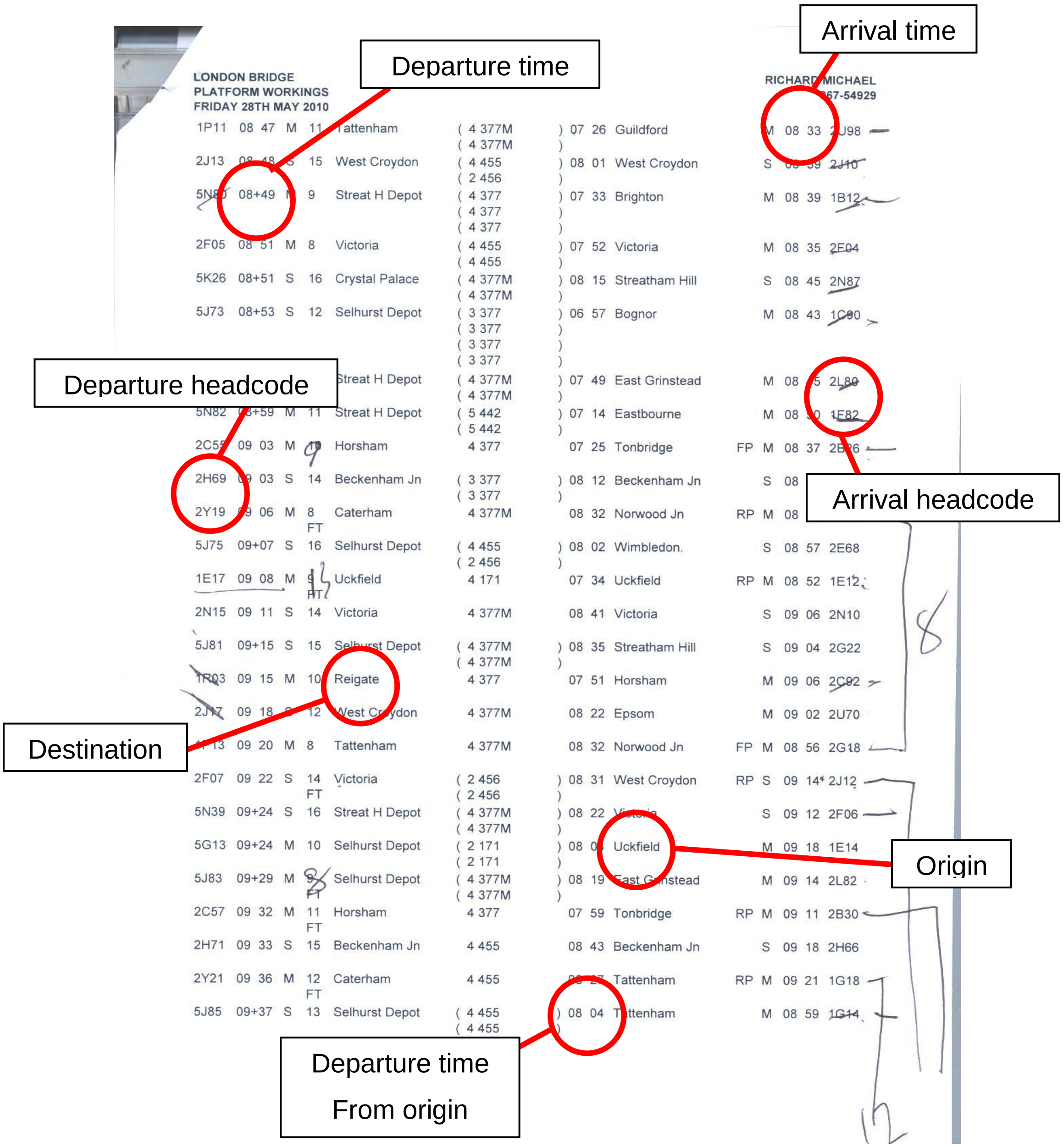
> "ARS optimally routes trains using timetable data, current train positions and an internal representation of the rail network. It can handle severely disrupted service patterns and assist the signaller in the event of train or infrastructure failures" (Balfe, 2010)

ARS determines the route and timings of each train using the central timetable services database and uses complex algorithms to decide which trains to route first.

2.5.4 Information Systems

2.5.4.1 Simplifier

The simplifier is a paper list that every signaller has access to. It depicts the running of each train including the platform workings. It assists the signaller in managing the station area. See Figure 14.


LONDON BRIDGE
PLATFORM WORKINGS
FRIDAY 28TH MAY 2010

RICHARD MICHAEL

1P11	08 47	M	11	Tattenham	4 377M / 4 377M	07 26	Guildford		M	08 33	2U98
2J13	08 48	S	15	West Croydon	4 455 / 2 456	08 01	West Croydon		S	08 39	2J10
5N80	08+49	M	9	Streat H Depot	4 377 / 4 377 / 4 377	07 33	Brighton		M	08 39	1B12
2F05	08 51	M	8	Victoria	4 455 / 4 455	07 52	Victoria		M	08 35	2F04
5K26	08+51	S	16	Crystal Palace	4 377M / 4 377M	08 15	Streatham Hill		S	08 45	2N87
5J73	08+53	S	12	Selhurst Depot	3 377 / 3 377 / 3 377 / 3 377	06 57	Bognor		M	08 43	1C80
				Streat H Depot	4 377M / 4 377M	07 49	East Grinstead		M	08	2L80
5N82	08+59	M	11	Streat H Depot	5 442 / 5 442	07 14	Eastbourne		M	08	1E82
	09 03	M	10	Horsham	4 377	07 25	Tonbridge	FP	M	08 37	
2H69	09 03	S	14	Beckenham Jn	3 377 / 3 377	08 12	Beckenham Jn		S	08	
2Y19	09 06	M	8 FT	Caterham	4 377M	08 32	Norwood Jn	RP	M	08	
5J75	09+07	S	16	Selhurst Depot	4 455 / 2 456	08 02	Wimbledon.		S	08 57	2E68
1E17	09 08	M	9 FT	Uckfield	4 171	07 34	Uckfield	RP	M	08 52	1E12
2N15	09 11	S	14	Victoria	4 377M	08 41	Victoria		S	09 06	2N10
5J81	09+15	S	15	Selhurst Depot	4 377M / 4 377M	08 35	Streatham Hill		S	09 04	2G22
1R03	09 15	M	10	Reigate	4 377	07 51	Horsham		M	09 06	2C82
	09 18		12	West Croydon	4 377M	08 22	Epsom		M	09 02	2U70
	09 20	M	8	Tattenham	4 377M	08 32	Norwood Jn	FP	M	08 56	2G18
2F07	09 22	S	14 FT	Victoria	2 456 / 2 456	08 31	West Croydon	RP	S	09 14*	2J12
5N39	09+24	S	16	Streat H Depot	4 377M / 4 377M	08 22	Victoria		S	09 12	2F06
5G13	09+24	M	10	Selhurst Depot	2 171 / 2 171	08 0	Uckfield		M	09 18	1E14
5J83	09+29	M	9 FT	Selhurst Depot	4 377M / 4 377M	08 19	East Grinstead		M	09 14	2L82
2C57	09 32	M	11 FT	Horsham	4 377	07 59	Tonbridge	RP	M	09 11	2B30
2H71	09 33	S	15	Beckenham Jn	4 455	08 43	Beckenham Jn		S	09 18	2H66
2Y21	09 36	M	12 FT	Caterham	4 455	08 27	Tattenham	RP	M	09 21	1G18
5J85	09+37	S	13	Selhurst Depot	4 455 / 4 455	08 04	Tattenham		M	08 59	1G14

Figure 14 - example of a paper simplifier

2.5.4.2 Platform Docker

The platform Docker is a tool that assists the signallers in managing the station area. These can be list based Dockers, but the Dockers being referred to here are graphical-based docking tools. There are several locations that use graphical docking tools, but they have evolved through use at one particular area so they all differ in the form. The one shown in Figure 15 is unique to Glasgow Central Station. This tool is used by signallers located at the West of Scotland signalling centre. The platform Docker is an extremely large decision aid that sits on the desk of the SSM. It is essentially a timetable in graphical form detailing the occupation of each platform at any one time. It consists of a large sheet of paper placed on rollers at either end which sits underneath a Perspex sheet. Throughout the day the paper is rolled along and any alterations to the plan can be marked on top of the Perspex using a China graph pencil.

The layout of the graph is a time based representation of platform occupation. Time runs along the horizontal axis of the graph and the platforms run along the vertical axis of the graph

Figure 16 shows a close-up view of the platform Docker. Each of the lines with boxes at either end depicts a train sitting in the station. The length of the line indicates the length of time the train is sitting in the station. The ability to mark any changes directly onto the plan means the signaller is able to identify the state of the station by glancing at the Docker at any time.

Figure 15 - graphical Docker at Glasgow

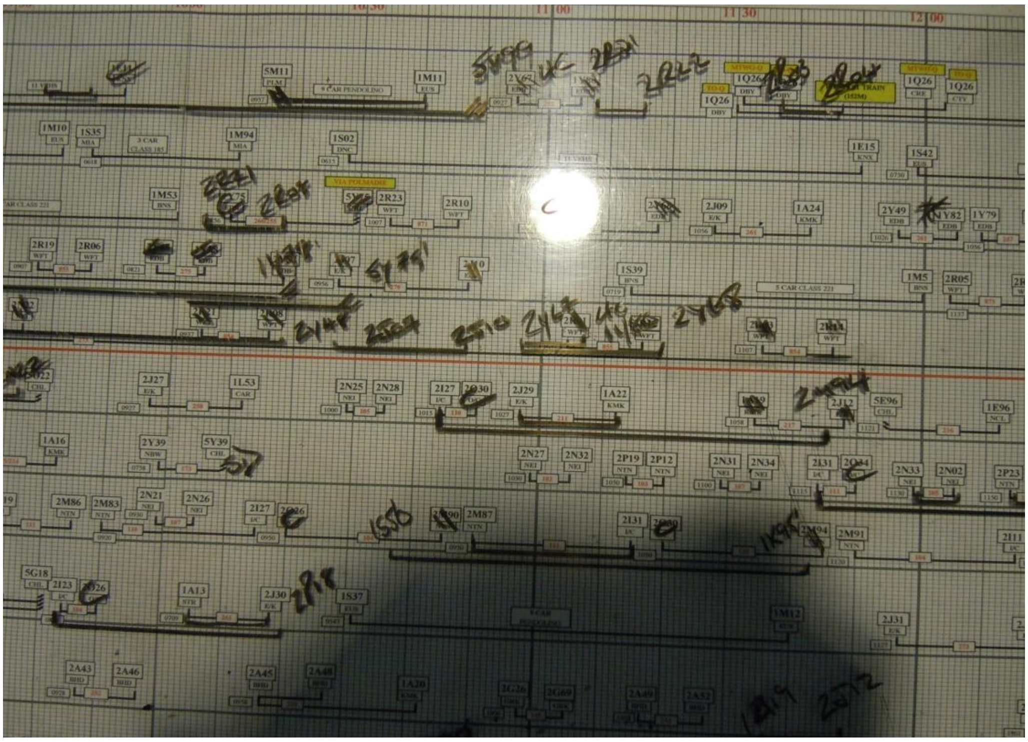


Figure 16 - annotated Docker

2.5.4.3 TOPS

Total Operating Processing System (TOPS) is a computer system that manages rolling stock and determines the location of each train on the rail network using track circuit information. TOPS provides a way of managing information relating to the train, such as its maintenance history, its route, and its location. The adoption of TOPS in the 1960s by British rail led to a new numbering system for all trains on the UK network that is still used today.

2.5.4.4 TRUST

TRUST stands for Train Running System on TOPS (see figure 17). This is essentially a copy of the timetable but is based on actual train running. Users can query an individual train on this text based system and this will then tell them detailed information about the running patterns and operation of that train. This also gives signallers information about when they will become responsible for a particular train.

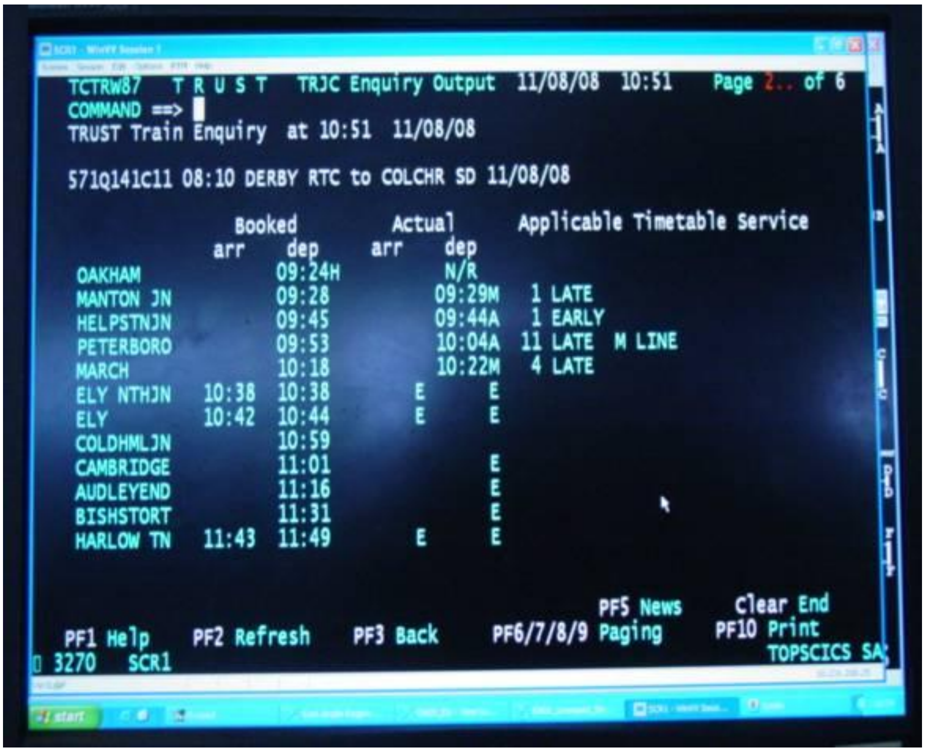


Figure 17 - TRUST screen

2.5.4.5 CCF

CCF (Control Centre of the Future) is essentially an extension of TRUST but a map-based system (figure 18). This shows real time train running information and trains are colour-coded according to their status.

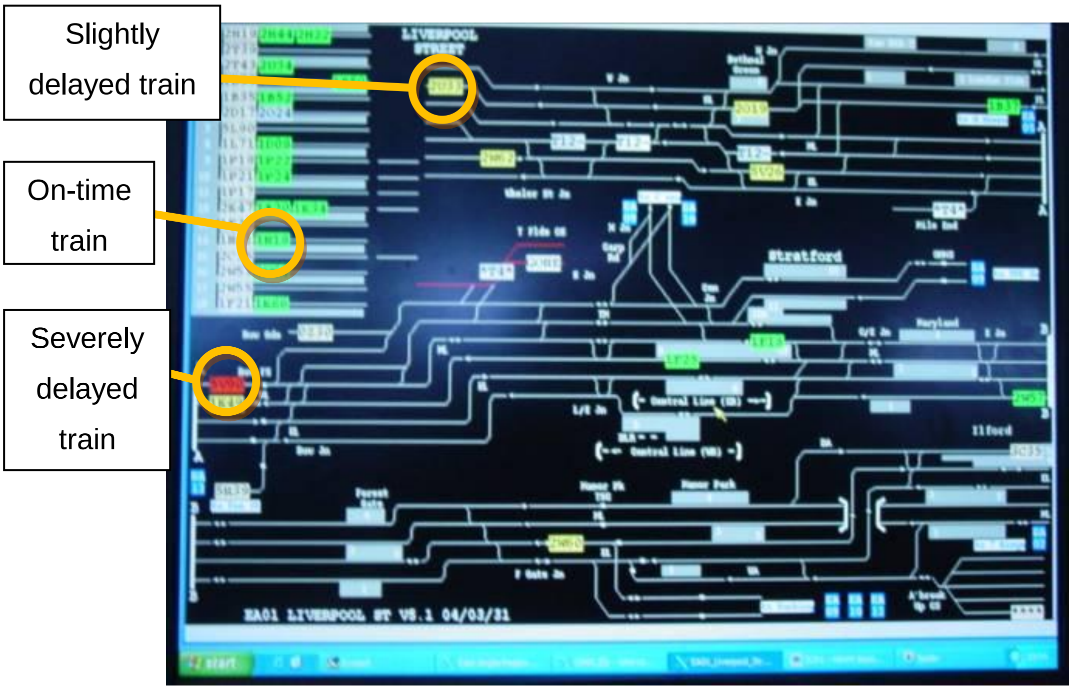


Figure 18 - CCF screen

CCF provides an overview of the signallers' area and allows them to view the state of their area at a glance. For example if the signaller glances at CCF and sees a red box, they will know that a train is very delayed. If they glance and see all green, they will know that their area is running to time.

2.5.4.6 <u>Train register book</u>

The train register book was traditionally used in small signal boxes to keep a record of every train passing through the area. More recently, electronic signalling has meant that all of this information can be recorded electronically meaning the train register book is only required to record incidents or abnormal occurrences in that area.

2.5.4.7 <u>Real-time Train Graph</u>

The real time Train Graph is a system that allows operators to see the future predicted state of the railway. It is a graphical representation with time along the horizontal axis and timing points such as stations along the vertical axis. A train's path is depicted by a line, so in figure 19 a line running diagonally from top left to bottom right depicts a train running in the up direction (to London) the portion shown here being from Darlington to York.

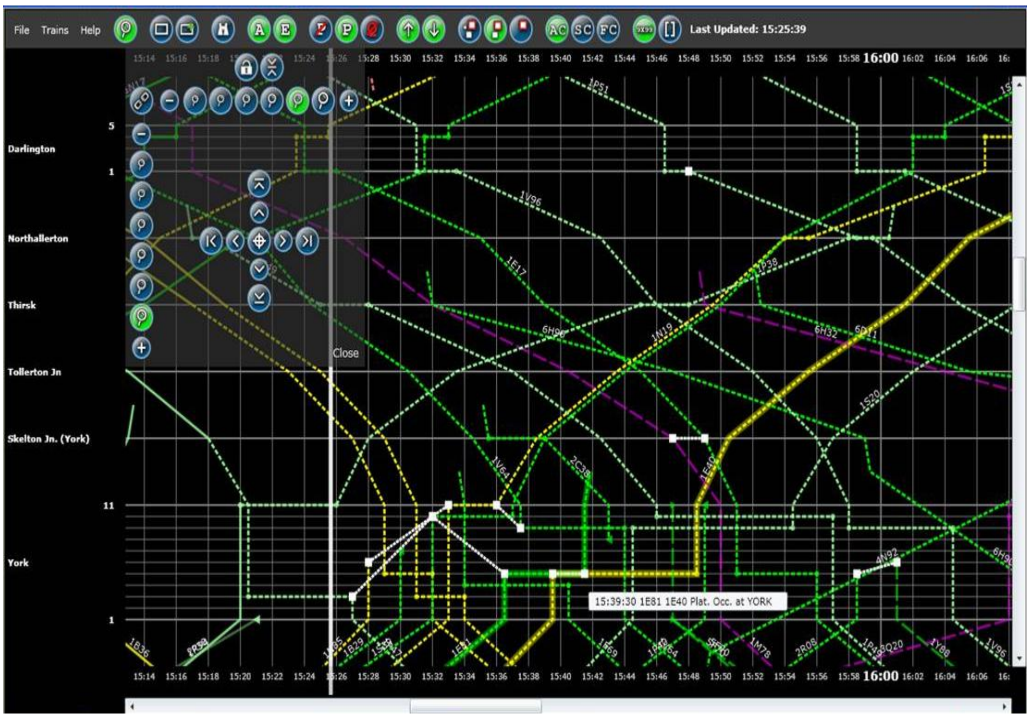


Figure 19 - Real time Train Graph

York station can be seen at the bottom of the picture. The station has been expanded and platforms 1 to 11 are visible. Horizontal lines on the station area indicate a train sitting in the station. It is easy for a trained signaller to identify from the graph whether a platform is a terminus or a through platform. If it is a terminus platform, the train will arrive from one direction and leave in the same direction making a U-shape. If a through platform, the train will arrive in platform and carry on following a diagonal line.

The Train Graph uses real-time information from TRUST to feed it. It will flag up any conflicts and make the operator aware of them. A conflict may be that the train is running late and may hold up a train running on the same line. In this instance the Train Graph will notify the operator of a conflict and it will be up to the operator to manage this. By querying the conflict the operator will be presented with different options for conflict resolution. These will usually involve a conflict between two trains so the conflict resolution options will be to leave things as they are or at a regulating point run one train in front of the other. The Train Graph will let the user know how many minutes delay each of these options will incur. It is then up to the operator to choose which option they wish to use.

2.5.5 The future of signalling

2.5.5.1 Traffic management

The Train Graph is one small part of a large program within Network Rail called Traffic Management (TM). Traffic Management can be summarised to be a combination of new roles, processes and systems functionality which will improve operational performance and increase network capacity (Mazzarello and Ottaviani, 2007). The new system will automate many tasks and offer additional capabilities. These include:

- Real-time planning
- Prediction of future operating situation
- Identification of conflicts
- Resolution of conflicts
- Reconfiguration of areas of control when operational needs dictate

The main goal of Traffic Management is to integrate signalling and control, which will increase the ability to deal with incidents. By integrating the signalling and control functions it should reduce the amount of communication and will enable all roles to utilise the same tools which will mean a better flow of information throughout the country.

The main characteristic of Traffic Management is the ability to manage operational issues proactively through improved decision-making support. The system will predict conflicts and will enable real-time timetabling and re-planning to be carried out quickly. The increased functionality of the system will enable control areas to be reconfigured quickly and the train service to be manipulated by the Train Graph through a drag and drop system. It will be possible for the operator to drag a train path (line on the graph) on the graph and this will alter the path of the train.

The key activities and tasks of traffic management are detailed in Table 3: There will be six key roles involved in traffic management, which are listed in Table 4.

Table 3 – Key activities and tasks of the Traffic Management System (Tapsell, 2013)

Activity	Key tasks of the TM system
Manage and monitor train movements	• carry out day-to-day route setting • monitor progress against the planned timetable • predict future train timings • allow manual intervention by the operators
Manage disruptive events	• certain faults and failures logged automatically • details automatically passed to Asset Management • allows protection to be applied automatically
Re-plan and recover service	• conflict detection and resolution • contingency plans • management of the VSTP (Very Short Term Plan) process
Manage infrastructure access	• manage possessions and blockages of the line • implement relevant protection • provide auto alerts for overrunning possessions or blockages • able to remove protection with operator authority
Manage information distribution	• inform all affected parties • provide train service updates through central system • operators able to amend an update when required
Prepare current plan	• prepare current plan from train plan • reflect infrastructure restrictions • validate current plan as conflict free

Table 4 – Traffic Management Roles (Tapsell, 2013)

Role	Responsibilities
Dispatcher	Responsible for delivery of the train service and the management of train circulation during normal running
Incident Manager	Responsible for managing any incidents or disruptive events requiring trains to be prevented from passing through the affected area
Service Delivery Planner	Will take ownership of the current plan prior to its implementation
Service and Infrastructure Manager (SIM)	Responsible for supervising the team of dispatchers, incident managers, and service delivery planners
Information Controller	Responsible for the monitoring of train services and incident information passing from the TM system
Timetable Planner	Take ownership of the train plan 5 to 7 days before implementation

The traffic management programme is currently in prototype stage and will be developed further prior to rollout which is planned from 2016 onwards.

2.6 Chapter summary

This chapter has detailed the rail environment and the current roles, technologies and strategies used to manage the rail network day-to-day. This information is important in understanding the role of planning and decision-making within rail signalling operations.

3. COGNITIVE ARTEFACTS AND PLANNING

3.1 Introduction

The classical view of cognitive ergonomics is concerned with the interaction between a system and the human mind and how one can affect the other (Hollnagel, 1997). A result of the information revolution through the 1950s and 1960s, where technology began to play a larger part in peoples everyday lives, cognitive ergonomics considers how technology can affect problem-solving, planning, reasoning and human attention. By looking at the interaction between the work environment and the worker, distributing the cognition across systems (whether social, technological, or people) can be a way of making work more efficient.

Hollnagel states three main aims of cognitive ergonomics:

- To identify or predict the situations where problems may arise
- To describe the conditions that may either be the cause of the problems or have a significant effect on how the situations develop
- To prescribe the means by which such situations can either be avoided or that impact reduced

In this rather simplistic view, Hollnagel states that cognitive ergonomics is concerned with the design of use of tools, considering the work situation as a whole and how actions may influence and be influenced by these. Any unwanted consequences are referred to as human error and that designs should work to minimise this. By concentrating on how human cognition affects work and is affected by work, it is possible to then establish how other parts of the system (such as other people, or cognitive artefacts) can influence how an operator carries out their work: they can be analysed together as a joint cognitive system (Woods and Hollnagel, 2006). The cognitive systems engineering approach that emerged in the 1980s (Hollnagel and Woods, 1983) aims to discover how people adapt to different situations by adopting different strategies and behaviours. By understanding how people behave, and how they interact and use available tools or aids in order to utilise their existing knowledge to handle real-world problems, we can start to understand how these behaviours and strategies can be optimised.

3.2 Cognitive Artefacts

Anything that aids, enhances or improves human cognition can be described as a cognitive artefact (Norman, 1990). These can range from a simple pen and paper, a graph, a list, a table of information, or a computer program. Norman (1990) expands this list to include any information source. The definition has evolved over time, and there is still not one complete definition for what something must have and provide in order to be a cognitive artefact.

Kaptelinin and Nardi (2006) argue that cognitive artefacts can change and improve cognition by being used collectively. Cognitive artefacts can be further split into two types: if an artefact has been developed by the user to make their job or task easier, this can be described as an endogenous. If an artefact has been designed externally by a third party and installed into the workplace with little design input from the users, these are described as exogenous (Jones and Nemeth, 2005). Any artefact can be used on a personal basis and used to distribute information within and between teams and groups. If an artefact has been altered or updated, then these changes can be easily observed by somebody else and adhered to as necessary; for example hospital status boards, or flight strips. In a study carried out by Xiao et al (2002) interactions were monitored between staff and a large display board in a trauma centre. A strip arrangement was used on a magnetic board where each strip indicated a scheduled surgical case. There were also colour-coded strips to indicate non-emergency cases, emergency cases, and non-scheduled cases. There were many standard annotations that staff used for instance a green dot on the top of the strip indicated that the patient was in isolation. Notes and messages could also be written in empty spaces around the board to alert staff of any issues or changes. Wears et al's (2007) study a similar display board that has been developed and further evolved by the users. They conclude (and building on previous work by Nemeth et al (2003)) that these boards must display six particular properties in order to be useful. They must be malleable, ecological, locally owned, widely available, informal and accessible. By being clearly visible, and easily manipulated, the board becomes part of the human cognitive system (Xiao et al., 2002) by displaying three key characteristics:

- It "remembers" cases to be scheduled and their current status and results
- It "displays" any constraints and different options to the user
- It "simulates" possible scheduling solutions.

The user can easily refer to the board at any time to get reliable up-to-date information about the complex system. Two key conclusions drawn from this research were that the board aided joint planning, and the size of the board (or any artefact) was vital to its success: particularly in collaborative environments: too small and it could not be seen by enough people at the same time, too big and the information was easy to miss.

One significant conclusion drawn from Wears et al (2007), is that when converting current artefacts such as the display boards into electronic artefacts there are two standout needs. These are the need to view the artefact from various different locations, and also store a trace of activity that can record any changes that have been made. Not only would this be important in a medical setting but also many other environments: Specifically the physically safety critical ones (e.g. transport air traffic control) where activities following particular incidents and accidents may need to be re visited or analysed. However in contrast, workers may use such artefacts in their non-electronic state to record notes and reminders that they do not wish to have permanently recorded.

3.3 Design and Evaluation of Cognitive Artefacts

There are many ways to approach the design of artefacts and interfaces. Some consider the technology first and foremost and focus on what the new technology is capable of. Alternatively, the most familiar approach within the field of ergonomics in human factors is the 'user centred' approach. By establishing the limits of human operators and exploring the decisions and problems they will have to face, the design can fulfil the expectations of the user. A control centred approach considers the human and machine as the system, and focuses on how they interact. By introducing predictive displays, the system may help the user by staying ahead of the process. An ecological or 'use centred' approach, (ecological interface design (EID)) looks at the issue in a broader sense and focuses on the interaction between humans and work rather than humans and machines (Flach et al., 1998), with an implication of "right information", "right time", and "right way" (Hollnagel, 1987). The methods have a strong focus on unanticipated events that pose the greatest threat to system safety (Vicente and Rasmussen, 1992) and the overall goal of EID is to make complex relationships and constraints in the work environment visible to the user. This enables the users' cognitive resources to be used for complex problem-solving or decision-making. This is consistent with the theory of computational offloading (Rogers and Scaife, 1998). The basic tenets of EID is that depending on how the information is presented one of three levels of cognitive control is activated. These are skill based behaviour, rule-based behaviour, and knowledge based behaviour, based on a well established taxonomy (Rasmussen, 1983). By using an abstraction hierarchy, this builds the picture of the system at different levels which can be used to determine what information should be displayed, when and how. The five levels are:

- Functional purpose - describes the goals of the system, the relationships between them, and potential trade-offs
- Abstract function - underlying principles that direct the goals of the system
- Generalised function - processes involved in the principles found at the abstract function level
- Physical function - the components required to carry out the processes identified at the generalised function level
- Physical form - what it will look like and the location of the components identified at the physical function level.

Cognitive dimensions are tools that use a checklist approach to evaluate the usability of 'information artefacts' (Green and Blackwell, 1998). Information artefacts can be interactive, or non-interactive. These tools are designed to encourage discussion and are designed specifically for non-specialists. The framework considers the concepts of notation (marks or symbols), environment (operations required to manipulate the symbols), and medium (how the information is displayed). Evaluating the artefact along 13 dimensions a 'profile' of the artefact is developed. Although the approach is aimed at all types of artefact, it seems to be more relevant for applications of programming language (Blackwell and Green, 2000). The cognitive dimensions have names such as; viscosity, role expressiveness and diffuseness, and are viewed by some as not translating well into an industrial setting (Clarke and Becker, 2003). For this reason, this approach was not used during this study as the nature of the data collection to carry out this method is very involved, and not suited to the environment studied. However, when used correctly, this approach can help to identify flaws in the design of an artefact and help to identify areas to improve.

3.4 External Representations

The value of external representations in problem-solving has been well documented. Larkin and Simon (1987b) compared sentential representations to diagrammatic representations and by using simple examples such as a pulley system they document a clear distinction between sentential and diagrammatic representations. They argue that a diagram can improve problem-solving by grouping all used information together reducing the need for searching data, and they automatically support perceptual interferences. However, if the right information is not grouped together sufficiently (and therefore able to be referenced by spatial location) the diagram may not help solve those issues. By using a diagram to display information the representation can offload cognitive processes from the user. In order to use a diagram effectively the user is required to use different approaches than the ones habitually used for interpreting an everyday environment (Cheng et al., 2001). The diagrams in themselves do not contain all of the information the user needs to interpret it correctly: How the user interprets the diagram can depend on the prior experiences and knowledge of the user. It is in interpreting the diagram and using it alongside knowledge and experience that can then lead a user to predict future situations, for example a diagrammatic representation of a weather map could be used to predict the weather for the following day. In order to do this however, the user must have prior knowledge of weather systems in order to create a mental model of the situation of which inferences can be made.

The distributed cognition approach explores how cognitive activity can be distributed across many different people, external artefacts and teams of people (Hutchins, 1995). This approach argues that the value is not in the individual, nor solely the internal or external cognitive activities, but that the distribution between a group of people interacting with artefacts can differ significantly from the cognitive properties of the individuals. Hutchins argues that it is the interaction between people and between artefacts that makes the system successful. One stand-out paper that considers the nature of external representations in problem-solving develops a theoretical framework from which to study the problem (Zhang, 1997). The framework (figure 20) considers the complexity of the mind and of the environment and considers all as a distributed system (Zhang and Norman, 1994).

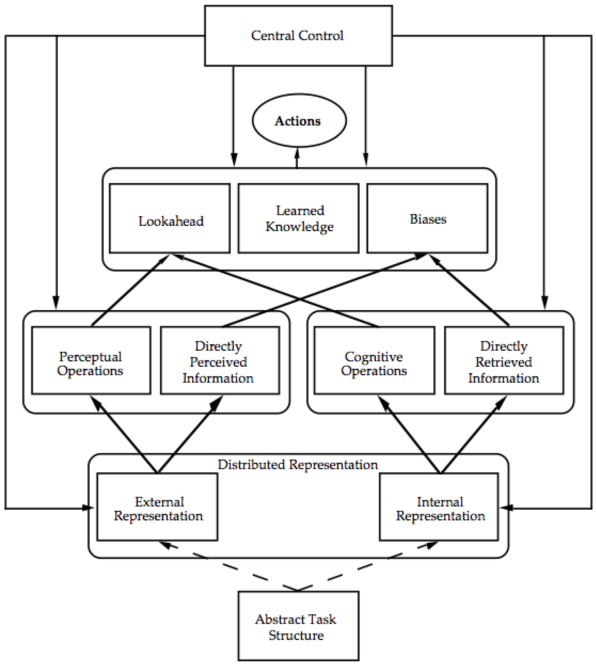


Figure 20 - External representations in problem solving (Zhang, 1997)

By breaking down each component of the mind and also the external environment this framework aims to present itself as a functional model and also a methodology. Zhang argues that external representation based problem-solving can be evaluated by considering each of the objects in the model. One of the main assumptions of this framework is that external representations provide information in their own right and when combined with internal representations can determine the problem-solving behaviour. The main point Zhang is trying to convey in this framework is that external representations are not merely inputs to internal functions; they support and influence actions (the third tier of the model). External representations contain information that can be instantly perceived by the user (Ware, 2012). This may be tasks such as identifying that objects lie on a straight line, or if there are two groups of objects of the same size. Cognitive operations that require computation or knowledge to be retrieved are activated by internal representations.

The next level of the framework considers the look ahead and biases. By mentally imagining a sequence of actions the user may consider several options and choose the best one of the task. Biases can either support the task or guide away from the goal. Learned knowledge acquired by completing a task more than once can influence both look ahead and biases. The ability to look ahead and 'plan' is dependent on the task. The more complex the task, the less likely it is to consider all of the possible sequences of actions that lead to the completion of the goal. At the top of the model is central control. This consists of the mechanisms of working memory and attention, decision-making, memory retrieval and so on (Zhang, 1997). Zhang argues that specific operations and behaviours are the result of different representations. By using a basic puzzle (tic-tac-toe) as the basis of this experiment, Zhang has been able to control the experiment extremely effectively in laboratory conditions. It is also extremely difficult to look ahead in this task, which mimics real life (often unpredictable) problem-solving scenarios. The main focus of the experiment is on the manipulation of the external representation and the effects this has on problem-solving. Zhang concludes that external representations are key components of cognitive tasks which can determine cognitive behaviour.

By using artefacts to assist with situations and to handle work a few authors, rather than considering the external artefact as a part of the system in the sense described above (distributed), consider artefacts as external inputs. Hollnagel (1997) describes how the use of reliable artefacts that result in predictable outcomes for the user can enhance the ability to be in control by providing additional capacity for the user as extended cognition. This theory only appears to work if one human is interacting with an artefact, as the constraints that this theory proposes (the output of the artefact being predictable) rule out another human to interact with. Hollnagel does state that the outputs of the human can be constrained through the use of rules and procedures but even then conflicts can occur, misunderstandings can happen and the output is unpredictable.

Scaife and Rogers (1996) build on this theory of extended cognition but constrain it to be only artefacts. They argue that by using an external artefact which can be a graph list or computer, utilising the predictable and constant outputs of these artefacts can lead to computational offloading for the user (Kirsh, 2013). That is, some of the cognition is taken from the user and carried out by the artefact. They identify three main types of computational offloading. These are:

- Re-representation - how external representations make problem-solving easier or more difficult.
- Graphical constraining - how graphical elements can constrain the interferences made about concept
- Temporal and spatial constraining - how representations can make relevant aspects more salient when distributed over time and space

3.5 Problem Solving and Planning

Problem solving can be described as being distributed across internal and external representations (in this case this could be the external presentations in the environment, the system or the individual task) which are then perceived in the "world" (Zhang and Norman, 1994). Scribner (1984) observed dairy workers placing bottles into crates and observed first-hand the trade-offs that are often made between planning (in the internal sense) and acting (in the external sense). Workers would often engage in mental calculation strategies so that the physical effort of moving bottles was reduced - hence the trade-off between the two. O’Hara and Payne (1998) introduced the theory of implementation cost. This accounts for the fact that the amount of planning that takes place when problem-solving is related to the external action and is dependent on task characteristics. The cost in this sense could be mental effort, physical effort or time and how these effect the external action. They argue that when the implementation costs are higher (for instance greater mental effort) the more efficient the solution. O'Hara and Payne (1998) conducted four experiments using a puzzle in which participants were required to enter a sequence into a keypad to make a move. The results showed that more planning took place when a longer keying sequence was required to be inputted. It also led to an increased understanding of the task. This would not be regarded as planning in a traditional sense: it is almost a preplanning activity, where users manage existing information, knowledge and physical aids to establish how best to carry out a task, consistent with Zhang’s (1997) framework. There have been many accounts in the literature of traditional planning studies, looking mainly at scheduling and focusing on the scheduler in terms of their task, role and monitoring activities (Jackson et al., 2004). Very few deal directly with this preplanning activity. Xiao et al (1997) describe a field study looking at the behaviours of anaesthesiologists. Xiao regards these as expert practitioners who manage complex systems. These practitioners are able to anticipate future tasks by using their knowledge and experience as an input. By focusing on the realisation of plans rather than just focusing on how plans are generated, Xiao et al were able to conduct a field study in order to understand the planning behaviour of anaesthesiologists during surgical operations. They refer to preplanning activities as preparatory strategies and they identified eight types of preparatory planning activity:

- Planning for contingencies - pre-empting troublesome scenarios
- Selecting foci of attention - identifying individual potential problems
- Reviewing options - using current information to guide
- Formulating general guiding rules - anything to avoid or specify
- Formulating local rules - ad hoc rules specific to one scenario
- Configuring the workplace - adjusting the working environment to be efficient for that scenario
- Placing triggering queues - reminders in the environment
- Making the workplace failsafe - eliminating sources of error

They also examined the properties of these planning behaviours and found some unique key features involved with them. One observation was that the anaesthesiologists combined mental and physical activities as in reconfiguring their workplaces to involve specific items in specific places, as well as preparing mentally. The researchers also found that the more experienced practitioners were able to pick out key points and keywords and identify issues and risks associated with them quickly during team discussion, which would allow them to prepare accordingly. They term this fragmentary planning, that is, the practitioner utilises their past experiences to only prepare for things that have potential deficiency. The standout point from this study was the clear emphasis on the identification of problems as opposed to the solution. The practitioners observed in this study appeared to account for a list of questions that were non-exhaustive, rather than generating sets of planned action sequences. From their extensive field studies Xiao et al propose a conceptual model of planning:

> "Human planning is a process of preparing action resources (as opposed to a process solely of formulating a collection of action sequences), and the functional role of planning is to enrich action resources (as opposed to solely controlling action sequences), thus enhancing one's ability to achieve successful performance in interactions with work environment".

One thing lacking from this study was the consideration of interruptions during these planning phases. Nystrom et al (2010) investigate the impact of similar and dissimilar interruptions presented during the planning phase of the task. Using a robust methodology based on previous research in the area they present participants with 'task similar' or 'task dis-similar' interruptions during a Tower of Hanoi task. Their results showed that interruptions were more disruptive if they were similar to the task they were carrying out. One thing this study does not account for however is acquired knowledge and experience and whether this affects the ability for the participant or practitioner to be able to continue with their task or indeed improve on their planning following an interruption .

This study provides a clear and comprehensive account of the utilisation of experience and prior knowledge in planning for, reacting to, and anticipating future events, and concludes that planning is not sequential and is a process of enriching resources. Although this is not a unique opinion, the importance of preparatory strategies in planning have previously been overlooked during the design of decision aids (Wiener and Curry, 1980, Carrera et al., 1991). Kirsh (1995) also focused on the function of space and the organisation of the workplace for planning and activity. They aimed to classify the functions of space and hypothesised that the properties of spatial dynamics simplify internal computation by observing people carrying out everyday activities, such as shopping, working, and playing computer games. They were interested in how people set up their environment in order to manage the workplace for a particular task. That workplace could be a computer screen or physical workshop for instance. The research observed people utilising many different strategies in order to make the problems less complex. Strategies such as grouping similar puzzle pieces together, and placing small items of a dismantled bicycle on a piece of newspaper were all regarded as ways to save themselves excess computations and minimise errors. They summarise that people form a tightly coupled system with their environments. Both Kirsh and Xiao demonstrate that a large portion of the problem-solving process can be seen to contain prior knowledge and experience in order to prepare their workspace and therefore alter their strategies to maximise gain and minimise computational effort.

3.6 Planning, Decision Making and Artefacts

By understanding the planning and decision making processes carried out by operators, tools and artefacts can be designed to assist with these planning activities. By utilising artefacts that have been adapted or designed explicitly to assist with that task, the artefacts can heavily influence how a task is carried out.

A much studied planning support tool is the flight strip used by air traffic controllers. Flight strips are generally used in a number of different ways. They provide the controller and any other trained person with vital information about the current state of the airspace under their control. The strips can also be annotated with any alterations that need to be made. This also provides a permanent record of any changes made to a flight plan. Durso et al (2005) mapped the activities carried out during normal operation of an air traffic control centre. Writing on the strips was the central activity and managing the strips was often done in bursts when required. Mackay (1999) also observed annotating activity and described how the paper strips allow the controllers to offload mental effort by doing so. In terms of eliminating paper flight strips, various attempts have been made to convert the paper method to an electronic version. Durso et al (2005) documents arguments from many different viewpoints ranging from the controller, engineers, and anthropologists. One of the main arguments they cited was that paper flight strips would not support future control sufficiently. New systems, new ways of working and advancing technology mean that having a way of interfacing the strips with these technologies would be beneficial. One conclusion that was drawn from a study from the late 1990s suggests that any electronic system should work in conjunction with radar, but replace the flight strips aspect of our traffic control. Fields et al (1998) suggest that any electronic system should be able to look into the future and display the current state of the airspace so that conflicts can be detected and routines could potentially be improved. However when different media provide similar information, Hutchins (1995) suggests that redundancy could be a factor in the robustness of the system.

In a rail specific example from the Netherlands (Van Wezel and Jorna, 2009) the researchers carried out a task analysis in order to design a planning support system. Many studies where a task analysis was involved in getting to a final design have been based around the theory that planning is a subset of problem-solving (Crandall et al., 2006). The planning tool designed as a result of this study still appears to be based on a very linear view of decision-making and does not appear to allow for the operator to use his or her initiative in degraded situations. Although, the authors do note that the algorithms described in the study and the bottom-up approaches used to design them would be useful to make a tool that would support problem-solving for small subtasks of larger tasks, rather than digitising everything.

There have been many examples of cognitive needs not being met resulting in a badly designed tool that was not used (Woods and Roth, 1988). They describe a situation where users become lost and "do not have a clear conception of relationships within the system, do not know their present location in the system relative to the display structure, and find it difficult to decide where to look next within the system" (Woods, 1984). Elm and Woods (1985) describes this as the “getting lost” phenomenon. The authors looked at an example of computerising a database application for a nuclear power plant. The system was designed by taking the current instructions as implemented on paper, and transferring them to a computer. It was found that the system was hard to navigate and it was difficult to recover the system after failure. Elm and Woods described this as “getting lost”, as participants were unable to keep up with plant behaviour and were unaware of what was going on. These results were replicated even by operators experienced in using the paper tools. The system allows the operator to easily see what was currently happening, but it is incredibly difficult to anticipate future instructions or keep a trail of recovery activities. The main conclusion, and a key feature of the redesigned system, was the ability to complete tasks in parallel (which was a feature of the paper-based tool that was not allowed when it was rigidly transferred to an electronic version) as not all tasks are sequential, especially in emergency situations.

3.6.1 Advantages of Paper-Based Tools

The resilience of paper, in particular for the purposes of individual and collaborative interaction, is a concept that has continued to prevent the redevelopment of many existing tools into electronic forms (Luff et al., 1992). From their observations of different organisational environments (an architectural practice, a medical centre and a London Underground control room) Luff et al aimed to establish how personnel used various different information sources in order to aid collaboration. They conclude that for artefacts to support collaboration they are informed by three factors:

1. The document’s tailorability - the ability to customise the documents to suit different needs, for different people and tasks
2. Their ecological flexibility - the ways in which the document can be used
3. Restrictions on the movement of personnel - the ability of the document to be shared

One behaviour they observed was on the London Underground control room, where staff cover their timetables with cellophane sheets, mark any changes on top with felt pens, then rub the changes away when they have been carried out or no longer relevant. The flexibility provided in this way of working enables the artefact to be tailored to a particular situation at that particular time. For example, based on the situation and the availability of staff at the time, the staff can tailor their annotations on the timetable to suit. Therefore if there is a second signaller on shift at the time, it may be necessary to write extra notes or annotate in a different way. This altered timetable can then be seen by anybody who is nearby, but in addition the new information on it can be conveyed to other parties via face-to-face communication, additional notes, telephone or radio. It would be very easy to replicate these paper timetables on a computer-based system, however, many artefacts are only ever brought into play or altered when things go wrong. With that in mind, annotating an electronic document when there are other issues to be dealt with could be considerably more difficult than annotating a paper document. Although some of the concepts regarding computer design within this paper are now considerably out of date (20 years), the fundamental concepts and their findings are still very current. Rogers et al (2003) took a similar approach to looking at the use of artefacts to aid collaboration. They also identify the use of a variety of media representations in order to aid collaboration within a working environment. Their main conclusion was that any additional artefact or information source bought into an existing environment must support the existing collaborative activity that is carried out. Both studies suggest that by computerising a more individual part of the process, for example electronic list timetables in the example of a London Underground control room would in turn aid existing collaboration and make information sources more robust. This is a message also supported by Payne (2013).

Nemeth et al (2003) again used the distributed cognition approach in their study within the medical domain. Their substantial study involving 25 nurses and 40 anaesthesiologists over several months led to some very specific recommendations that any cognitive artefact must contain in order to be beneficial in the work environment. As a minimum, an artefact must be:

- Accurate - it must be current and valid in its representation of the system state.
- Efficient - impose the least burden on users to create and use information.
- Reliable - available for use when needed
- Informative - contain information that pertains to circumstances of interest to the team
- Malleable - able to be manipulated by those who used them

These recommendations appear to be consistent with other significant work in this area. However in contrast to Luff, Nemeth et al conclude that all existing paper artefacts could be converted into electronic artefacts so long as the five recommendations were adhered to.

3.7 Situation Awareness

Endsley (1995, 2013) defines situation awareness as "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and projection of their status in the near future" and proposes a three level model of situation awareness (perception, comprehension and projection) that has stemmed from work in dynamic environments. The first two levels referred to the awareness and understanding of the situation. Level III refers to predicting the future state and continuous assessment which can be used to plan what to do. Any deficiencies in any one of these three levels can impact substantially on decision-making. Keeping the situation awareness up to date is a challenging task in a rapidly changing complex environment. Operators need to use this information to make effective decisions quickly.

From extensive work with pilots, Wickens (1995) suggests that a good level of situation awareness is vital in three areas:

1. The external environment
2. The system
3. The individual task

The framework Endsley presents provides a view of situation awareness in terms of its overall role in the decision-making process. How the information is presented to the user (in terms of design, layout, complexity and automation level) will have an influence on the Situation awareness of the user. By being aware of the environment and elements within it (level 1) they then add to this picture with experience and prior knowledge to form a holistic view of the environment (level 2).

The interaction with the external data presented to the user also becomes important and the accuracy of the user's built mental model is dependent on the level of expertise. By using learned strategies experienced operators can regulate their workload more effectively (Thunberg and Osvalder, 2006).

Many domains in which situation awareness have been investigated have a large element of naturalistic decision-making. It has been explained as "the way people use their experience to make decisions in field settings" (Ainsworth and Loizou, 2003). These decisions involve high-stakes, substantial time pressure, and often have to be made with a lack of information and across a team. Any wrong decision affects not only the individual but also the organisation. In Blandford et al's study (2010) looking at emergency medical dispatch, the operators often referred to 'a mental picture' that they used to manage the situation. This consisted of static and dynamic information from many different sources and at differing qualities. As the situation changes the operator (in this case an ambulance dispatcher) uses this changing information to build on this mental picture that is then used to evaluate and predict the outcome of any decisions.

By understanding how external representations and cognitive artefacts can aid decision-making and strategy development, as well as preparatory planning activities (as discussed in the previous section) we can start to identify how artefacts can assist in maintaining situation awareness in the three areas defined by Wickens (1995). By using a cognitive artefact to assist in maintaining and updating situation awareness the possibility of errors may be reduced.

3.8 Summary

This chapter aimed to identify the key literature relating to cognitive artefacts and planning. It has identified how cognitive artefacts may be used to aid decision-making and planning and enhance the performance as well as the situation awareness of these cognitive tasks. This is has highlighted the importance of well-designed artefacts to improve their benefits and the possibility of offloading some of the cognition from the user onto an artefact or tool. Several theories were discussed relating to the design of artefacts and their required attributes. These theories will be developed and discussed throughout the remainder of this thesis.

4. TECHNOLOGY ADOPTION

4.1 Automation and Electronic Tools

In Jenkin's et al's study (2010) the authors present an approach that aims to enhance system performance by using a structured method to develop an approach to design. The driver for their research was six questions that inform the design of the display:

1. Why is the information needed?
2. What information is required?
3. When should the information be displayed?
4. Whom should the information be presented to?
5. How should the information be represented?
6. Where the information should be presented?

Question one is often overlooked when new systems are being designed. If the users see no clear benefit in the new system, artefact or tool then they are unlikely to think of it as useful.

The main issue faced when introducing new or replacement technologies into established environments is whether it will be willingly accepted and effectively used by users (Venkatesh et al., 2003), especially when the current systems are well used. There is much literature within the Information Systems field that aims to measure and predict the acceptance of a new technology within the context of a working environment using quantitative methods. One of the most well known, validated (King and He, 2006, Faaeq et al., 2013) and replicated of these is the Technology Acceptance Model (see figures 21 - 23) (Davis, 1989b). This has been adapted and added to in the past 20 years (see Venkatesh et al. (2003) for a review) but the basis remains the same: the uptake and acceptance of any technology can be determined by perceived usefulness and perceived ease of use, with perceived usefulness found to have the greatest influence (Davis, 1989a).

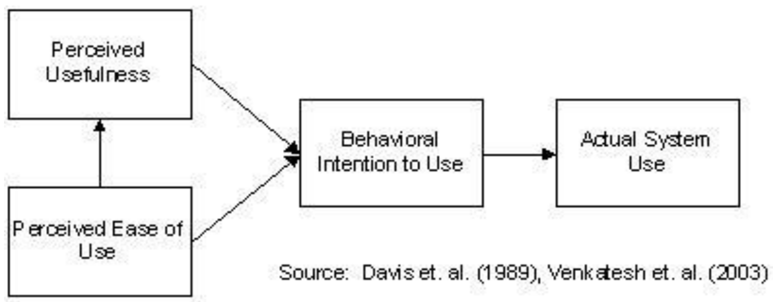


Figure 21 - Technology Acceptance Model (TAM)

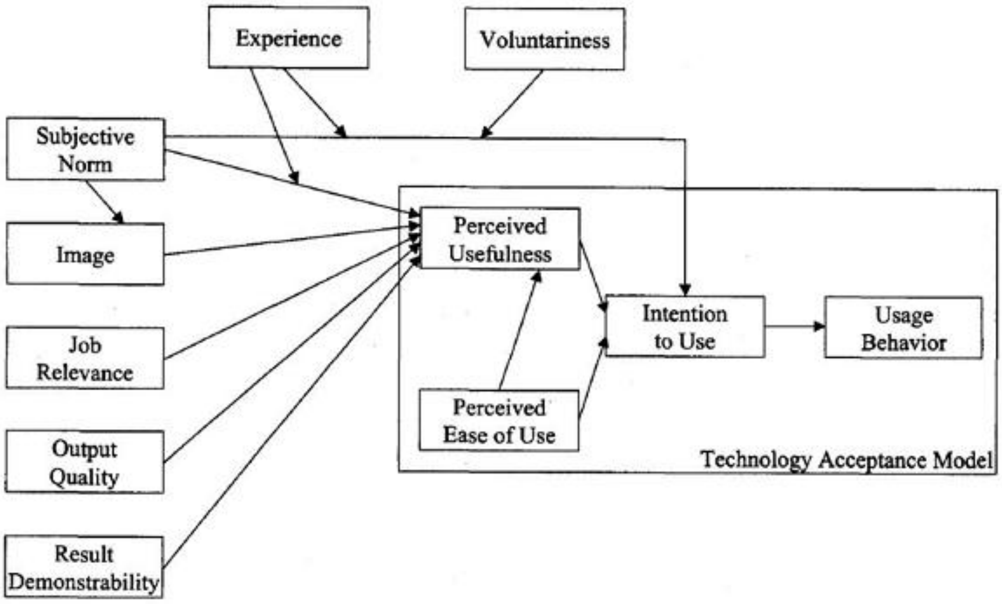


Figure 22 - TAM 2

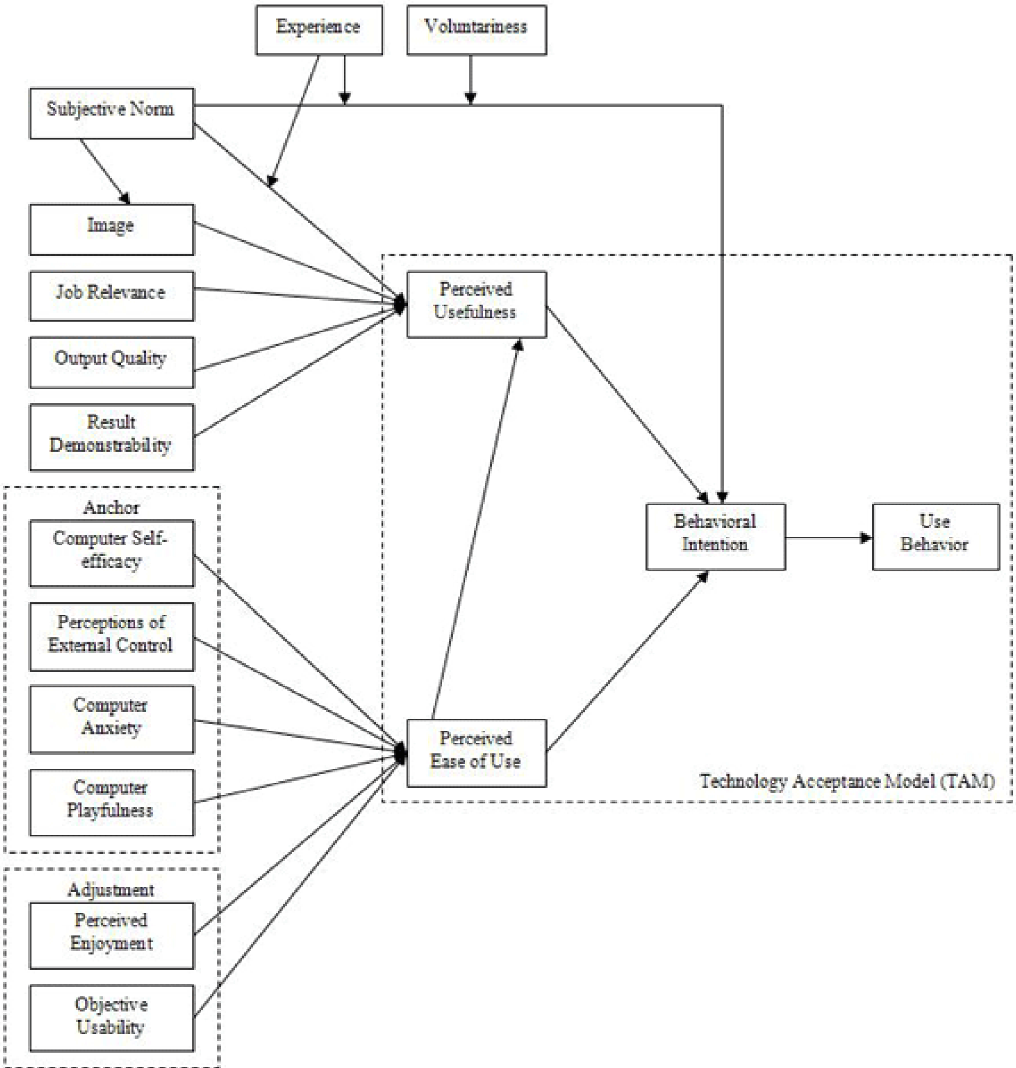


Figure 23 - TAM 3

Although TAM provides feedback about general usefulness and ease of use, it does not provide specific feedback about the artefact itself. Roger's (1995) Innovation Diffusion Theory (IDT) however, specifies different characteristics of a system that are believed to determine the acceptance and rate of adoption, and therefore can provide more identifiable feedback for use within a design process. These characteristics are:

- Relative advantage
- Compatibility
- Complexity
- Trialability
- Observability

The first three have been shown to have the greatest influence on uptake. Relative advantage and compatibility were positively related to innovation adoption ($p<.05$) and complexity negatively related to adoption ($p<.062$)(Tornatzky and Klein, 1982). These are the characteristics that directly compare the technology to existing systems. If users perceive the new technology as advantageous over existing ones, compatible with their existing ideas and values and perceive the system to be easy to understand and use then uptake is more likely. Of course, this is easier to measure or report if a new system is replacing an existing one; if the new system is offering novel functionality or it is likely or intended to change the way in which a job or task is completed, these characteristics may be harder to apply. Trialability and observability are characteristics more concerned with the rollout of a new technology. The additions to TAM, known as 'TAM2' (figure 22) made by Venkatesh and Davis (2000) suggest key forces underlying judgements of perceived usefulness that are complementary to IDT. The researchers then developed TAM further, leading to TAM3 (figure 23), where they propose a number of determinants of perceived ease of use. These are almost stand-alone additions to TAM2 in that the determinants of perceived usefulness will not influence perceived ease of use and the determinants of perceived ease of use will not affect perceived usefulness. The main addition in the new model is the effect of experience will increase the influence of perceived use on perceived usefulness.

4.2 Adoption of Technology

Rogers (1995) also suggests that users can be divided into five categories depending on the speed of uptake. These are: innovators, early adopters, early majority, late majority, and laggards. Rogers estimates that innovators and early adopters make up 16% of the population whereas adopters and laggards account for 50%. In a study looking at purely IT adoption, 326 participants were used that stemmed across the five categories that Rogers suggests (Agarwal et al., 1998). This extended Rogers' theory by using belief, personality and attitudinal variables to categorise adopter categories. They hypothesise (among others) that early adopters of an IT innovation have more positive attitudes towards the use of the innovation than do late adopters and early adopters of an IT innovation exhibit greater personal innovative use in the domain of IT than do late adopters. All seven of their hypotheses were supported by the data and appear to support the theory that there are differences in attitudes between early and late adopters of IT technology. Again focusing on IT adoption, Moore and colleagues (1991) again use Rogers' Innovation Diffusion Theory as a basis to develop a tool for studying the initial adoption of innovations. The tool consists of eight scales designed to measure voluntariness, relative advantage, compatibility, image, ease-of-use, result demonstrability, visibility and trialability. This tool although a good starting point for many investigations, only considers the initial adoption of innovations and does not consider long-term use and must be adapted for different situations.

4.3 Trust

Trust was also found to be an important issue in the uptake of technology. There have been many studies addressing this topic in different environments and using different drivers (Doney and Cannon, 1997, Koller, 1988).

Muir and Moray (1996) propose a model of trust that contains six components which are: Predictability, dependability, faith, competence, responsibility, and reliability. They state that trust starts with faith, then the other components come into play with operator experience. This theory addresses the issue of the initial trust in the system, whereas it does not take into account past history or experience with the system or technology. One study that does, identifies process, purpose, and performance as trust constructs and give some insight into why the technology was developed or parts of it automated (Lee and Moray, 1992). These two theories appear to be complimentary to one another and also appear to support TAM2 and TAM3.

One aspect that the Technology Acceptance Model doesn't deal with directly is reliability. This can seriously affect the operator's trust of the system (Wickens and Xu, 2002). If a system is not very reliable this can have the potential to undermine trust in the system and therefore outweigh any potential benefits that the system could potentially provide (Parasuraman and Riley, 1997). Likewise if there are any faults in the system, the operator is less likely to trust it as the expectation of any system automated or otherwise taking over from human operator is that it will operate perfectly (Lee and Moray, 1992). Moreover, the type of fault will affect the level of trust in the system. If there is a fault in the system that is unpredictable and inconsistent, then this will have a greater effect on the trust of the system rather than a significant but expected fault (Muir and Moray, 1996). This is because if a fault is regular and expected, then the workaround that the operator develops becomes the norm. Another aspect that affects the trust of the system is the availability of data. If the automated system bypasses the raw data and is no longer available then the operator is less likely to trust the system (Hoffman et al., 2013). If this is available the operator views it as more reliable, as the raw data is available if things go wrong.

A substantial and concise literature review on the topic of trust carried out by Atoyan and colleagues (2006) concludes with a number of recommendations drawn from the literature about how to increase trust in new decision aid systems. One of the overarching themes of their conclusions is that the user should always be aware of why the automation is there. This parallels quite nicely with the work of Lee and Moray (1992) that users need to feel that the automation has a purpose and this will serve as a building block to trust in the system. Another key factor and one considered here to do with trust of the system is that the user should always be aware of when the data are incomplete, unreliable, invalid, or missing. If the user is not aware of these facts, they will not trust the system as they will feel that it is giving them incorrect information. If the user is aware of the fact, then they will devise processes and workarounds to compensate for such errors. In this case it is likely that they will still trust the rest of the information. Drawing on the ironies of automation (Bainbridge, 1983) Atoyan highlights the importance of the automation being adaptable. If the automation is rigid and does not coincide with the user's existing mental model than they are less likely to use it successfully. They also concluded that trust and perceived usefulness and ease-of-use are closely linked.

One study addressing trust and risk with regards to the technology acceptance model is a 2003 study concerning consumer acceptance of electronic commerce (Pavlou, 2003). Although this study is concerned online commerce, the concept of trust is applicable to most technology acceptance fields. Trust is a key determinant of perceived usefulness, and Pavlou's study found that trust is a significant predictor of actual transaction intentions ($p<0.01$) i.e. the intention to use the technology. The research also found that the effect of trust on perceived usefulness, perceived ease of use and perceived risk was significant.

Within the framework of the TAM, users have been found to perceive the technology easy to use if they have prior experience of the technology (Gefen et al., 2003) . In some cases however, the existing technology will remain in place when the new technology is introduced. This means that use of the new technology is not compulsory and the users are not being forced or required to use it. This is useful from an analytical perspective (if the use of a technology is non-compulsory then it can be assumed that use of the technology is an indicator of its successful adoption, and, in terms of TAM, perceived usefulness or ease of use) but may also be a disadvantage as users may be less willing to persist with learning how to use the technology or overcoming initial barriers to use or concerns, and thus may be quick to reject or ignore the new system. However, some examples of technology in the literature are completely voluntary, such as Internet banking or on-line shopping. Some technologies could not present any new data to the user; it may just display data differently – therefore the change to the task is potentially in the form of supporting reasoning or decision-making with existing data sets, rather than enhancing the cognitive tasks by providing new data.

If the users have prior knowledge and experience of a system, as rail staff have experience of the railway system, they also have existing mental models of how the new technology should work. When introducing new technologies, Zhang and Xu (2011) argue that the existing mental models of users need to be modified or restructured in order to continue to guide their interaction with it. If the new technology does not fit the existing mental model, it can lead to frustration for the operator and will affect uptake and adoption (D Apollonia et al., 2004). Existing familiarity however has been shown to lead to increased trust with a system and also lead to an increased belief that the technology is easy to use (Gefen et al., 2003).

4.4 Summary

This chapter discussed the notion of technology acceptance and adoption when considering integrating newly designed tools into working environments. The importance of considering the end state of the tool in terms of user acceptance and perceived ease-of-use can clearly be seen in this chapter. By considering the users' needs as well as potential issues with system trust the tool has a higher chance of being accepted. The technology acceptance model is used as a basis for the methodology and discussion of an artefact studied as part of a case study in chapter 7.

5. QUALITATIVE STUDY OF RE-PLATFORMING

5.1 Introduction

This chapter covers the qualitative research carried out into existing planning strategies used by signallers to manage the station area, particularly during disruption. More specifically, this case study is focussed around the artefacts used by signallers and Shift Signalling Managers (SSMs) to assist in this real-time short term planning activity. Qualitative data were collected at a number of suitable stations, where a variety of tools were available to the signallers. The wider scope of this chapter is to draw conclusions from this case study to address the first two thesis research aims with a focus on station areas:

1. To understand the existing strategies used by signallers to regulate and re-plan.
2. Evaluate existing decision support tools and their use and integration into signalling environments.

A methodology was developed that combined aspects of Cognitive Task Analysis (CTA) and Cognitive Work Analysis (CWA) in order to understand how decision support tools currently aid the signallers, and therefore how new versions of the tool can be designed in the future. It will also contribute to fundamental understanding of how people use and interact with physical artefacts to support real-time decision-making. The challenge from a cognitive ergonomics perspective is to establish the impact existing artefacts have on decision-making, and ensure any future tools complement the existing systems and processes.

The organisation and planning of the running of station areas within the UK Rail Network is a complex task. Trains must arrive in their correct platform, at the planned time, so that passengers can travel on the right train. Timetables are worked out months in advance and every train unit has a specific planned 'working timetable', based mainly on the maintenance requirements of the particular train. Minor disruptions and timetable changes can happen frequently, typically 20 times per day for the stations in this case study. When disruption occurs, the operator (the station signaller) must plan around the problem and ensure that movements return to the planned timetable as quickly as possible keeping disruption and delays to a minimum. Due to the density of the working timetable and layout of specific stations, often minor disruptions can then lead to significant knock-on effects which require further operator attention.

The movement of trains in the station area involves co-ordination within and between groups. Typically the Train Operating Companies (TOCs) will inform the SSMs of any changes to the timetable. These changes are then fed to the signaller who makes the change and signals the train into the correct platform. Any changes may then have to be communicated to many sources, including TOCs, station staff and train drivers (see Figure 24.)

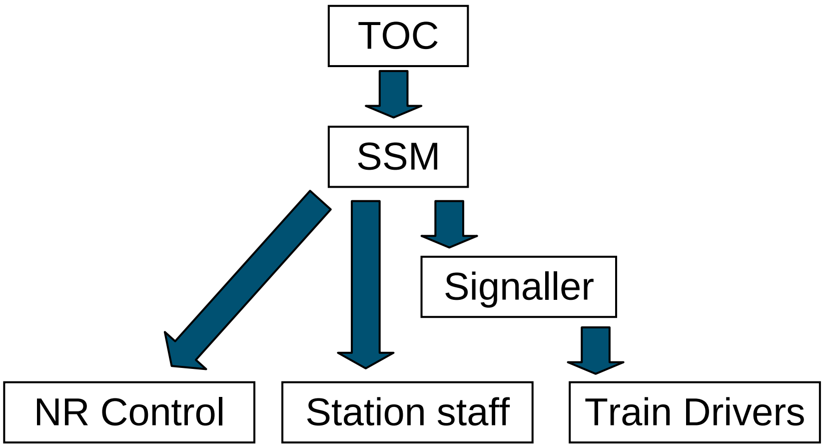


Figure 24 - Example of information flow

Most signallers use list based representations to handle the station areas, many using two lists: one showing the trains in arrival order and one showing the trains in departure order. Some use a graphical representation. See section 2.5.4 for a description of these tools, and Figure 14 and Figure 15.

From a human factors perspective, by capturing how these tools have evolved and are used, we can develop a fundamental understanding of how the planning tasks are completed by the joint cognitive system of the signallers, artefacts and technologies.

5.2 Methodology

5.2.1 Methodology rationale

The starting point for this study was a tool used to manage train operation at Glasgow Central Station. There was anecdotal evidence that this tool enabled signallers to manage the station area efficiently, and minimised delay. In order to address the research questions in this thesis, it is important to extract richer data on exactly how the planning activity is currently carried out using the tools available, and identify the key issues that need to be addressed in future design activities. This section describes the qualitative methods used and their suitability for this case study.

The initial visit at Glasgow took place with the assistance of an Subject Matter Expert (SME), providing accurate insight into the situation and a good basis for the start of the development of the research questions (Farrington-Darby et al., 2006). This initial visit along with other operational visits and key literature provided the initial stimulus for the case study.

In order to accurately capture the characteristics of real-world behaviour, methods were utilised from the naturalistic decision-making (NDM) domain (Klein, 2008). Calling upon guidelines set out by Orasanu and Connelly (1993) this case study appeared to fit within these boundaries. Table 5 contains the key factors of NDM and those specific to this case study with appropriate details.

Table 5 - Key factors of NDM and factors specific to this case study

Key factor of NDM	Specific to this case study
Ill structured problems	Problems are not well defined and the signallers often do not have access to all the appropriate information
Uncertain, dynamic environments	The railway is changing minute by minute and a problem identified 5 minutes earlier may no longer be an issue
Shifting, ill-defined or competing goals	The signallers may have to take account of information from other signallers, SSMs, Network Rail control and TOC control.
Action/feedback loops	The outcome of one decision will influence the action taken for the next problem
Time stress	Network Rail are charged by the minute for late trains
High-stakes	This industry is safety critical; signallers have to make decisions with safety at the forefront of their thinking
Multiple players	There will be various people involved in every decision made by the signaller, from station staff to drivers to TOC controllers and Customer Information Service (CIS) personnel
Organisational goals and norms	The wider goals of Network Rail must always be adhered to and the goals of the TOC and FOC companies must also be taken into account

It was first necessary to understand the process of re-docking trains, so a Task Analysis was carried out. From the early work of Taylor (Hammond, 1971), through to the development by Miller (2005) considering inputs and outputs, Task Analysis has been used as a way to optimise working practices by understanding the processes that an operator goes through when completing their task. As work practices have developed and more automation has been introduced, there became a need to develop a method by which to study these decision-making and problem-solving tasks. Cognitive Task Analysis (CTA) was developed to counter this problem (Rasmussen, 1985). CTA techniques aim to understand the cognitive functions of work and describe how they are accomplished in real work settings in order to define how the cognitive functions can be better supported (Naikar, 2006). Commentary from the SME indicated that the signaller was making some complex decisions when managing station areas, and so traditional task analysis methods would not be sufficient (Ryder and Redding, 1993). Sufficient focus was required on the cognitive aspects of the task and so a CTA approach was considered the most appropriate. This approach builds on task analysis, and tries to “account for the variability in behaviour caused by differences in knowledge and cognitive strategies...focusing on the tasks and actions required to achieve systems goals” (Vicente, 1995).

Cognitive Task Analysis does however have limitations, especially when looking at future use and future design in environments that deal with unanticipated events. By utilizing certain aspects of Cognitive Work Analysis (CWA) (Vicente, 1999) it is possible to identify the key decisions that are made and makes it possible to predict how new systems may affect work. Rather than focusing on tasks alone, this method also looks at what operators act on; the work domain. The stimulus that makes them carry out their tasks that can be identified using CTA. CWA is a way of ensuring that new systems are able to cope with those events efficiently, unlike CTA. This allows unanticipated events to be designed for (Vicente and Rasmussen, 1992). Specifically within the rail domain, operators may deal with unanticipated events daily.

The overall philosophy of CWA is a formative approach and the objective is to determine how computer based support systems could be designed in order to allow workers to meet the challenges they face.

More specifically, CWA:

1. Models the context in which the activity takes place, not just the activity
2. Theoretically motivated layered approach to the analysis, design and evaluation of human computer interactive systems
3. Aims to design interfaces that are uniquely suited to support human activity in previously un encountered situations – i.e. using an electronic, semi automated tool to aid decision-making / problem solving and in turn, planning
4. Recognises that the main role of human operators in modern complex sociotechnical systems is to deal with unanticipated events
5. Focuses on the constraints (rather than particular ways of working) that shape the work in the first place and deal with the work patterns that workers form to deal with unanticipated events (Lintern, 2009)

Rather than using the strict framework proposed by Rasmussen and colleagues, the researcher has aimed to recognise the importance of the CWA approach and build the ethos of this into the initial data collection and analysis. Table 6 shows a list of the kinds of questions that should be asked in order to design interfaces that support unanticipated events. These questions are mapped to the dimensions commonly referred to within CWA.

Table 6 – Example questions to ask in analysis (Fidel and Pejtersen, 2004)

Dimension	Examples of Questions to Ask in Analysis
Environment	What elements outside the organization affect it?
Work domain	What are the goals of the work domain? The constraints? The priorities? The functions? What physical processes take place? What tools are employed?
Organizational analysis	How is work divided among teams? What criteria are used? What is the nature of the organization, hierarchical, democratic, chaotic? What are the organizational values?
Task analysis in work domain terms	What is the task (e.g., design of navigation functionality)? What are the goals of the task that generated an information problem? Constraints? The functions involved? The tools used?
Task analysis in decision making terms	What decisions are made (e.g., what model to select for the navigation)? What information is required? What sources are useful?
Task analysis in terms of strategies that can be used	What strategies are possible (e.g., browsing, the analytical strategy)? What strategies does the actor prefer? What type of information is needed? What information sources does the actor prefer?
Actor's resources and values	What is the formal training of the actor? Area of expertise? Experience with the subject domain and the work domain? Personal priorities? Personal values?

Due to the lack of prior research in the railway domain relating to re-platforming, it seemed appropriate to use semi-structured interviews to gather data from signallers. Utilising the initial visit and existing research (Roth et al., 2001), interview questions were developed. However a more structured approach was required that was able to fulfil the requirements of the combined CTA / CWA approach described above. One such method is the critical decision method (Klein et al., 2002), which is described as a knowledge elicitation strategy. Consistent with CWA, CDM uses a set of probes to determine how operators interact with their environment in order to make decisions during non-routine incidents. The CDM aims to probe different aspects of the decision making process and identify where the operator utilised prior knowledge to handle a non-routine situation. It is a retrospective interview strategy that focuses on a past experience or incident by using a set of cognitive probes. It follows a five-step process to build a complete picture of the incident and the decision making strategies involved.

1. Select incident - an incident or event should be chosen that illustrates a non-routine procedure
2. Obtain unstructured incident account - the operator should be asked to describe the incident from a certain point (such as an initial alarm or telephone call) to a certain point (such as returning to normal operations)
3. Construct incident timeline - construct a timeline consisting of key events
4. Decision point identification - decision points should be identified on the timeline and any decisions that were seen as having potential alternatives should be investigated further (see point 5)
5. Decision point probing – use a set of probes to investigate further the options for each decision.

This approach was chosen because it appeared well-suited to the ad hoc nature of the majority of the data collection. In an environment such as the signal box where the operator is carrying out their duties, a structured interview would be too restrictive. Although specific incidents were not the focus of this case study, operators were asked to "think of a time when…" thus recounting an incident retrospectively. Therefore, using CDM as a basis for questioning it was possible to get a thorough account of potential situations encountered by signallers.

Using Glasgow as the first station in this case study, 7 other stations were subsequently examined. The following questions were addressed during the study (adapted from Roth et al (2001)) utilising the CTA / CWA approach discussed above. These questions were derived to help support the overall aims of this thesis, specifically to understand the current strategies used by signallers when re-planning:

- What decisions are the SSMs / Signallers now making?
- What are the inputs to those decisions and what are the outputs?
- What are the main factors affecting the possible outputs?
- What information is currently communicated / shared between the SSMs / signallers and the TOCs and other train personnel, and what information is not currently shared but would be useful to share?
- Complicating factors that make managing station areas difficult:
    - Physical characteristics (station, trains),
    - Organisational factors (job role, TOC role),
    - Number of trains per hour.
- The strategies that they have developed to facilitate performance and maintain the big picture:
    - What do they do? How do they do it? Who do they contact?
    - Where do they get their information from?
- The communication systems and how they are used.
- Information sources available and how they are used.
- The artefacts within the control room and how they use them:
    - Docker, simplifier, notes,

- The computer systems in the signal box and how they use them
- Suggestions for improved communication systems and/or computerized support systems.

Although the interest was not in specific 'incidents', the nature of the questioning technique and the probing method of CDM seemed suited to exploring the domain further in terms of specific tasks and key decisions in order to allow information to emerge in an exploratory manner. A total of eight signal boxes were visited at least once (referred to as boxes A – H). A visit typically lasted three hours, but due to the nature of the domain, availability of signallers was opportunistic. SSMs were spoken to at all sites visited, and if signallers were instrumental in the management of disruption at a particular site then they were interviewed. A total of 11 SSMs and 14 signallers were interviewed. All participants were on shift and performing their tasks during the visits, so around 30 hours of general observations were also gathered.

By using the methods and approaches described approve, a better understanding of how the work is performed and how different artefacts are currently used to support it was established. The processes investigated in this case study are existing processes (re-platforming and regulating) using existing systems (TRUST, CCF etc). These processes and systems will remain in place but new technology is planned to replace / support them. It is in this context that the qualitative research into the current use of artefacts to support planning was carried out.

The results from the qualitative analysis was analysed using three broad categories, based on the Roth et al (2001) study:

- Situation analysis and diagnosis (What are they doing? What information do they have? etc)
- Evaluation (How is information communicated? What artefacts are used? etc)
- Planning and scheduling and execution (How is the operation carried out? How do they record it? etc)

Separating the work in this manner is also consistent with existing theories of planning and decision-making in that by utilizing preparatory procedures (analysing and evaluating the situation) in combination with their expert knowledge, users can respond easily to on-going events and plan for future tasks (Xiao et al., 1997).

5.3 Research Method

5.3.1 Stations

The stations were selected based on:

- Number of TOCs
- Complexity of station area
- Number of signalling panels
- Type of docking tool
- Type of signalling system

Eight stations were selected that were considered to have a good cross section of the above features. The selected stations were then discussed with an SME to validate their suitability. Other points were considered during this process, such as whether Automatic Route Setting (ARS) was present or not, and the grading of the signallers. As a result of these discussions one of the initial eight choices was discarded and an alternative substituted.
A summary of the stations selected and their attributes is given in table 7.

Table 7 - Summary of stations used in qualitative case study 1

Station:	A	B	C	D	E	F	G	H
Number of Panels	1	1	1	2	2	2	1	1
Terminus Platforms	14	9	6	24	19	9	0	11
Through Platforms	0	9	0	0	0	6	12	6
Control System	VDU	VDU	VDU	NX	NX	NX	NX	VDU
ARS	No	Yes	Yes	No	No	No	No	Yes
Type of Docker	Graph	Graph	List	List	List	List	List	List
Signallers	1	1	1	2	2	2	1	1
TOCs	5	5	1	1	2	3	5	6
Type of Stock	Diesel and Electric	Diesel and Electric	Diesel and Electric	Diesel and Electric	Electric	Diesel and Electric	Diesel and Electric	Diesel and Electric

5.3.2 Participants

Eleven Shift Signalling Managers (SSMs) and fourteen signallers were interviewed for the study. Each participant had at least four years signalling experience.

5.3.3 Apparatus

If the participant was willing, the interview was audio recorded. If not, the interview was recorded in note form on a pre-printed proforma (Appendix A).

5.3.4 Procedure

The Local Operations Manager (LOM) was contacted at each location with an explanation of the information that was required and also what the research was exploring. All of the LOMs contacted replied positively and initial visits were arranged and carried out.

The signaller was first informed of the research objectives and was asked to give their verbal consent. If the signaller agreed to the visit being audio recorded, the recording was started and they were asked to give a brief explanation of their panel, describing the control area, traffic density, and anything that made their area unique. During the initial visits general data were collected about the station and recorded on the pre-prepared form. Each visit lasted an average of 3 hours and was carried out while the signaller was carrying out their normal duties. During this time, the signaller was asked questions following the semi-structured format that was developed (described in the previous section) and general observations were also recorded. Care was taken not to be too intrusive due to the real world nature of the environment, and the interview put on hold or even postponed if the signaller was experiencing high pressure or a serious incident.

5.3.5 Analysis

The data gathered during the interviews and observations were analysed using theory-led thematic qualitative analysis (Hayes, 2013).

5.4 Results

Transcripts for all of the recorded interviews were made as soon as possible following the interview. Notes were taken during all of the interviews and these were typed up and collated as soon as possible after the visits. Each transcript was coded twice and analysed using NVivo to code and group the data. Initially, 50 themes were identified, which were then reduced to 26. These were sorted into three top level groups (consistent with Roth et als (2001) work) via a card sorting exercise with 3 SME's. Card sorting was used as a way to condense the data and make it manageable and easier to present. The three top level groups resulting from the card sort were:

- Problem interpretation
- Evaluation
- Solution implementation

These three high level groups were used as the basis for the layout of the data in the remainder of the chapter.

5.5 Cognitive task analysis

Sorting the data revealed various tasks carried out by the signallers as well as situations they were carried out in and various limiting factors. During the focus group session with SMEs (3 SSMs based at Glasgow and Edinburgh) these data were grouped into five key situations and six functions encountered when re-docking trains. These are highlighted in blue in table 8.
The processes used when re-platforming using the Docker have been described fully in Appendix B.

Table 8 - Key themes from interviews

	Observations	Interviews	Freq. (comment)	Freq. (Participant – max 25)
Problem interpretation				
-Communication	X	X	15	9
-Disruption	X	X	69	25
-TOC involvement		X	56	20
-Planned changes		X	35	16
-Ad-hoc changes		X	29	13
-Regular situations				
Late running trains		X	72	25
Cancelled services		X	55	22
Stock swap requests		X	47	19
Line blockage		X	12	12
Platform blockage		X	9	8
Evaluation				
-Trial and error	X	X	15	4
-Heuristics	X	X	33	18
-Performance		X	12	8
-Platform attributes	X	X	34	19
-Train attributes		X	13	6
-Information	X	X	36	16
Solution implementation				
-Time		X	4	3
-Telephone	X	X	16	5
-Station staff		X	23	11
-Regular functions				
Stock swaps	X	X	41	16
Spare train	X	X	15	5
Step-up sets	X	X	32	14
Split Sets	X	X	12	10
Join Sets	X	X	13	10
Re-Dock trains	X	X	55	25

Five regular situations were identified that may require action from the SSM / signaller which can be seen in table 8. Each situation can take many forms. For example, a line blockage could be due to a failed train, a points failure or an animal on the line. It may be on a route into the station or at the station neck. However, despite this variation, they were treated as one situation. These were dealt with by signallers by using one of the six work functions identified (table 7). These six work functions can be further reduced to two basic functions used in the station area: re-docking (moving a train to another platform); and "stock swaps" (moving the service of one train to another physical train). Stock swaps cover the work functions other than re-docking as they are all essentially different instances of changing service from one train to another. The general process involved to manage this in the station area is similar despite the particular way the new stock is made available.

The basic function processes (re-docking and stock swaps) are presented as flow charts in Figure 25, Figure 26 and Figure 27. Figure 25 and Figure 26 show the flow chart for re-docking, without and with decision points marked respectively. Figure 27 shows the flow chart for stock swaps, with decision points marked.

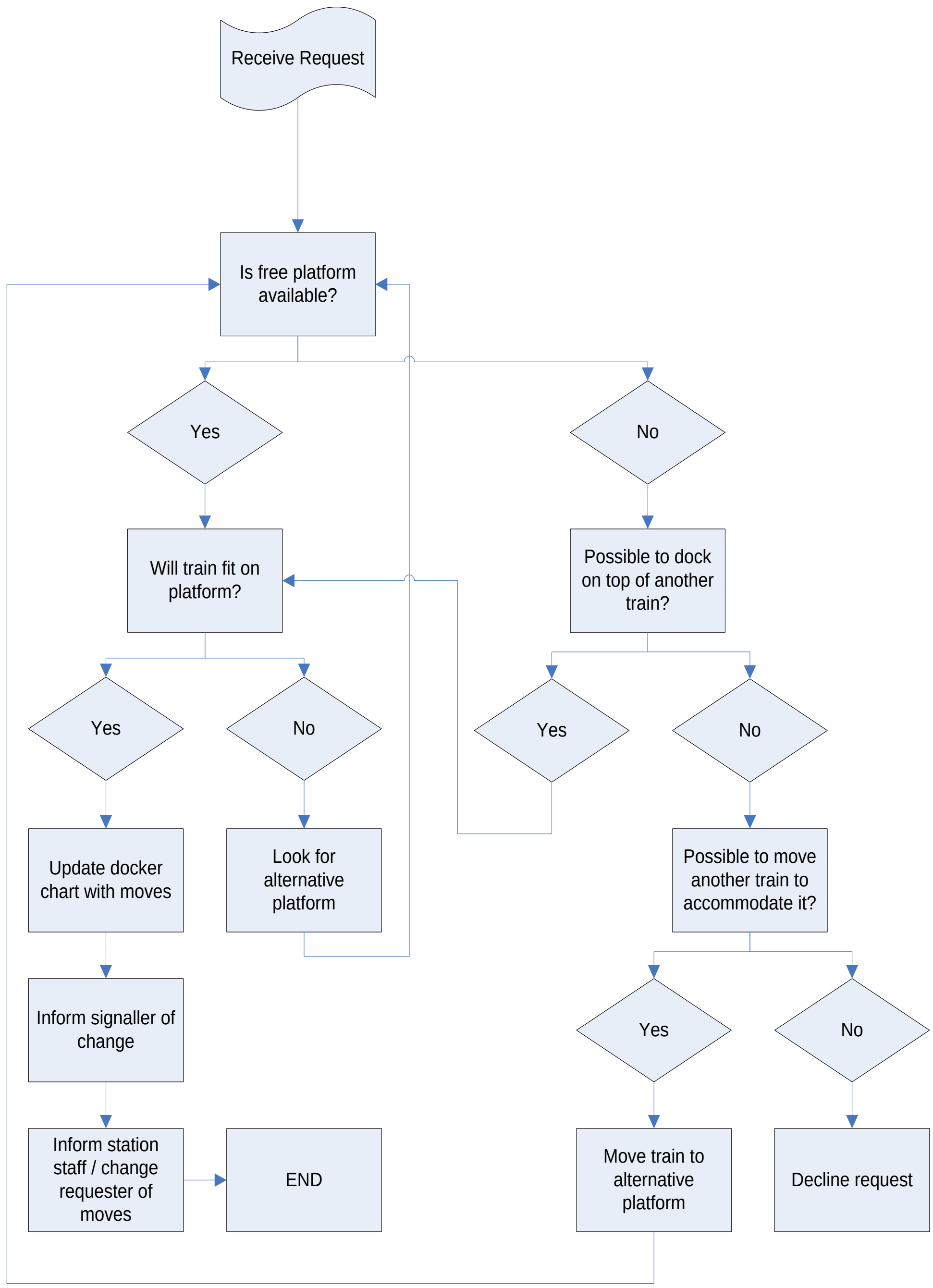


Figure 25 – Basic function: Re-docking train

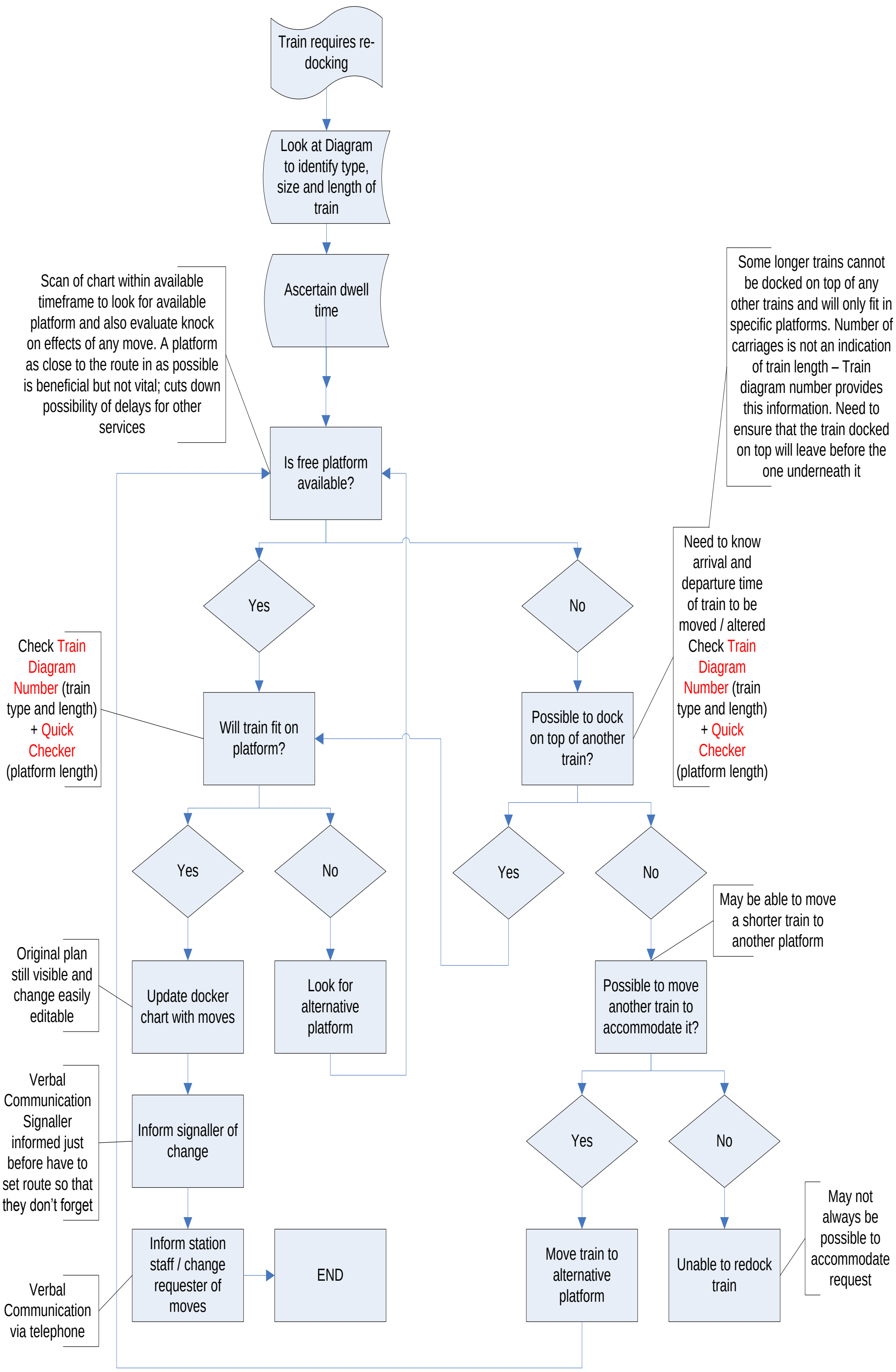


Figure 26 – Basic function: Re-docking train (with decision points)

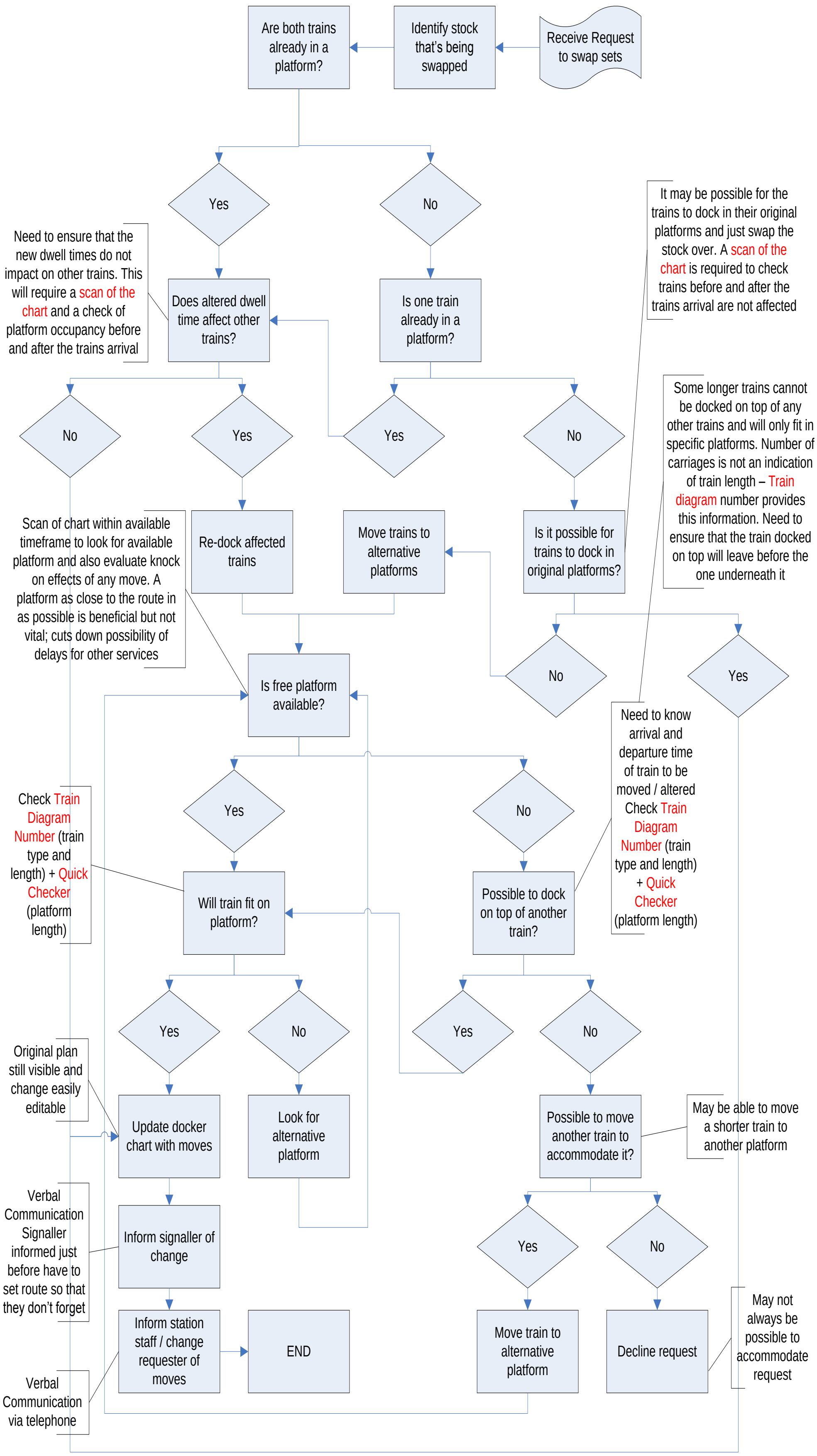


Figure 27 - Basic function: Stock swaps (with decision points)

The key decisions when carrying out these functions are summarised below in table 9. This format is adapted from Roth et al. (2001); the additional 3 columns (limiting factors, input / artefacts and communications) were added as they emerged from the data. Limiting factors was seen as important due to the number of factors that affect the decisions that are made. Input / artefacts is a key point of interest for this research. Communications were deemed to be important as who is instrumental in aiding decisions and how these decisions are reached are key to efficient operations.

Table 9 – Summary of key aspects of task analysis of docking activities

Decisions	Situations	Limiting factors	Input / artefacts	Comms	Example from analysis
Where to place a train	Set swaps Cancelled services Late running Platform blockage Line blockage	Existing trains Trains due to arrive Trains due to leave Routes in and out of platform Size of train Size of platform Allocated TOC Platform Location of platform Blocking through routes Booked platform - passengers Type of train	Simplifier Docker – list Docker – Graph Daily workings	Station manager TOC Train running controller Signaller	The signaller may identify a train that needs to be swapped and call the station manager for his advice as he has a different viewpoint
Which trains to swap	Set swaps	TOC requirements Maintenance schedule Booked platform Train availability Dwell time	Stock changes sheet Simplifier Docker	TOC	The TOC may have a plan based on maintenance requirements. The signaller may call to double check.
Whether a train need to be re-docked	Late running trains Cancelled services	Lateness of train Availability of platforms Existence of limiting through platforms Type of train Availability of routes in and out of station	CCF Simplifier Docker	TOC	The signaller will use CCF to identify a late running train. He may then use his experience to decide if this will impact other trains sufficiently to require re-docking.
If a late running train needs to be replaced with a spare train from the depot	Late running trains	Lateness of train Availability of another train Availability of another driver	TOC CCF Simplifier (Docker)	TOC	Certain services cost more money when delayed than others. The signaller will use this information along with real time info from CCF to develop a plan, which may involve using a spare train with the go-ahead from the TOC

Decisions	Situations	Limiting factors	Input / artefacts	Comms	Example from analysis
If a late running train needs to be stepped up	Late running trains	Lateness of train Availability of trains – long lyers Compatibility of sets Driver route knowledge Busyness of station	CCF Docker TOC	TOC Station manager	Certain trains may impact other services more than others. If this is the case the SSM may step up the service but will consult with the station manager and the TOC first
Should delay be accepted	Late running Cancelled services Platform blockage Line blockage	Lateness of train Impact on other services Type of service (long distance, local)	TRUST TOC Simplifier Docker	TOC	The SSM may identify a late runner using CCF. He will then use the docker to identify the impact this will have on the running of the station and react accordingly
Whether a train needs to be stepped up or replaced	Late Running Cancelled services Platform blockage Line blockage	Situation of train (late, broken etc) Availability of replacement train Nature of service (local, long distance)	CCF information TRUST information	TOC	If a train has broken down, the service can be cancelled or replaced. The SSM may assist the TOC in developing a plan, using the docker
Is a train suitable to swap	Stock swaps Step ups	Size of train Length of platform Power type of train Maintenance schedule of train	Simplifier Docker	TOC	Although this information is available on the docking tools, signallers would know train attribute information off by heart
Is it possible to split trains	Split trains Step ups	Coupling mechanism Availability of driver Further working of train	Simplifier Docker	TOC Station manager	This information is not readily visible on the list dockers, but is on the graphical one
Is it possible to join trains	Join trains Step ups	Coupling mechanism Planned working of trains	Simplifier Docker	TOC Station Manager	This information is not readily visible on the list dockers, but is on the graphical one
Is it possible to carry out the TOC request	Stock swap Platform move Cancelled service Split sets Join sets Step ups	Availability of trains Availability of platforms State of services Impact on other services	Simplifier Docker	TOC Station Manager	TOC requests were upheld more often using the graphical docker rather than the list

Decisions	Situations	Limiting factors	Input / artefacts	Comms	Example from analysis
Can a stock swap be dealt with immediately	Stock swap	Availability of trains Availability of platforms State of services Impact on other services	Simplifier Docker CCF	TOC Station Manager	The impact on other services was more visible on the graphical docker
Which trains can be swapped	Stock swaps Step ups	Type of trains Availability of trains Driver route knowledge	Simplifier (Docker)	TOC	The SSM may consult with the TOC if the information required is regarding detailed route knowledge that only the TOC has access to
Out of which platform to send a train	Platform moves Stock swaps Step ups Join trains	Booked platform Availability of platforms Length of train Route out of station Limiting through platforms	Simplifier (Docker)	Station Manager Signaller	This decision requires train and route knowledge that is available on the artefacts but is known to most operators questioned
To which platform to move a train	Platform moves Stock swaps Step ups Join trains	Booked platform Availability of platforms Length of train Route out of station Limiting through platforms	Simplifier Docker	Station Manager Signaller	Gaps at platforms were more easily identified using the graphical docker.

Table 9 shows a summary of the task analysis carried out on the docking activities. It further reinforces the complexity of factors involved when deciding whether or not to re-dock of train that is seen in the flow chart of basic processes.

Additionally, the complexity of the tasks is increased further by infrastructure considerations. There are many differences between stations that need to be taken into account, for example the layout, the variety of artefacts used (or the lack of them), the number of TOCs involved, the different levels of task complexity and the frequency of disruption. All these factors add into the process complexity; however the intention was to use the different stations in this study to bring out the different aspects of the core work functions.

5.5.1 The nature of decision-making in re-platforming

The following discussion is structured in terms of the key decision-making strategies used by the operators in order to carry out their duties identified in the interviews (Table 8). The three top level themes are:

- Problem interpretation
- Evaluation
- Solution implementation

This follows the structure of the information presented in table 8. The remainder of this section will consider these three top level themes and their subsections and discusses the findings in more detail.

5.5.1.1 Problem interpretation

This section covers the data that was deemed as the operators being alerted to an issue. This is consistent with the CWA approach that aims to analyse the work domain rather than just the tasks.

a) Communication

At all of the signal boxes visited the SSM / regulator was used as the first point of contact regarding stock changes. However, the initial contact could come from many sources:

- Station co-ordinator
- Train planners (TOC)
- Fleet controllers (TOC)

One of the main issues observed was that the TOCs often had access to the train running information in a different form to the signaller (which was often in complex list form focusing on staff allocation), so when the signaller and TOC attempted to devise a plan together it was often a laboured process. One box had overcome this problem by issuing the TOC the same information, in the same format which meant that communicating which train required attention was less laborious:

> "it's really easy. You just say train such and such, 3rd one down on page 2 and they can find it straight away. Then we work out what to do with them!" (Box C).

This example illustrates how the information form can influence the nature of communication. By using a reference to relative position of items on a document, information was quickly and easily referenced by both parties with little room for mistakes.

The main route of communication was usually direct from the TOC to the SSM. This was the case at seven out of the eight sites visited. However, at Box E the TOC normally consulted with the station co-ordinator before informing the SSM. The TOC and station co-ordinator (SC) then developed a plan together. It was up to the signaller to make the resulting swap.

> "9 times out of 10 they come up with the right solution. When this happens the swap is relatively easy and we just do it".

The same signaller also commented that the communication route through the SSM and e-mail system used currently for planned swaps sometimes failed:

> "We get loads of swap requests sent through [to the SSM] every day. The emails can sometimes be missed by the SSM as he has all the updates coming into his inbox". (Box E)

This demonstrates the problems that were encountered when the same system is used for receipt of information that has different levels of time sensitivity. The signaller is required to respond immediately but is also required to maintain a level of sufficient situation awareness throughout. The role of the artefacts used by the signallers was also considered. The SSM at Box A uses the Docker tool, along with frequent verbal communication with the TOC to handle any disruption.

> "I'm never off the phone to him [the fleet controller]; he's always wanting something. We usually sort it out between us". (Box A)

By conversing mainly by fax, this communication and joint co-operation is bypassed at Box C due to the TOC having access to the same information, in an identical form to the SSM / signaller (a list Docker and simplifier).

b) Disruption

Disruption, in this case, refers to any event that is preventing the railway from running to its planned timetable. Disruption in a general sense was mentioned by every participant that was interviewed, and dealing with disruption is an everyday task for the signallers and SSMs. How it was dealt with and the general culture surrounding disruption varied considerably from box to box. There were no general rules of thumb that were used by every box when dealing with disruption, each one had different scales of when to deal with something, or when to leave it, and how to deal with it.

For example, two of the boxes visited (E and F) stated that they would only deal with a train running less than 5 minutes late during off peak times:

> "You just can't do it! There is no room. We just have to take the hit, even if it causes more disruption". (Box E)

This was not a view shared in boxes where the TOC was more proactive in dealing with issues or at stations that used graphical Dockers:

> "We always try. Sometimes you just can't do a move, but you at least have to give it a go. If you can't do it, you are then just trying to keep things as close to plan as possible". (Box A)

Box A generally tried to move late trains if they were going to impact on other services. This may not have been very often, but if a train was very delayed, it could impact significantly on the trains around it. This appeared to be easier to manage with the graphical Dockers. None of the boxes who used List Dockers were as inclined to deal with late running trains.

c) TOC Involvement

Dependent on location, there were varying degrees of problem identification from being concerned about a small delay to leaving the signaller to it. This was very dependent on the TOC; they were found to be either very proactive or very passive in their management of abnormal situations. The range of involvement was from none at all i.e. leaving the signaller to decide how to handle the situation, to being very prescriptive in terms of which train, how it was affected, why it was affected and the specific plan for the signaller to implement to overcome the problem. This was the case at Boxes C and G especially. However, being this prescriptive often meant the signaller was less inclined to make decisions when the TOC had not specified explicitly what was to be done.

> "If they haven't faxed it though, then we can't do it. If we do, it will be wrong". (Box C)

This can be seen as the operator becoming 'out of the loop' and not being willing to take on the task themselves when they are not used to doing it. This negative relationship with the TOC was seen to be the most extreme at Box C; however relations seemed strained at other boxes too:

> "If they think it's that important, they can sort it out themselves. I don't have time to sort out their sh*t!" (Box D)

The list users found it particularly difficult when the precise changes were not specified by the TOC. The most common requests received from the TOC were stock swaps. One signaller commented that it was so time consuming to make some changes and deal with the associated knock-on effects that they could not do it:

> "If the TOC wants to change something, they can sort it out". (Box E).

The TOC responsibility ranged from none at all (Box C) to a considerable amount (Box A). Box A is all terminus platforms, primarily deals with one TOC and manages both diesel and electric trains. The same responsibility is found at Box D. The key difference is the level of responsibility the signaller holds with regard to stock changes.

Stock changes at Box B are handled in a similar way to Box A, in that it is ultimately the TOCs decision but the TOCs often seek the advice of the SSMs due to them also having access to a graphical docking tool. The fact that box A and B were able to deal with stocks swaps more efficiently and were more willing to take them on may also be due to the fact that they can have more of a say in how the changes handled. They feel more empowered to help the TOC because they know that their opinion and the decision will be listened to. This demonstrates the perceived value of the graphical Docker, not only for the direct users but also the people with whom they collaborate to complete the task.

d) Planned Changes

Planned changes were generally stock swaps and platform changes. Depending on the box, these were made and either faxed, emailed or telephoned through from the TOC to the SSM. The majority were the day before, but some were just before shift changeovers. Again, the relationship with the TOC had the greatest influence on the planned changes. If the relationship was good, like for instance at Box A, then the planned changes were minimal; most of the changes were ad-hoc. At the majority of the other boxes, if the changes were not faxed through the day before, then they would not deal with them, or not give them top priority:

> "Unless they are on this sheet [holds up sheet of paper] we don't do them". (Box D)

Another aspect of the planned changes was whether they were effective or not. This had less to do with the general relationship with the TOC, and more to do with simply who the TOC planner was at the time and their skill at doing the task:

> "Sometimes you come in and they all just work. Other days it's awful. You have to change them all yourself. You can spend all morning on the phone!" (Box C)

Whereas some boxes were less inclined to help if the changes did not work:

> "If they don't work, we don't do them. So I ring them up and ask them to sort it out". (Box H)

e) Ad-Hoc Changes

Ad-hoc changes, as mentioned in the section above, were more frequent at the boxes that had a stronger relationship with the TOC, where communication was more frequent. These were generally boxes A, B and G. At all three of these boxes, these ad-hoc changes were a regular occurrence and most of the changes were incredibly short notice. They were generally maintenance based stock swap requests. The requests were all made by telephone and the demeanour was generally friendly banter:

> "Afternoon [TOC train planner name] I wondered how long it would be before you were pestering me again… well it depends how many more you're going to ask me to do. I finish at 2. [Signaller name] is on then, can they wait? Make him sort them out!... go on then…" (Box A)

These were sorted out quickly at the boxes with graphical Dockers. The changes would be marked on the Docker as the SSM was on the phone. They would confirm to the TOC that the change was in hand, and let the signaller know of any changes that were required as a result of the alterations. Box G would look to the TOC for extra guidance but would not turn a change down. They would generally call the TOC and say that that particular change was not possible but to suggest another.

When the other boxes were asked about ad-hoc changes, one box had a very strong opinion:

> "We can't do them. Unless it's faxed through with the platforms on at least two hours in advance, we say no". (Box D)

When asked why they were so negative towards ad-hoc changes, three of the boxes (D, F and H) had the same opinion, that if they started doing them, that is all they would be doing.

> "Once you do one, they will keep doing it. Why would you bother planning in advance when you can call us up and we will do all the work for them?" (Box F)

This was in stark contrast to Box A, who were more than aware that their willingness to help was their downfall:

> "We can't *not* do it now. We would get in a right mess. But some of them [the TOC train controllers] just take it for granted now that we will do it and not kick up a fuss… But, when everything is running ok, you don't mind. It's when they call you up when the sh*t has hit the fan and the Docker is covered in pencil marks. Then we mind". (Box A)

This opinion was shared by all of the operators interviewed at Box A. They viewed themselves as 'the victims of their own success' and put that all down to the Docker:

> "If we didn't have the Docker we couldn't do it. Simple as that. It would take far too long. You would have to get them in advance". (Box A).

f) Late running trains

If the train is late arriving it may impact on services docking behind it. Box A in particular was very proactive in dealing with late trains. The SSM uses TRUST to track the train and monitor its lateness. He will then make a decision on what to do based on how late it is and the trains around it.

If another train was due to dock behind it, the SSM may choose to re-dock the other train in anticipation. This was not something that was observed at any other boxes.

At Box A, if the service has a short turn around in the station, the SSM may step-up services so that staff have the time to change ends, etc. This would be done in close contact with the TOC. If it is not possible to do that (i.e. if it is peak running and spare trains and platform space is limited), it may be necessary to incur a delay on the train departing again. The SSM would clear this with the TOC prior to making this decision so that NR are not attributed the delay.

If the train is due to arrive after it was supposed to depart, the TOC would advise – either accept the delay or step up services if possible to cover for the missing train. If the train is late departing it may impact on services due to arrive in that platform. If services are due to arrive, the SSM may re-dock the arriving train in anticipation. If the train is in front of another train and blocking it in, it may be necessary to step-up the train that's being blocked. These strategies were observed frequently at Box A (with a graphical Docker), but not observed anywhere else.

At stations with list Dockers, late running trains were not proactively managed, nor were they actively dealt with very often. Boxes that used a graphical Docker were found to be particularly efficient at handling late running trains. Late runners were quickly identified, and potential solutions were spotted quickly. One particular move observed at Box A involved eight changes to ensure there were no further delays due to one service running late. Each one of these changes involved dialogue with the TOC, station staff and signallers, but it took less than three minutes to develop the plan for the eight changes and inform everyone involved.

Another box which handled similar traffic (locals and long distance) at a terminus station found it difficult to develop plans to handle late runners:

> "Eight step ups [changes] to handle one late runner? Nah, there's no way we could sort that. We have all these bits of paper to sort through... [holds up lists] it would take us five minutes just to find the trains. We are too busy, we don't have time for that". (Box E)

This was commonplace at busier stations that handled a dense service and did not have a graphical Docker. Delays were usually accepted and the knock on delays could take a few hours to deal with. Some signallers used strategies in this situation to minimise the repercussions of the delays, rather than the delays themselves:

> "We always try and get the [TOC name] running on time. They cost a fortune!" (Box F)

These reactive strategies were used frequently when the delays were mounting and the signaller was waiting for a gap in the service to start to rectify the situation. Many boxes felt unable to plan a strategy to deal with knock on effects from late runners, but could focus easily on each train as an individual object and deal with them one by one, minimising the damage as much as possible.

For late running trains, the way the issues were interpreted was very signaller specific. There were many strategies observed during this case study for how signallers identified the issues. A train running 5 minutes late could be identified by one signaller to be an issue that needed to be resolved therefore requiring action and could be identified by another signaller to not require any action at all.

> "If you have one a few minutes late, you try and step up sets to help out, but then because the service is so tight, especially round the peak, you end up getting delays coming in. Sometimes you can do it, and not

get any delay, but most of the time, if that happens, you're f*cked". (Box E)

g) Cancelled services

Services could be cancelled for a number of reasons, including bad weather or failed services. If a train develops a fault that is not major, or requires some kind of service that is not planned, the TOC may request a stock swap or some step-ups in order to allow a certain train to be moved to the depot or worked on in a platform. If the train needs to be looked at in a platform, it may be up to the SSM to arrange a suitable platform for it to dock in. It may then be necessary to re-dock any trains that were due to arrive in that platform. This will involve close contact with the TOC as to how long it's likely to be there so that the SSM can arrange re-docking of other trains. It may be necessary to step up trains and then use the train after the maintenance crew have finished working on it. If the train has to be moved to the depot, it may be possible to bring in an empty train straight away to replace it, but in many cases, services will be stepped up until an empty train is brought in.

One incident observed at Box A involved all of the services going to a particular place being cancelled due to overhead line problems. This service accounted for four trains per hour arriving and departing the station. The TOC and the SSM devised a plan together that meant strengthening another service (i.e. joining the spare trains on to them) until the problem was fixed. The SSM amended the graphical Docker and changed all of the trains and services over the next 3 hours. This also involved some platform alterations due to the trains being longer. These changes did not appear to take very long to implement, and the station staff were alerted very quickly about the alterations. The situation was monitored, and when the lines were fixed, the trains were de-coupled and ran instantly on their planned routes.

Cancelled services were observed more at boxes A and B. These boxes were able to plan around the obstruction using the Docker more effectively than the other six boxes. At boxes C to H cancelled services were for the most part dealt with by the TOC.

h) Stock swap requests

Although stock swaps are a situation that requires action from the signaller, they are also an action in themselves. Stock swaps are often used in order to maintain a maintenance schedule for a train. By shifting a service from train A to train B, train A could then be made available for some general maintenance, or to fix a minor fault. The TOC train planner specified which services needed to be swapped and when, and the SSM tried to then accommodate it.

As Stock swaps are discussed in depth in the other sections of this discussion relating to other factors, it is not felt necessary to discuss them further here.

i) Platform Blockage

If a service has failed, this does not necessarily mean that the train will not run. It could be anything from a warning light to broken air conditioning to a faulty door. If this is the case and the train is still running, the service will be replaced by another set – this could be a “long lier” (i.e. a train which stays in the platform for an extended period) of the same type or a train due to leave after that service. Ideally, the failed train will then be placed in the platform that it is due to go out of for its next working service while the fitters work on the fault. In the majority of cases observed, the fitters were able to provide a rough estimate of how long it would take to fix the fault in order to aid planning.

As a consequence of the platform being occupied, other services that were due in to that platform in the meantime needed to be placed elsewhere. However, depending on the size of the platform, the type and length of the train, and also the dwell time of services, certain services may be able to dock behind the failed train if they are due to depart before the next working of the failed train. The service is then stepped up until the failed train is fixed or a spare train is brought in.

The TOC may advise a certain stock swap or will ask for SSMs advice. One option would be to step up sets. This would continue until either the failure was fixed or an empty train was brought in to replace it. If it was blocking in another train, it would be necessary to step up this one also.

The TOC may advise a set split or join 2 sets depending on what stock was available. If the train was stuck in the station, all trains due to dock in that platform would either have to be small enough to dock behind it or be moved to alternative platforms.

If maintenance was expected and planned, then any platform closures were included in the changes to the plan document that the SSM receives daily. This would instruct the SSM to dock trains on different platforms in order to keep a certain platform clear. If this is the case, the SSM needed to mark the changes on the Docker and then check for any conflicts or clashes. If there are any, the SSM then informed the TOC and they developed a plan together.

If maintenance was unexpected and a platform needed to be closed, the SSM was informed, and trains were routed into alternate platforms until maintenance was complete. Again, the SSM was in close contact with the TOC and station staff to ensure the platform was used again as soon as possible.

The boxes that had a graphical Docker were able to spot potential gaps and available platforms more easily than at other boxes at boxes C to H the SSM had less influence upon the potential changes to the service and any platform swaps than at boxes A and B.

j) Line Blockage

If there was a points failure close to the station, it may render a platform unusable. In this case trains were routed into alternative platforms. This involved close contact with the signallers, COMMS centre and platform staff. If it wasn't possible to do this (e.g. at peak running where no platform space was available) it was necessary to cancel services or incur late running. If trains are unable to leave a platform, the TOC may again decide to cancel the service, agree to a delay, or make certain stock swaps or step ups.

Infrastructure failure can also lead to the need to step up services. In most cases, infrastructure failures will lead to late running of trains, which in turn requires services to be stepped up until the fault is rectified. However, the failures could be anything from an unusable platform, points failure, signal failure or bridge strike. These could be blocking routes in and out of the station, or blocking trains in the station. For example, during one visit, a signaller at Box B received a call from the station staff to say that a platform had to be closed with immediate effect for the foreseeable future due to a signal failure. This meant that the trains already in the platform could not leave, so these services had to be stepped up in order to overcome this.

This is a situation that was not directly observed at other boxes; mainly because the SSM was more instrumental in making the swaps. The request is emailed to the SSM, the SSM checks the swap to see if it is possible and then informs the signaller. At box D, the SSM prints off the email and hands it to the signaller, as and when they arrive, which can be up to 20 times per day. The fact that they are sometimes missed then leads to further problems later on when the TOC assumes that the swap has been made and it turns out it has not.

5.5.1.2 Evaluation

This section discusses the concept of evaluation, and how the operator interacts with their environment to make an informed decision about what to do next.

k) Trial and Error

This strategy was only seen in the boxes that used a graphical Docker. The signaller was able to physically try out moves, draw them onto the graphical Docker and see what effect this move had on other trains. If the move did not work, it was erased and another solution was tried. The list users had no simple way in which to see if a move would be successful or not.
Box A had to deal with more short notice, ad-hoc changes than observed at any other box.

> "Stock swaps are planned movements and the decision is ultimately that of [the TOC]. They will specify 'swap this with this' or we will come up with something between us. Although planned doesn't necessarily

> mean that we get much notice… It's usually about five minutes". (Box A).

In this case, the TOC would call the SSM directly. The main reason for these swaps was usually maintenance on diesel trains. In this case the TOC would explain which trains needed to be swapped. If the swap was a straightforward 'swap one service for another' then the TOC would usually have a good idea of which trains and which platforms. However, most of the time the TOC identified a train that required swapping, but would ask the SSM to suggest solutions. Using the Docker whilst on the phone, the SSM would sketch out potential swaps / moves and discuss them with the TOC whilst doing it. Often they would come up with a solution together. Although relatively happy with the arrangement, the SSM did comment on the matter:

> "I think we are victims of our own success. Because it is so easy to use the [graphical] Docker to make changes and plan, we get asked to do it all the time. That said, it does mean that we save time as if we have sorted the move, we know it's gonna work". (Box A).

l) Heuristics

Sometimes, the operator would 'borrow' a train to replace another that has failed, or is severely delayed. They kept using alternative trains until an empty train can be brought in, or the original train was fixed. The main reason observed for this was to overcome late running services. At most of the boxes visited, the SSM kept an eye on the service using real time train planning systems. If a train was running late, the signaller would assess whether the situation needed attention through various rules of thumb, usually developed by the operators themselves utilising their experience:

> "If he is 2 minutes late there [points to bridge on screen] then he is ok. If he's 5 minutes late he's not, as other services will usually impact on him, and we will have to hold him outside the station, here [points to section on screen just outside the station area]. So we have a look where he is going, assume he will get delayed even more. If he is in the station for a long time and nothing is on top of him, he's ok; he's delayed going in but ok coming out, and so is everything else. If not, we start looking for alternatives". (Box A)

This was a typical rule used by the operators as the first stage of the decision-making process. Many, like this one used static objects such as bridges or crossings to identify how late the train is likely to be when it reaches the station. However, how much the operator could actually do in these situations was different from box to box. This is for a number of reasons including; workload of signaller, complexity of station area, density of services, routes in and out of the station and whether the services are local or long distance.

m) Performance

Performance was usually mentioned in line with delay attribution. All of the operators interviewed were very aware of the delay attribution process and the fact that they would often get attributed delay if services were late. Most stations would call the TOC to make them aware of situations (i.e. if a certain requested stock swap would incur delay) to ensure that Network Rail do not have to carry the delay charge.

A general rule employed at all of the boxes was to ensure that the services that incur the greatest penalties were given priority. Boxes A and B generally had fewer knock-on delay minutes attributed them than boxes C to H. This was mainly because the initial delay was fairly easy and straightforward to deal with at all of the boxes, but when there were several trains delayed at once or delay the impacted on other services, this is difficult to spot quickly using the list Docker. The boxes that had access to the graphical Dockers were able to spot potential problems quickly and identify solutions and create plans effectively. It is these knock-on effects that can substantially increase the number of delay minutes that are attributed to a box.

n) Platform Attributes

No two stations are the same in terms of physical attributes. Factors such as number of platforms, length of platforms and availability of platforms all had an effect on the types of moves that were possible. The main consideration was the type of platforms. Four of the stations visited had only terminus platforms, three had terminus and through platforms and one had just through platforms. This in itself led to operators developing and using different strategies to overcome problems.

Terminus platforms are relatively simple to operate. If train A arrives first, train B may dock on top of it and must leave first to allow the train A to leave. The only consideration in this case is whether there are sufficient routes into the platform. Most stations had a rule of thumb that if a train was moved you would either try and keep the service running out of its booked platform or as close to it as possible. This not only assisted the station staff and in turn the passengers (passengers already waiting at a platform will not have to walk far) but will also assist the signaller in terms of routing the train into the platform. Another rule of thumb observed at most of the stations was a 'top / bottom' split of the station. If a train was coming in on one of the top lines, the operator would try to re-dock it in a top platform. Similarly trains coming in on a lower line were preferentially re-docked in the bottom half of the station.

Through platforms add another dimension of complexity to the situation. At these stations the possibilities become diminished due to the restrictions these platforms bring. Through platforms require the train to pass through the station, so the exit must be clear. At some stations Platforms shared entrance and exit routes, meaning platforms had to remain clear in order to leave a clear route to / from the other platform.

> "It's not as easy as just having 'in / out'. We have to think about what the other platforms are doing as well". (Box B)

On top of platform types, platform lengths are a consideration. All the stations visited had platforms of different lengths that could handle differing amounts of trains. This was not just a case of ‘platform X can take a X car’ as different train carriages were different lengths. It was considerably easier to visualise the platform and train lengths using the graphical Docker than using the list Docker. The SSMs at boxes C to H were frequently checking platform lengths when making an alteration. Boxes A and B were able to carry out the changes with speed, although this may have been because boxes A and B made more changes than the other boxes and were more familiar with the processes involved.

o) Train Attributes

Train types are a key factor when swapping or moving trains to another platform. All but one of the stations handled a mix of diesel and electric trains. Each TOC may have different sized carriages, which can impact on which platforms they can dock in. For instance, some platforms may accommodate a 4 car train, whereas the same platform may only accept a 3 car train made up of different carriages. The SSMs at all of the boxes were able to remember which sets made up which trains by experience, but all of the information was also available on TRUST and by looking at the diagram.

p) Information

The majority of the signallers observed knew the timetable off by heart and could recall the working timetable without referring to it – but the ability to identify the state of the other trains affected varied between locations. Signallers using the lists were able to find the trains relatively quickly – but if there were many trains in their proximity it took longer to identify them. In contrast, the signallers using the graphical Dockers were able to identify the trains and establish the surrounding situations very quickly. The list users typically referred to both lists side by side, marked the affected trains and then looked for other trains with the same platform number. The graph users were able to glance quickly and identify all potentially affected trains. This was not a lone opinion, and many other signallers who used the list based Dockers often refused changes as:

> “You can get in a right mess. By the time you have worked out where to put it you end up with more trains delayed. It’s not worth it”. (Box D)

The signallers who used the graphical Dockers however, seemed to have the opposite problem:

> “yeah, we do a lot of changes here. It's cos they know we’ll do them”. (Box A)

Alongside the Dockers, the signallers also used CCF and TRUST to get access to train information. They would also call upon the signallers in the box for up to date information and many of the boxes had a good relationship with the station managers:

> “I'm just calling up the station manager to tell him what we're doing. He’ll tell me straightaway if we can't do it. He's sound, [name] is. Things are easy when he's on”. (Box E)

5.5.1.3 Solution implementation

This section discusses the findings regarding how the signallers used the acquired knowledge and information drawn from different places and use it implementing action.

q) Time

Time was mentioned implicitly four times during the interviews. Each mention was in relation to not having enough time to make a change or not having the information or request in time. One signaller commented that they were often asked to make stock swaps at the last minute:

> “They call up sometimes with 10 minutes notice. If you already have something going on, you can’t do it. There isn’t time”. (Box C).

The boxes with access to graphical Dockers did not mention anything about time constraints, but they were often expected to (and successfully carried out) changes at the last minute:

> “you never get much notice, usually about 5 minutes! That's if they tell you at all..”. (Box B).

r) Telephone

With the exception of one box that conversed with the TOC via fax only (Box F), most of the contact with the TOCs is via telephone. Also, in order to implement a change, the SSM must contact third parties in order to make that change or establish whether it can be made. One SSM commented that they spent most of their day on the phone “telling three different people the same thing, over and over again”. It was noticeable during the visits that box A received more phone calls from the TOC than any other box, however this was also the busiest box visited.

s) Station staff

In terms of personnel contacted after a change was made, they included all of the above and sometimes the COMMS centre. The COMMS centre is responsible for feeding the information out to passengers. If a stock swap was made at short notice, the SSM would usually contact the COMMS centre or the station co-ordinator to make them aware of the change. Any planned changes were also fed to the COMMS centre in advance, but if platforms were not already allocated, these were sent through to them from the SSM. Often, the COMMS centre would disperse the information to the station staff and the customer information boards.

Sometimes the SSM would converse directly with the station staff, and in some cases would look to them for advice:

> "They are the ones who will know, and they are the ones who have to OK it. It's their call when all said and done. If they don't want a train moved we can't do it. But then they can also sometimes see moves that we can't". (Box G)

The station manager was not so instrumental in changes at Boxes A and B.

t) Re-dock trains

Re-docking trains is a large part of each of the functions discussed below. In order to move a train to a different platform the SSM must consider a number of factors and act accordingly. All of these limiting factors can be seen in more detail in the task analysis in section 5.5. Qualitative results for other regular functions where re-docking is used is given in the following sections.

u) Stock swaps

Most of the boxes were not instrumental in arranging stock changes. As already mentioned, most planned stock changes are emailed / faxed through to the box daily and are then planned for. This was particularly the case at Box E. The changes were faxed through to the SSM by the TOC fleet controller. These are then checked by the signaller who will ensure that they will not impact on anything else and that all knock on effects have been accounted for. This will involve the signaller using the Docker list and simplifier in order to identify the trains and identify potential issues. If, when the signaller is checking the moves they are found to cause problems, the signaller will call the TOC and tell them that the swap is not possible. In these cases the swap with either be abandoned or the TOC will try and suggest an alternative solution.

This sort of arrangement was seen in some form at most of the boxes visited; the signaller would carry out changes specified by the TOC if possible to do so. At Box A however, the SSMs / regulators have substantially more input into any changes made. Daily planned changes are sent through to the box. When the relevant time becomes visible on the Docker, the change will be drawn onto the graph. Often the SSM would make the decision regarding which platforms to use, and some stock swaps could involve moving more than two trains. However, unless there was severe disruption, these changes were usually possible.

v) Spare train

Spare trains were often used to replace failed trains, or services that were extremely late. Often these wouldn't be available straight away. Services would be stepped up, and then brought in when available. If the station was close to a depot, and train crew were readily available, the arrival of these trains could be quite rapid.

The other option is to use a long lier to replace a service. Two of the boxes visited had a daily long lier that was used primarily for this purpose;

> "we have a diesel sprinter in platform 6. Sits there all day, so we just use him as and when we need him". (Box E).

Box A was also observed using a train that sat in the station all day to replace a service:

> "We get these locals, only used at peak times, so they sit in platform 3 all day. We use it sometimes if we have a failed train". (Box A).

Box E had three spare trains that were kept in sidings that could be used to replace services.

> "We know that we are quite lucky that we have the capacity to do this". (Box E).

w) Step up sets

'Step ups' were used primarily to overcome late running, or failed or cancelled services:

> "The difference between step ups and stock swaps is that steps ups are forced upon us through train failure, infrastructure failure and so on". (Box A)

Sets are 'borrowed' to replace a service, and then another is used to replace that service and so on, until the original train becomes available again or a replacement can be sought:

> "Step ups. You are basically robbing Peter to pay Paul. Looking anywhere and everywhere to get a set. Splitting sets, joining sets, anything. We can step up for hours. I think the longest I have done it is about three hours. Ideally an empty set will be brought in eventually to get you back on track". (Box B)

The operators would rarely consider using a split train as a step up or even a stock swap due to the complexity of the information available to them. In contrast, boxes with access to a graphical Docker had fewer difficulties. The graphical format allowed the signallers to see quickly and easily if the train was due to split and when it was departing. This made it easier to use these trains as step ups and swaps. At one box, it was commonplace:

> "This train comes in, a four car to handle the peak, then the front train goes off at 10.46 leaving the rear portion in the station. That doesn't move now until about six o'clock, when it re-joins the other one to trundle back to the depot. It's only a 2 car, so stuff can dock on top of it, but it is handy to use as a step up. We use it all the time, like a back up". (Box A)

Using a timetabled split like this was observed at other boxes; however few of them had the luxury of a spare train 'sitting in' all day.

When step ups are carried out, the process has to eventually end: either by using the train that had to be stepped up in the first place or finding a spare train. Through dialogue with the TOC a solution was sought. If the solution was to bring a train from the depot, the TOC would arrange and notify the box. The main factor to consider was whether the driver had sufficient route knowledge. This however was left up to the TOC to organise in all cases. Knock on effects from any change were common place in most of the boxes, but again, whether they were minimised efficiently or not differed from box to box. In the boxes where the operators had less input into the changes, knock on effects and delays particularly from late running trains were more common. The process of stepping up trains seemed more laboured: referring to a simplifier, list Docker and the TOC during times of disruption. Boxes where the operators gave input more regularly seemed to be able to handle step ups due to late running trains and plan for any subsequent knock on effects. This could imply that boxes that had a greater input had a better understanding of the situation from being more involved. It could however imply that the practices and artefacts used at different boxes affected the range of decisions the signallers were able to make.

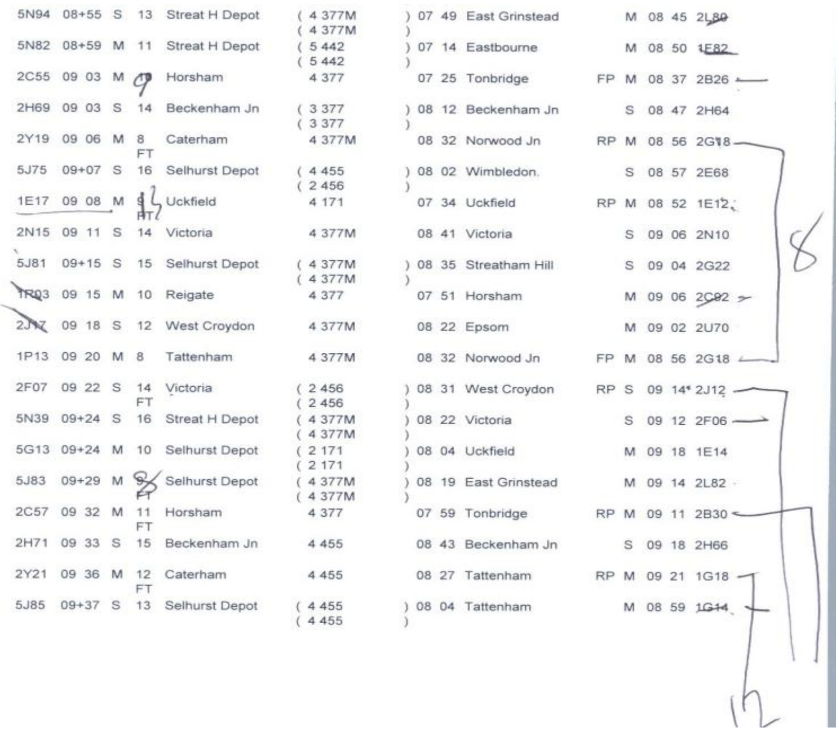
Any TOC failures are reported to the SSM via the TOC or on occasion station staff. If there is a driver missing, it may be possible to replace them before the train is due to leave. Usually this is not possible, so services will be stepped up until a driver can be found. This will mean leaving the train in a platform for a time, so depending on the train and the size of the platform, services may be able to dock behind, or may need to be re-docked.

Step ups were observed being used more readily in boxes that had graphical Dockers.

x) Split and join sets

Splits are usually timetabled just before the evening peak. Trains run as joined units all day, and then split to provide a more frequent service – e.g. a service every 15 minutes instead of 30 minutes.

Dealing with these splits appears simple on the face of it; the moves are timetabled and do not require platform moves. However, some stations appeared to struggle handling these moves if there was also disruption in the station area, or the trains required stepping up in addition. The main problem seemed to arise when stations were using the simplifier and a list Docker. The simplifier shows trains in arrival order and the list Docker shows trains in departure order. If a train arrives as a double set due to split, it will show as one train arriving on the simplifier. There will then be two departure head codes written next to it. On the list Docker, if a train splits it will be shown as two separate trains in the order they depart. The signaller then goes through the simplifier to find the relevant trains and their arrival /departure times – these could be up to 8 hours in advance or previous. The main method observed for the signallers keeping on top of these was for them to annotate the simplifier / Docker, drawing lines to draw associations between trains (see Figure 28).



5N94	08+55	S	13	Streat H Depot	(4 377M (4 377M	) 07 49)	East Grinstead		M	08 45	2L80
5N82	08+59	M	11	Streat H Depot	(5 442 (5 442	) 07 14)	Eastbourne		M	08 50	1E82
2C55	09 03	M	10	Horsham	4 377	07 25	Tonbridge	FP	M	08 37	2B26
2H69	09 03	S	14	Beckenham Jn	(3 377 (3 377	) 08 12)	Beckenham Jn		S	08 47	2H64
2Y19	09 06	M	8 FT	Caterham	4 377M	08 32	Norwood Jn	RP	M	08 56	2G18
5J75	09+07	S	16	Selhurst Depot	(4 455 (2 456	) 08 02)	Wimbledon.		S	08 57	2E68
1E17	09 08	M	9 FT	Uckfield	4 171	07 34	Uckfield	RP	M	08 52	1E12
2N15	09 11	S	14	Victoria	4 377M	08 41	Victoria		S	09 06	2N10
5J81	09+15	S	15	Selhurst Depot	(4 377M (4 377M	) 08 35)	Streatham Hill		S	09 04	2G22
1R03	09 15	M	10	Reigate	4 377	07 51	Horsham		M	09 06	2C92
2J17	09 18	S	12	West Croydon	4 377M	08 22	Epsom		M	09 02	2U70
1P13	09 20	M	8	Tattenham	4 377M	08 32	Norwood Jn	FP	M	08 56	2G18
2F07	09 22	S	14 FT	Victoria	(2 456 (2 456	) 08 31)	West Croydon	RP	S	09 14*	2J12
5N39	09+24	S	16	Streat H Depot	(4 377M (4 377M	) 08 22)	Victoria		S	09 12	2F06
5G13	09+24	M	10	Selhurst Depot	(2 171 (2 171	) 08 04)	Uckfield		M	09 18	1E14
5J83	09+29	M	9 FT	Selhurst Depot	(4 377M (4 377M	) 08 19)	East Grinstead		M	09 14	2L82
2C57	09 32	M	11 FT	Horsham	4 377	07 59	Tonbridge	RP	M	09 11	2B30
2H71	09 33	S	15	Beckenham Jn	4 455	08 43	Beckenham Jn		S	09 18	2H66
2Y21	09 36	M	12 FT	Caterham	4 455	08 27	Tattenham	RP	M	09 21	1G18
5J85	09+37	S	13	Selhurst Depot	(4 455 (4 455	) 08 04)	Tattenham		M	08 59	1G14

Figure 28 - Section of annotated list Docker (platform workings).

Many signallers carried out the task of sorting out which trains were to split and join and marking them down at the beginning of their shift, using both the simplifiers and the list Dockers. Looking at one, then the other, working out when the trains arrive and when they split.

> "If you don't spend time sorting all this out, and getting it straight in your head, you can get in a mess, especially when things start to unravel…" (Box F)

Signallers observed using simplifiers and list Dockers all seemed to struggle with split trains as far as initially identifying them and planning what is where. One signaller whilst on the phone to the TOC was observed tracing his finger down the hand drawn line over two pages in order to 'find' a train.

Non-timetabled splits can be the result of a cancelled / failed train or a late running service. Provided a driver can be found, splits can be an effective way of overcoming problems and 'creating' an extra train with minimum effort.

The main issue regarding train splits seemed to be being aware that the train was available to be split: Only trains already coupled can be split. This information was available on the simplifier, paper Docker and graphical Docker, but was not instantly obvious:

> "The diagram can give you a clue, but you have to know that it's a joined train. Only your experience can tell you that". (Box D)

Even the graphical Docker only obviously shows trains that come in joined then split straight away: if they come in joined, and leave joined, the graphical

Docker does not show this. All of the SSMs and signallers interviewed were experienced operators and knew instantly if the trains could be swapped.

Splits and joins can be a useful way to overcome train failures:

> "That was just the station staff: the COMMS centre who we give the changes to who do the train announcing, they're just telling me they've got an Edinburgh coming through, we've got to move for them. But he is running 14 late. It should come in at 10.55, meaning a late start for the next train. Looking at the diagram I can see its normally a 2 car, but due to all these problems its coming in a 4 car so they've notified us about it and [the TOC] are changing the sets so they are bring them in and splitting them. So the train that was due to come in to make it no longer needs to come in as his work is covered". (Box B)

Joining sets is handled in a similar way to splitting sets. The paperwork is annotated in the same way but it is used as a tactic to handle slightly different situations. The trains have to be identical otherwise they won't 'tie up'. This information can be gained from looking at the diagram number.

Ad-hoc joins were often used if trains were in the way. If a train service is cancelled and the sets are lying in the station, joining them with another train and running them as a strengthened service was an effective way of dealing with the situation. In the example below all the local services were cancelled due to a problem on the line which meant there were excess sets in the station:

> "If the weather is fine and everything is going ok, it's a great job. Anybody could do it, but days like this are horrendous. We have all these trains and only so many platforms and trains are in the platforms so trains can't get in or they can't get out. Basically it's like a car park with no spaces left. That's when you start moving trains around. A lot of the time you just double the sets up. So 3 cars and 4 cars will be doubled up to make 6 cars and 8 cars just to get them out of the station. We will speak to Scotrail first to tell them what we are doing obviously, but that's all experience. You know you can't have 25 sets lying on the station – you have to get rid of them. As long as we notify the station staff, they will get it tied up, and [the TOC] as well 'cos obviously the station staff are expecting a 3 car to come in and a 6 car will turn up". (Box B)

Signallers without a graphical Docker had no way of visualising the station when changes were made, and so were less inclined to make changes;

> "You can't plan. You deal with stuff when it happens" (Box E)

This was the response of one signaller when asked if joins were used as a way of dealing with delays. The annotated paperwork was said to be hard to follow, and although changes were logged, it was observed that only two to three changes were made at a time and a great deal of effort was required to do this, with many signallers commenting “I’m sorry, I just have to sort this” when arranging joins, being unable to answer questions simultaneously.

5.5.1.4 Summary of all key findings

Table 10 summarises all of the key factors identified in table 8 and discussed in the sections above. This aims to provide a brief overview of the key differences identified when considering decision-making and planning using the list or graphical based docker.

Table 10 - Differences between Docker types

Factor	Docker type	
	Graphical	List
a)Communication	Communication mainly with TOC via telephone	Mixed methods of communication, including fax, telephone and e-mail
b) Disruption	Able to identify problem trains quickly and put plans in place to work around the disruption	Able to identify problem trains quickly but dealt with each problem on a reactionary basis
c) TOC involvement	The TOC would generally ask for the SSM's advice and leave the final decisions up to them	The TOC would specify a lot more prescriptively which trains to be moved where
d) Planned changes	Planned changes were minimal that they were marked on the Docker as soon as possible	Planned changes would be sent through to the box as early as possible and check through. Any issues would be fielded back to the TOC
e) Ad hoc changes	High number of ad hoc changes dealt with successfully	Low number of ad hoc changes as they did not feel able to cope with them
f) Late running trains	Late running trains were actively monitored and dealt with	Delay from late running trains was often accepted
g) Cancelled services	Able to plan around disruption effectively using Docker to identify gaps	Often lead to knock on delays
h) Stock swap requests	High number of stock swap requests	Generally a low number of stock swap requests
i) Line blockage	Able to plan around disruption effectively using Docker to identify gaps	Often lead to knock on delays
j) Platform blockage	Able to plan around disruption effectively using Docker to identify gaps	Often lead to knock on delays

Factor	Docker type	
	Graphical	List
k) Trial and error	Able to try swaps and changes out on the Docker before committing to them	More difficult to visualise changes and potential problems that any alterations may cause
l) Heuristics	Rules of thumb often used	Rules of thumb often used
m) Performance	Generally low number of knock-on delay minutes due to being able to plan around disruption	A higher number of knock-on delays
n) Platform attributes	Able to visualise platform attributes and could generally manage stations with little need for reference	Often needed to check reference material for length of platforms
o) Train Attributes	Train attributes not easily identified on the docker. Prior knowledge and experience required.	Train attributes readily available on the simplifier.
p) Information	Easily identify and assess the state of the railway quickly and access information easily	Easy to identify trains, but difficult to identify relationships between them.
q) time	Last minute requests prevalent	Last minute requests prevalent
r) Telephone	The majority of phone calls were from the TOC	An even spread of incoming and outgoing
s) Station staff	Relationship with station staff was very much down to individuals	Relationship with station staff was very much down to individuals
t) Stock swaps	High number of stock swaps able to be executed in a very short amount of time	Low number of stock swaps often taking a long time to execute
u) Spare train	Easy to identify gaps using the Docker and plan round disruption effectively	More difficult to identify gaps using list based tool
v) Step up sets	High number of step ups able to be executed in a short amount of time.	Low number of step ups often accepting delay instead
w) Split sets	Able to easily identify splits on the Docker and easy to implement and make changes	More difficult to identify split trains even when list has been annotated
x) Join sets	Able to easily identify join sets on the Docker and easy to join sets and make changes	More difficult to identify join trains even the list has been annotated
y) Re-dock trains	Trains are re-docked easily and plans are able to be made to plan around disruption in a proactive manner	Trains are re-docked on a case-by-case basis i.e. reactively

5.6 Conclusions

When considering the signalling task and the strategies associated with it, performance is key. This can be twofold: Performance of the operator and performance of the railway network. One could be considered to affect the other directly. This case study has revealed that there are 3 main influencers to performance (in both senses) in this context: Artefact design, organisational context, and operator skills and strategies. Task characteristics were found to influence artefact design (as would be expected and anticipated through the use of CTA and CWA) which were in turn affected by wider influences (the work domain). Figure 29 demonstrates how different characteristics affect performance.

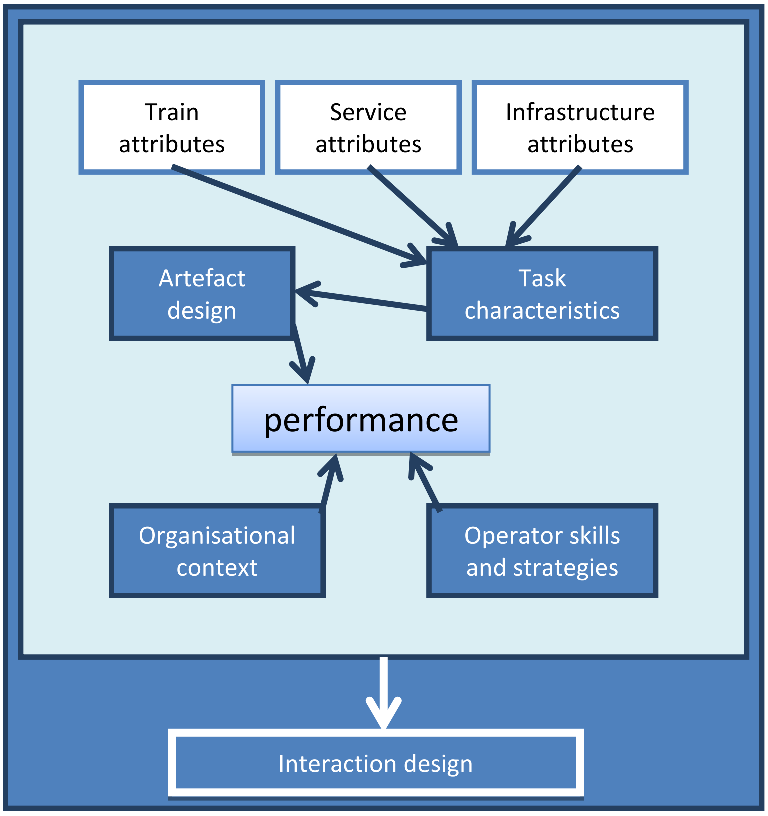


Figure 29 – Model of signaller influenced performance

Clear differences were observed between the strategies of the operators depending on whether they were using the list or graphical tools. The list based tools required a high degree of interpretation on the part of the operators and mainly allowed them to deal with each problem as it occurred. Short delays were commonplace and the operators were unable to deal with extreme disruption by themselves. The graphical representations facilitated more proactive management of problems arising in the station area which could be a result of any computational offloading taking place due to the 'at a glance view' that the graphical representation provides. The interactivity of the graphical Docker may explain the way it is used as a forward planning tool, to a greater extent than was observed at the stations that were using lists.

The stations using the list Dockers dealt with problems reactively rather than proactively, so that any other incident (such as a late running train) can considerably affect the alterations and it takes longer to get back on plan. By physically drawing the new plan on top of the old on the graphical Docker, late running trains can be handled with ease, as the “current” plan is fully visible. By adding this interactivity to a visualisation, more cognitive benefits can be gained (Rogers and Brignull, 2003). By marking changes directly onto the Docker, the signaller is kept in the loop, and is able to obtain instant feedback as to whether a change is possible allowing him to concentrate on problem solving. This ability to try out moves and rehearse strategies can strengthen the strategy and improve its effectiveness (Xiao et al., 1997). By relying on the list based Dockers and using them in a non-interactive way, the signallers internally formulate the solutions, requiring greater computational effort (Larkin and Simon, 1987b).

Currently, the graphical Docker provides a simple, reliable method of controlling station areas by providing an external representation of the problem (Zhang, 1997), which supports (and is supported by) the signallers internal understanding and representation of the problem. The Dockers have proved to be invaluable in managing disruption. By concentrating on the interaction between the internal and external representations (“knowledge in the head” and “knowledge in the world” (Norman, 1993), it is possible to identify the key properties of the Dockers and develop a clearer idea of what an electronic version should do.

6. RE-PLATFORMING EXPERIMENT

6.1 Introduction

This chapter covers the experimental study carried out to build on and quantify the qualitative findings presented and discussed in the previous chapter. In summary, the previous chapter suggested that by using a graphical Docker representation of a station area, the number of delay minutes could be decreased and complex problems could be dealt with more readily when compared to using a list based representation. Furthermore, due to the future direction that Network Rail is heading with regards to signalling systems, digitisation and automation, the need to transfer these graphical representations to a form with the ability to interface with existing electronic tools and computerised information systems has become apparent.

The experiment carried out for this chapter compares the two existing methods seen in the previous chapter (list based and graphical Dockers), plus an electronic Docker developed and built for the purpose of this experiment. Hence the research purpose of the discussion and conclusions from this experiment fed into the following thesis aims (numbering consistent with chapter 1):

2. Evaluate existing decision support tools and their use and integration into signalling environments.
3. Explore the implications of introducing new tools into signalling environments to support proactive control.
4. Develop recommendations for the development, integration and acceptance of decision support tools into existing and future rail signalling systems.

The concept of an electronic Docker that can interface with existing or proposed signalling systems is not new. Network Rail examined the feasibility of an electronic Docker previously, but struggled to build a persuasive business case in the past (although such a tool does form a small part of proposals for future tools). This thesis aims to better quantify any benefits that the graphical or electronic Docker has over a list based approach to support Network Rail in their future work.

From a research point of view, the work presented here will contribute to the field of cognitive ergonomics by providing quantitative evidence of the processes operators use when planning their decision-making and how this can be supported by artefacts. By providing evidence of how new tools can influence decision-making and planning within the signalling environment, this will then contribute towards providing some rail specific guidance on developing and integrating decision support tools into existing signalling environments, and how to ensure they are catered for and supported going into the future.

Case study 1 was initiated around a tool currently used by the signallers and Shift Signalling Managers (SSMs) at the West of Scotland Signalling Centre (WSSC) controlling Glasgow Central Station. Interviews and observations carried out at Glasgow and other stations around the country (discussed fully in the previous chapter) indicated that the graphical nature of the Docker in use at Glasgow enabled the operators to plan more effectively around disruption and develop complex plans to avoid accruing delay. This enabled them to handle complex situations more effectively, dealing with many issues at once, getting back on plan quickly and reduce overall delay minutes accrued. At stations without a graphical Docker (where list based representations were used), problems were dealt with reactively, as and when they arose, often failing to manage more than one problem at a time. This would often result in 'knock on' effects to other trains and platforms that would cascade down the timetable.

The overall aim of this experiment was to compare the use of list based, graphical and semi automated electronic tools used when re-platforming trains. The strategies and techniques identified in the previous chapters have all been included in the experimental design to be tested sufficiently. There have been many studies comparing representation type and the effect they have on decision-making problem-solving and planning capability (Scaife and Rogers, 1996, Zhang and Norman, 1994).

This was an exploratory experiment that used new techniques, procedures and methods (which are described fully in the following sections). The electronic tool was developed specifically for this experiment, so therefore has not been used in an experimental or actual setting previously. In fact, the process of developing the electronic tool gained further insight into the planning task complexity seen in the previous chapter (chapter 4). Based on the evidence gathered during the field study interviews, there were clear differences in the strategies used by signallers when re-planning, depending on which tool they were using. Figure 29 demonstrates the characteristics thought to influence performance. If 'organisational context' and 'operator skills and strategies' are removed from the equation, the artefact design can be considered to affect performance directly, which is in turn influenced by the task characteristics. In order to fully identify the influencing factors of artefact design, this experiment was designed to remove operator skills and strategies (prior knowledge) and organisational context to identify the key properties of each artefact and how they affect planning and decision-making.

6.2 Experimental Design

The overall aim of the experiment was to compare task performance in a signalling task between 3 different display types. This was done by asking participants to manage Glasgow Central Station for 45 minutes and keep delays and disruption to a minimum.

The experiment was a between subjects design, using 60 participants, assigning participants to one of 3 conditions:

- List Docker,
- Graphical (paper) Docker,
- Electronic Docker

Chapter 5 described the strategies and rules that signallers use when managing station areas. Using these as a basis, measures were designed to capture the nature of the planning strategies being used by the participants. For example, when using the graphical Docker, signallers would try to keep the delay minutes to a minimum, keep the number of moves to a minimum, and the number of platforms moved from the original would be kept to a minimum. For each planning scenario that the participants dealt with during the experiment, the following metrics were measured:

- Number of moves to get back on plan
- Delay minutes accrued
- Number of scenarios completed
- Time taken to complete scenario
- Number of incorrect (not allowed) moves
- Number of platforms moved from original
- Workload (using standard NR tool)
    - Mental Effort (5 point scale)
    - Pressure (5 point scale)
    - Difficulty (7 point scale)
- Scrap paper use (yes or no)
- Annotation of tool (yes or no)

6.2.1 Participants

60 participants took part in the study. They were all recruited through the University either through posters placed around campus, e-mail invite around local departments, or by advert placed on the student portal. 95% of participants were students, and the remaining 5% were staff. 66% of the participants were female and none of the participants had any prior signalling knowledge or experience.

A power analysis was carried out prior to recruitment to establish the effect size seen when using this number of participants. According to Cohen's classification, a large effect size will be observable for the graph versus the paper condition (0.88), and a medium effect size for the graph versus electronic condition (0.51). These calculations were based on pilot study data and given time and budget constraints, were sufficient for the experiment. Participants were then randomly assigned to each condition.

6.2.2 Apparatus Setup

A room was used within the University that was big enough to accommodate the experimenter and one participant. A 32 inch monitor and a standard 17 inch monitor were connected to an ordinary PC. The participant was seated in front of the large monitor, and the researcher had access to the small screen, the keyboard and mouse (see Figure 30). The participant also had available work area on the desk and scrap paper to make notes on.

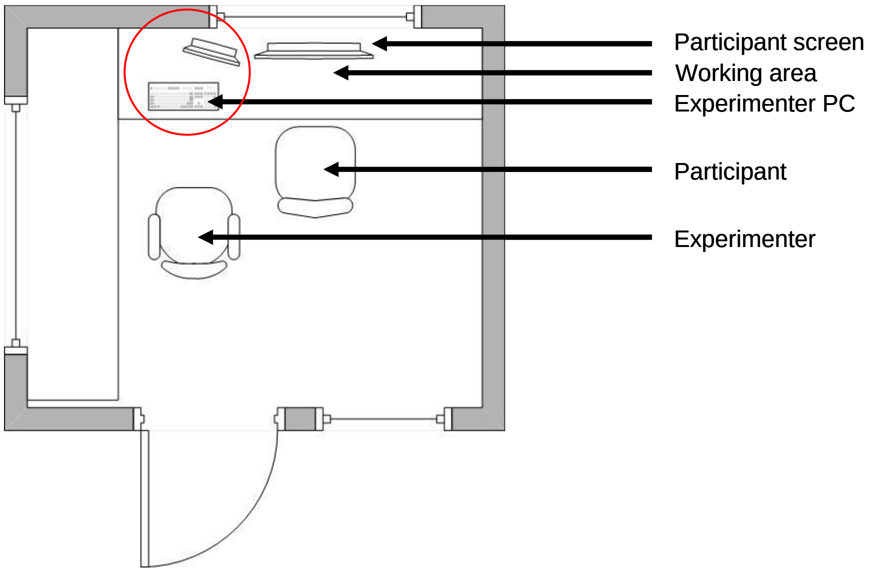


Figure 30 - experiment room layout

6.2.3 Network Rail Tool - ASWAT

One of the concepts to be measured within this experiment was workload, so work was completed to identify the most appropriate tool to be used to measure subjective reports of workload in a simulated signalling task. The Adapted Subjective Workload Assessment Tool (ASWAT) is a Network Rail developed tool used to measure mental effort, pressure and time load. This was adapted from the SWAT tool (Reid, 1984) developed in a military environment that measured mental effort, stress and time load. This was not appropriate for the signalling environment so the stress measure was altered to pressure instead (Pickup et al., 2005), following work aimed at developing the tool specifically for the signalling environment.

For the purposes of this experiment, time load did not seem appropriate, as there was an instant time pressure due to the experimental conditions, so an additional question was added, to establish how difficult the participants found each scenario. Therefore, three concepts were measured: mental effort; pressure; and difficulty. The SWAT and ASWAT tools use a three point scale but this was not considered to be of sufficient sensitivity to elicit the differences between the tools, so for this study two five point scales and a seven point scale were used.

For the effort and pressure questions, two additional points were added. The original three points for each question were very descriptive, for example "very little conscious mental effort or concentration required (activity is almost automatic, requiring little or no attention)", so with the added range of sensitivity it was decided to simplify the response wording. Table 11 summarises the simplified response wording.

Table 11 - Workload measure descriptives (additional points highlighted)

		Workload measure	
	Point No	Mental effort	Pressure
Adverb used	1	Very Little	Little
	2	Slight	Some
	3	Moderate	Moderate
	4	Considerable	High
	5	Extensive	Very intense

Care was taken to ensure that the additional points were using language that would be considered midway between the existing points.

The difficulty question that was developed used similar language to ensure compatibility. These are summarised in table 12. Seven points were used for the difficulty question in order to increase sensitivity to a level where it was possible to identify differences in perceived difficulty between the tools.

Table 12 – Difficulty measure descriptives

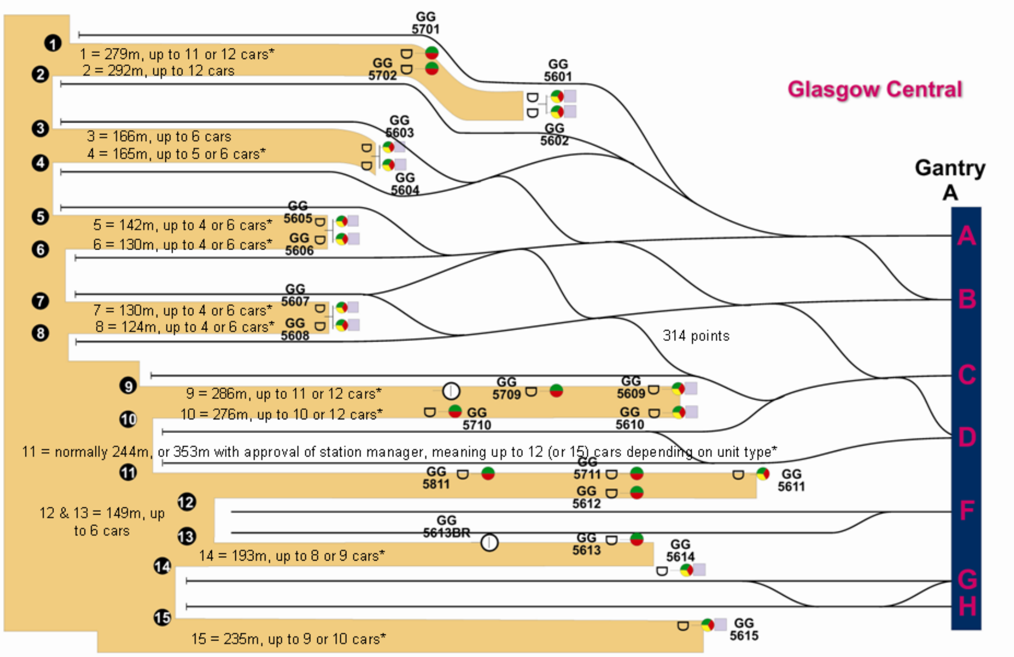
	Point No	Difficulty measure
Adverb used	1	Extremely Easy
	2	Very Easy
	3	Easy
	4	Neither Easy nor Difficult
	5	Difficult
	6	Very Difficult
	7	Extremely Difficult

Participants were provided with 10 of these questionnaires: one for after every scenario and were required to fill them out on completion of each scenario.

6.2.4 Station Layout

Glasgow station was used as the basis for the station layout as the graphical Docker was developed for this station and is currently used there. The focus and in depth knowledge of the types of scenarios and planning that occur in this station leant itself to being used in this experiment. The station layout was somewhat simplified for the purposes of this experiment.

The current Glasgow layout consists of 14 terminus platforms (see figure 31). Currently, platform 12 is not used, so this was not used in the experiment. The capacities for each platform are dependent upon the type of stock using the platform (see detail in figure 31). The lengths of the platform are written on the diagram, and details regarding types of trains are noted underneath.



NOTES on train lengths
Trains will tend to stop 2 metres short of the buffers, and if double docking or splitting will be positioned 2 metres apart.

ScotRail unit lengths as follows: 156/158 2 car = 46m. 314/318 3 car = 60m. 334 3 car = 62m.
380 3 car = 71m, 380 4 car = 94m, 380 6 car = 142m, 380 7 car = 165m, 380 8 car = 188m.

VT 9 car Pendolino (217m) can only use platforms 1,2, 9, 10, 11. Class 57 (for dragging moves) is 20m. 11 car will be 265m so can use same platforms.. EC Mark IV sets 2+9 (249m) can only use platforms 1,2, 9, 10 or 11.

VT and XC Voyagers; 4 car = 94.5m and 5 car = 117m. 8 car = 189m and 9 car = 211.5m. TPE 185; 3 car = 71m.

NMT (HST) 152m. UTU (cl31 +load3) = 77m.

***NOTES on platform lengths**
1 only 11 cars if 380s.
4 only 5 cars if 380s.
5 only 4 cars if 380s. 5 car Voyager can fit.
6,7& 8. only 4 cars if 156, 158, or 380s. 5 car Voyager can also fit.
9 only 11 cars if 380s.
10 only max 10 cars if 156, 158 or 380s.
11 only max 10 cars if 380s if up to 244m limit. Usage beyond this length requires station manager prior approval for safe usage beyond the arch.
14 only max 8 cars if 380s.
15. only max 9 cars if 380s.

NOTES on platform usage restrictions
Pl 2: tie ups/splits restricted for 6 car 156s.

156s / 158s cannot use 314 pojnts?

Train watering points on 1, 2, 9, 10 and 11.

Figure 31 - Current operational platform capacities Glasgow Central

The platform capacities although kept roughly true to life, were again simplified for the purposes of the experiment and shown in absolute car lengths (see Figure 32) using only one car type.

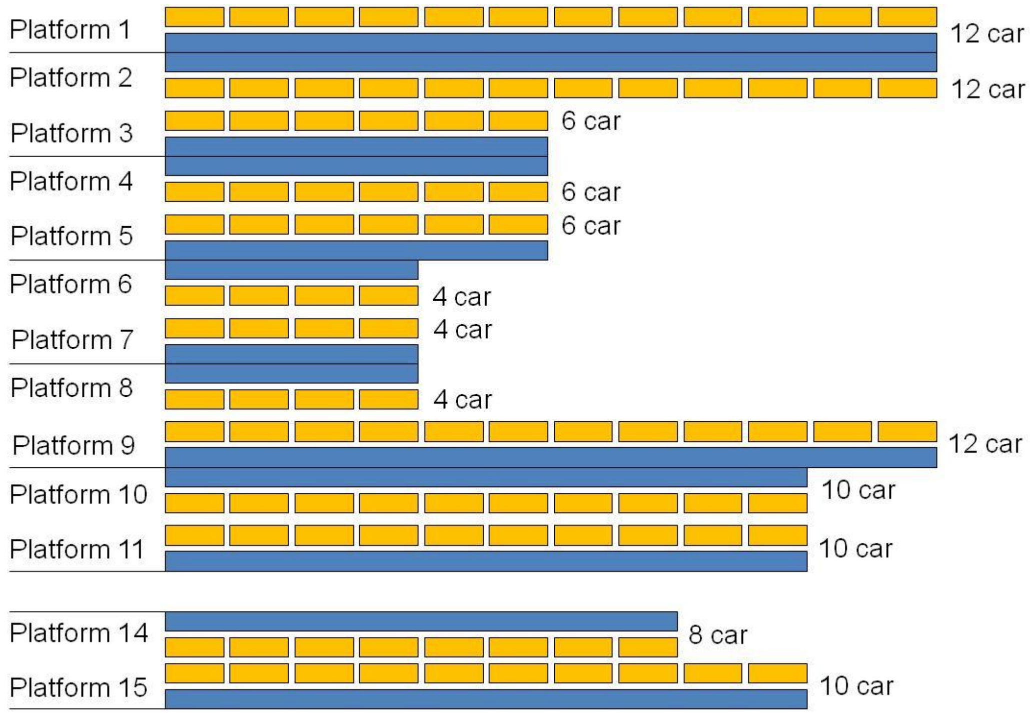


Figure 32 - Platform Capacities

Signallers normally consider routes in and out of the station, but these were not a consideration for this experiment.

A paper copy of the platform layout was created for participant reference during the experiment.

6.2.5 Train Types

Currently there are six different types of train that are seen in Glasgow station. These vary in length (i.e., number of carriages), power type, carriage size, and design. As detailed in the previous chapter, there are many restrictions when swapping trains around and joining / splitting them. For the purposes of this experiment these were simplified into four main train types all having equal car lengths:

- Sprinter – two car (S)
- Local - three-car (L)
- National - four car (N)
- Voyager - nine car (V)

No power types were specified: Electric was assumed unless stated otherwise in the scenario itself. A paper reference sheet was creating with this information for participant use during the experiment.

6.2.6 Docking tools

The docking tools were developed using current timetable data for Glasgow central station. A section of data spanning three hours was chosen, based on the number of trains, number of double docking sets, and available space. The time span chosen was from 10 AM until 1 PM. 10 AM was chosen as a starting time as this is after the peak; the service is still recovering from the peak so traffic is at a moderate level but there are still sufficient gaps to provide substantial choice when re docking trains. The interviews also showed that this is a time when TOC requests for changes were high.

6.2.6.1 Simplification of Data

Currently, the graphical Docker used at Glasgow details many factors including departure time from origin, and destination station (see Figure 33). This information is required mainly when dealing with stocks swaps. As discussed in the previous chapter stocks swaps require the operator to have sufficient knowledge of train types, and route knowledge in order to carry these out successfully. Stock swaps were not used in this experiment, therefore this information was deemed to not be required. As the aim of the experiment was to evaluate the strategies used across different tool types, and not to measure existing knowledge or training efficiency, the timetable was stripped down and simplified considerably. This involved:

- removing trains arriving prior to 10 AM
- removing origin and destination
- removing departure time
- simplifying the diagram number

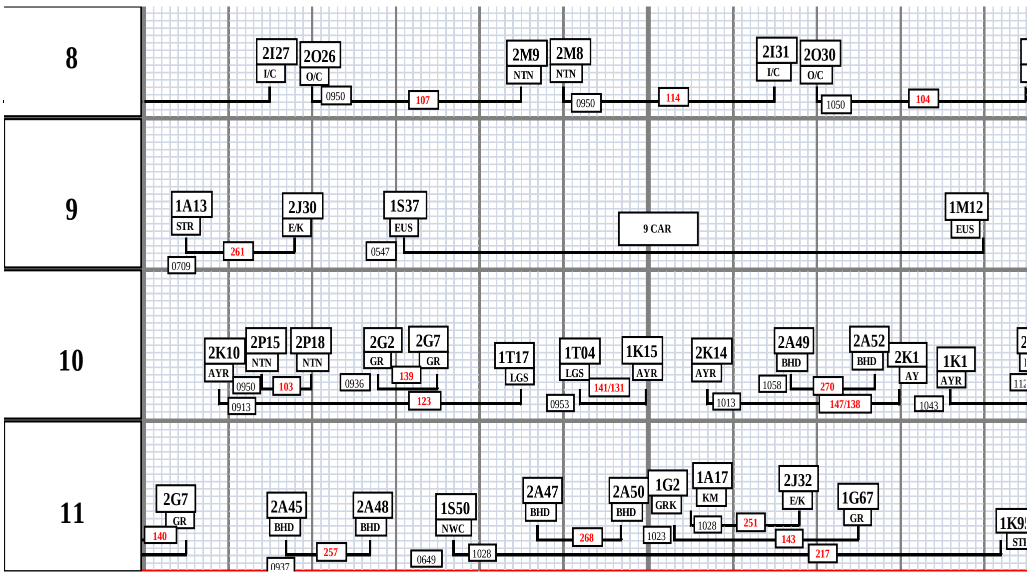


Figure 33- Graphical Docker before simplification

6.2.6.2 Graphical (Paper) Docker

Figure 34 shows the graphical (paper) Docker after the simplification outlined in the previous section has been carried out.

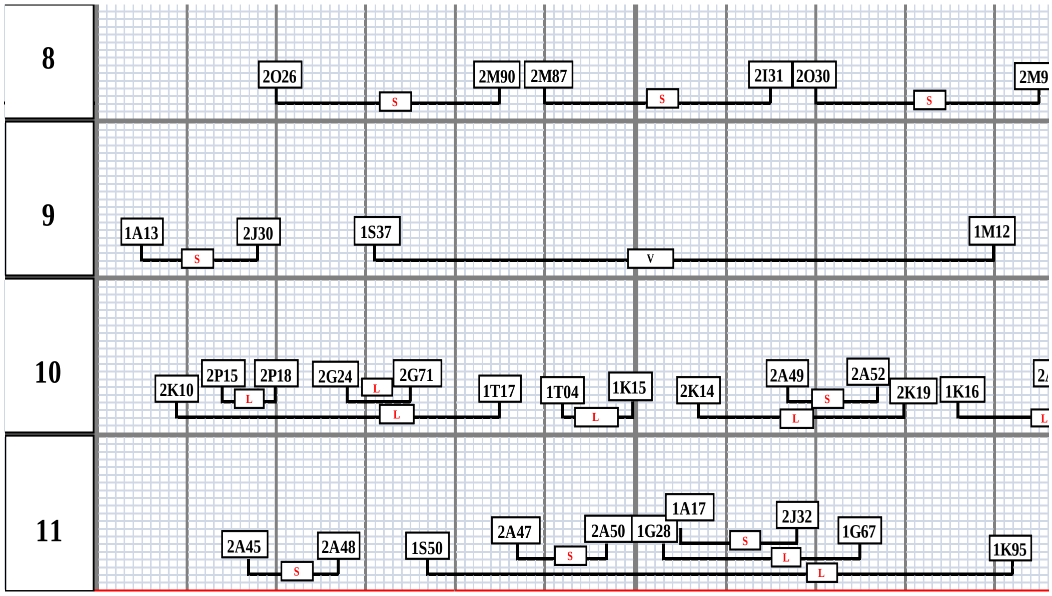


Figure 34 - Graphical (Paper) Docker after simplification

6.2.6.3 List Docker

The list Docker was devised to provide the same simplified information as the graphical Docker described in the previous section, and was arranged in arrival order (see Figure 35).

Platform	Train number on arrival	Arrival time	Train Type	Departure time	Train number on departure
15	1G22	10:03	L	10:25	1G73
5	2R21	10:04	L	10:16	2R08
9	1A13	10:05	S	10:18	2J30
3	1Y75	10:09	S	10:14	2Y52
10	2K10	10:09	L	10:45	1T17
10	2P15	10:14	L	10:20	2P18
11	2A45	10:17	S	10:27	2A48
14	2D16	10:19	S	10:37	2D19
8	2O26	10:20	S	10:45	2M90
14	2T80	10:22	L	10:30	2K79
1	5M11	10:23	V	10:40	1M11

Figure 35 - List Docker

This provides exactly the same amount of data as the graphical Docker but in list form. This was based on an existing tool used by signallers called a simplifier, which displays the information in a similar table form.

6.2.6.4 Electronic Docker

The electronic Docker was developed and built in Matlab as part of the experiment design. The software development was carried out by department staff and a project student following the electronic Docker tool requirements:

- Ability to identify type of train
- Ability to identify if splitting or joining in platform
- Ability to identify how long a train is sitting in a platform
- Ability to identify routes in and out
- Ability to move trains from one platform to another
- Ability to alter arrival and departure time
- Ability to alter train length
- Ability to close a platform
- Ability to add restrictions to certain trains i.e. diesel electric trains
- Ability to add restrictions to certain platforms i.e. no electric
- Ability to identify when trains differ from their original booked platform
- Ability to identify when trains have been altered
- Ability to identify when a move is illegal
- ability to identify when there are clashes
- Ability to drag and drop trains

Due to the ease of use observed by the operators at Glasgow when using the graphical docking tool, considerable effort was made to make the electronic docking tool as simple and intuitive as possible. The visual layout was closely based on the existing paper tool. The ability to drag and drop was seen as essential to the tool. Matlab was chosen as a high level tool that could be used to quickly develop a user interface. Development of the logic and processes of the electronic Docker to address the requirements and re-docking rules gave further insights into the planning process and task complexity.

After initial development, the electronic Docker tool was assessed by three operators at Glasgow. Changes were then made the tool including:

- Simplification of changing train length data
- Including a way of identifying where are train has been moved from
- Ability to print the current screen (for data collection purposes)

The electronic Docker was then built up into a stand-alone program which could be run on the experiment PC without requiring Matlab license or software. Figure 36 shows the electronic Docker, which can be seen to be very similar to the paper-based graphical Docker. The use of a large monitor made the scale of the platforms acceptable to work with. Figure 37 shows a close up of one section of the electronic Docker.

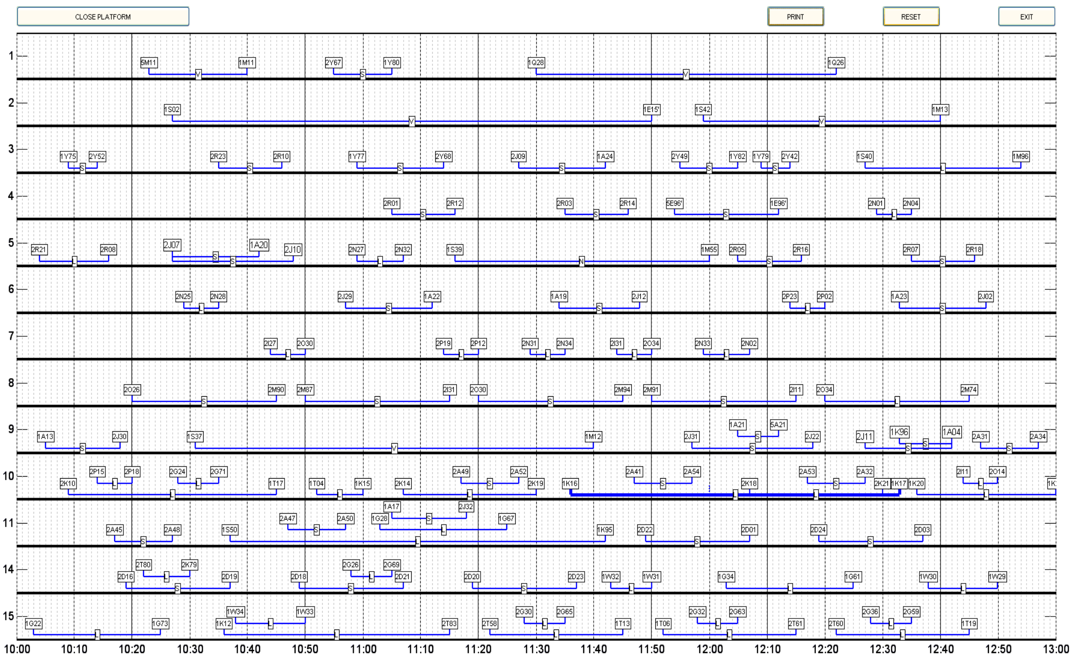


Figure 36 - Electronic Docker tool

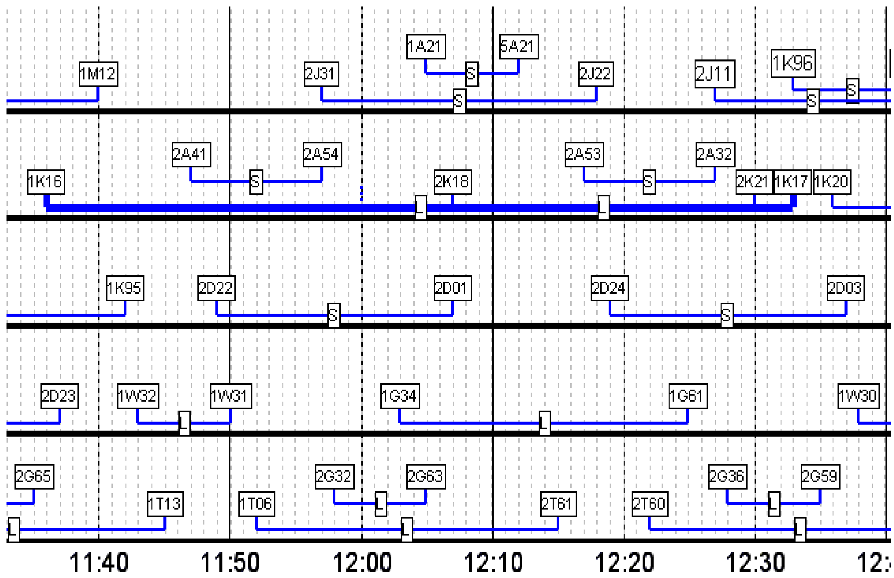


Figure 37 – Electronic Docker tool – close up view

One of the key developments in the electronic Docker over the graphical Docker was the ability to instantly identify whether a move was possible or not. This was done using colour coding; if a train was moved to a position where the train would not fit, would cause delay for another train or would block another train in the platform, that train (and any other affected train) would turn red. An error message would also appear in the centre of the train, for example "clash" (see Figure 38). When the train was moved a position that was acceptable, it would turn green. The process of developing the software to achieve this error checking highlighted the levels of processing that the signaller is carrying out to ensure successful re-docking. Compatibility of platform and vehicle and also cross checking with any vehicles in the vicinity of the re-docking vehicle must be carried out before the train can be re-docked. While this may seem conceptually simple, the details of step by step processes required in the Matlab program made the complexity more apparent.

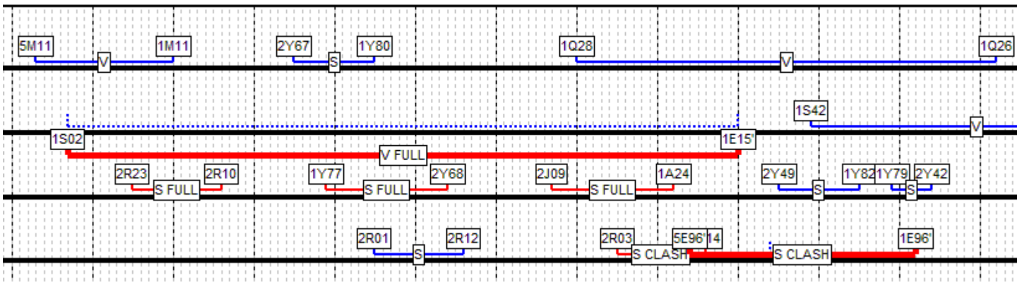


Figure 38 – Re-docking error checking example

6.2.7 Rules Generation

Using the cognitive task analysis detailed in the previous chapter (page 60), general rules of thumb were identified and converted into rules for the participants to follow. These were then verified by two SSMs at Glasgow. The rules were:

- Keep delays to a minimum
- All carriages must fit on platform
- Try to keep the train as close to the original platform as possible
- You may stack trains up to three deep if they will fit and not block the exit for other trains
- You must leave at least two clear minutes between trains. Ie, when a train departs a platform, two clear minutes must pass before another train can enter that platform

6.2.8 Scenario Generation

Again, using the task analysis in the previous chapter (page 60) common issues seen by SSMs and signallers interviewed were identified. These were:

- Dealing with an incident such as signalling failure, points failure or platform closure
- Moving the train to an alternative platform
- Joining or splitting trains (change in train length)
- Following orders from personnel within and outside the signal box; station staff, train operating companies etc
- Considering the proximity of passengers to platforms
- Observing restrictions to do with types of trains
- Dealing with early or late arrivals, or late departures
- Working around cancellations
- Performing multiple moves

The scenarios were designed to take into account all of the above, and with the assistance of the SSM is at Glasgow, were designed to increase in difficulty from the first scenario to the last. The scenarios were always presented in the same order to the participants. This was designed so that the scenarios increased in difficulty and any learning affects would be the same for all participants. This also meant that other measures, such as workload would not be affected.

Table 13 shows the content of each scenario. The added decision-making element in scenario 6 refers to an instruction given by the station manager. They request a change that requires more moves than entirely necessary – there is a more efficient way of carrying out the move. The participants have to decide whether to follow the station manager's orders or not: they are not told implicitly to do so. The 'creation of own rule required' element refers to scenario eight and an early arrival. The early arrival of the train causes large knock on effects that require many moves. The participants need to decide whether to accept the early train or delay its early arrival by two minutes. Again, the participants are given no guidance on early trains specifically.

Table 13 - Scenario summary showing issue frequency

		Scenario									
		1	2	3	4	5	6	7	8	9	10
Issues	Platform change	■	■	■	■		■	■	■	■	■
	Train length change	■									■
	Following orders						*1				
	Considering passengers			■							
	Dealing with an incident		■								■
	Late arrival			■				■			
	Late departure					■					
	Early arrival								*2		
	Platform closure									■	
	Multiple moves		■		■		■	■	■	■	
	Train restrictions				■						
	Platform restrictions				■						
		*1	added decision making element								
		*2	Creation of own rule required								

The particular details and wording of each scenario is included in the results and discussion of each scenario in section 6.3.1, where it is more relevant to have the detailed information at hand.

6.2.9 Pre-Experiment Presentation

A pre experiment presentation was developed in order to provide instructions to the participants and relevant training on the tools (see appendix C). The presentation included information on:

- Network Rail Background. What they do, what they own

- An overview of the task: Manage Glasgow Central Station for 45 minutes
- An overview of Glasgow Central
- Instruction on how platforming works in a terminus station (animation)
- Aims: To keep the station running to time
- An overview of disruption types and available strategies to deal with them
- The rules to stick to
- How to deal with late running (modified animation)
- Platform allocations (diagram)
- An overview of the tool (only the tool the participant was using was described)
    - List based
    - Graphical
    - Electronic
- The experiment task: 10 scenarios to solve
- Two example scenarios with answers were presented.

This then led into the experiment.

6.2.10 Pilot Experiments

The experiment was piloted twice prior to beginning data collection. The outcomes of these pilots and changes to the experiment as a result of them are detailed in the following sections.

<u>Pilot One</u>

The first pilot was carried out to test the experimental design. In order to do this effectively, the participant chosen (female) had an excellent knowledge of both experimental design and rail operations. This first pilot consisted of a run through of the presentations for all three conditions, and then a run through of the 10 scenarios using the graphical condition. The pilot revealed a number of issues and potential improvements:

- Each scenario was being timed individually. It was suggested that there should be a total time limit of 30 mins, and that total scenario completion could be an extra measure
- The presentation at the beginning of the experiment did not detail sufficiently the context of the problem
- The scenarios were not complex enough
- The pen given to the participant was said to be “too permanent” and made them hesitant to annotate the graph
- The researcher was being too helpful throughout
- The researcher’s data collection sheet was difficult to use
- The solution section of the post scenario questionnaire was not big enough

- The rules on the presentation slides and the printed sheet differed slightly
- The platform capacities sheet was difficult to read and interpret

Pre-experiment presentation

The pre-experiment presentation was revisited and revised to give participants a clearer view of the problem and so a better chance of choosing the right solution. An aerial shot of Glasgow station was included as was a short explanation of how the research came about. An animation of trains coming in and out of the platform and the problems related to that were also included.

Scenario complexity

The scenarios were revisited, and additional ones were developed. These were then shown again to the SSM at Glasgow, and the 15 scenarios were then cut down to 10. One of the main considerations was to ensure that the solutions were intuitive, but not obvious, and that no condition had an advantage over another. The 10 scenarios that remained were then ordered by difficulty.

The complexity element tended to come from having several events happen at once; a platform closure plus a blocked route plus a late train for example. The results of the pilot suggested that more of these types of scenario should be included in the final experiment.

Experimental procedure

During the first pilot, the participant commented that the experimenter was "giving a lot away," in terms of whether an answer was correct or not. This was overcome by adding additional instructions into the pre-experiment presentation:

> "I will start filming in a moment, and then we will go through two practice scenarios together. When these two practice scenarios have been completed, the experiment will begin and the clock will start. At this point I will not be able to help you, and I will not be able to tell you if your solution is correct. When you have solved the scenario and have an answer let me know and I will stop the clock".

The rules section of the pre-experiment presentation was also revisited and reworded to make it easier to understand and follow and the platform capacities sheet was reprinted to include pictorial representations of the trains on the platform plus a numeric entry of how many could fit on each.

Participant materials

For the actual experiment, the participants were provided with a pen, pencil and scrap paper, and told that they were free to write on the scrap paper or on the tools themselves. This was to try and overcome the issue of the participant being hesitant to mark the tools. The post scenario questionnaire was reprinted to include a larger area to write the solution to the scenario.

Pilot Two

The second pilot was a large scale pilot of the experiment methodology and involved nine PhD students (5 female, 4 male all carrying out design / human factors PhD's). However, the slot available was limited, leading to time constraints which meant that only the list and paper graph conditions could be trialled. This also meant that this pilot was carried out in a group setting as opposed to the one-to-one setting of the experiment. The primary aim of this pilot was to test the pre-experiment presentation for clarity, to check the timings, and to gather some results in order to carry out a power analysis and to ensure that the results gathered would provide the data required. Therefore the group setting was appropriate.

Due to the time constraints, it was only possible to complete six scenarios. The tables were set up in a horseshoe pattern facing a large presentation area. Participants were given a large desk each and prior to the arrival of the participants the conditions were set up alternately on each desk. When the participants arrived they were invited to sit wherever they would like. For this pilot session there were five participants in the graphical condition (3 female, 2 male), and four participants in the list condition (2 female, 2 male).

The participants were taken through the pre-experiment presentation, which was revised to include instructions on the use of both the list tool and the graphical tool (rather than just the one tool that the single participant in the actual experiment setting would be using). The inclusion of both tools in the same presentation was regarded as an issue in the sense of participants using the list based tool being able to get a sense of the functionality of the graphical tool. This meant that participants using the list based tool were potentially guided towards a specific type of problem-solving. This however, was not regarded as a major problem due to the fact that this was a pilot study and that issue would not occur in the experiment as it would be run on a one-to-one basis.

As expected, the participants using the list based tool took considerably more time solving the scenarios than in the graphical condition. For the actual experiment, it was decided that participants would be given a total time limit of 30 min, and the number of scenarios completed within the 30 min would be used as an additional measure. The total time would also be recorded as well as time for individual scenarios and would be used as an additional measure.

When the six scenarios were completed, a short focus group was carried out in order to obtain feedback on the experimental design. No major issues were reported although some minor changes to the presentation and the graphical Docker sheets were suggested.

When analysing the results, it became clear that there was extremely large variation in the solutions that were chosen by participants. An interesting observation was that participants in the list condition generally did not annotate the tool directly, but used scrap paper, whereas participants in the graphical condition annotated and manipulated the graph directly. This prompted the collection of the scrap paper / annotation information during the experiment. Despite the small sample size, more variability was observed in the list condition. The graphical condition yielded fewer delay minutes, while the list condition took longer, generated more mistakes and affected more trains.

It also became apparent when analysing the results that an additional measure, 'number of platforms away from the original' would be beneficial. This was added to the data collection sheet for use in the experiments.

6.2.11 Procedure

Three weeks were allocated for this experiment. Each day was split into eight timeslots and each timeslot was allocated a condition. Each condition had an equal number of sessions allocated based on time of day. Participants were then invited to select a slot via doodle poll.

The participants were shown to the experiment room, where they were asked to read the participant information sheet, and sign the consent form. They were also told at that point that the experiment would be filmed, but their face would not be visible. They were then guided through the 10 min presentation covering the purpose of the experiment, the background, how re-platforming works, the rules of the experiment, and how that particular tool could be used.

During the presentation, the participant was shown the tool that they were going to be using, the additional information sheets (the rules, train types and platform capacities) and the post scenario questionnaire. They were also advised that they had the use of scrap paper throughout the experiment.

The participant was then taken through two practice scenarios before the experiment was started and it was explained to the participant that the experimenter would no longer be able to have any input into solving the scenarios, and they would not be told at any point whether the solution they had come up with was correct or not.

The clock was started and the participant was taken through the 10 scenarios. Each scenario was read aloud to the participant once, and then the timer was started to capture the time for that scenario. This time was stopped when the participant announced that they had a solution to the scenario. The participant then wrote the solution down in the post scenario questionnaire, and completed the three questions. They then moved on to the next scenario. This process was repeated for each of the 10 scenarios. When all 10 were completed the timer was stopped, or if the 30 min was up before scenarios were completed the participant was made aware of this fact and the experiment was stopped. If the 30 min occurred during the completion of the scenario, the participant was allowed to finish. At the end of the experiment, the participants were asked a few general questions including:

- Did you understand clearly what you had to do?
- Were the solutions obvious? Why/why not?
- What would have made the task easier?

6.3 Results

All of the possible answers for each scenario were carefully listed and noted and each one was assessed by the number of delay minutes it accrued, the number of moves required, the number of trains affected by delay, the number of incorrect moves or illegal moves, i.e. the train will not fit and the number of total platforms moved from the original train position.

If an incorrect move was used, 100 delay minutes were added. This is not an unrealistic estimate as if a train is put in a platform where it will not fit then un-signalled moves may be required in order to move the train out of the way and into another platform to unload passengers. This will not only have an effect on the train in question, but also the train it is trying to dock behind and any other trains that it disrupts when making un-signalled moves.
The answers were then sorted into rank effectiveness order by the following ordered criteria:

1. Delay minutes (the fewer delay minutes the higher the ranking. If a train was moved into a platform where the train would not fit 100 delay minutes were added)
2. Number of moves (less moves meant a higher ranking)
3. Trains affected (a small number of trains affected meant a higher ranking)
4. Incorrect moves* (the fewer incorrect moves the higher the ranking)
5. Number of platforms away from original (the fewer number of platforms the higher the ranking)

For example, a solution that accrued no delay minutes and required four moves would be ranked higher than a solution that accrued four delay minutes but only required three moves. If the answers did not solve the scenario directly they were ranked last. The solution rankings were also evaluated and agreed by SSMs at Glasgow.

*Even though an incorrect move accrued delay minutes, it is still included in the effectiveness criteria due to the fact that the ability to make an incorrect move (i.e. not possible on the electronic version) is a disruptive event that may not only add delay minutes but additional workload for many operators such as signallers, controllers and station staff. Also, it is possible to make more than one incorrect move which would have extreme effects.

6.3.1 Task Performance Results

6.3.1.1 Scenario Completion

Only 50% of participants in the List condition completed all ten scenarios within the 30 minute time limit. The 20 participants in the list condition had an average completion rate of 88% (SD=17), the graph condition 97% (SD=8) and 100% completion for the electronic condition. A Kruskal-Wallis test showed that the effect of display type was significant, $X^2(2, N=60) = 15.317$, $p<0.0001$.
Tests of the three a priori hypotheses were conducted using Bonferroni adjusted alpha levels of 0.017 per test (.05/3). Results indicated that the completion rate for the list condition was significantly lower than in the electronic condition (U=100.00, N1=20, N2=20, p=0.006). The pairwise comparisons of the list condition with the graphical, and the graphical with the electronic condition were non-significant.

6.3.1.2 Solution Ranking

Each solution was ranked in terms of its effectiveness by the criteria described previously. The electronic condition provided the most top-ranked solutions, followed by the graphical solution, then the list solution. Table 14 shows the frequency of the ranked solutions by condition. For example, the red rectangle highlights the 1st ranked solutions to scenario one for each of the three experiment conditions. The top ranked solution was achieved by eight participants in the list condition, 13 in the graphical condition, and 19 in the electronic condition.

A Kruskal Wallis test showed that the effect of display type was significant across scenarios 1, 2, 3, 5, 6, 7, 8, 9 and 10 with regard to the solution ranking. There was no significant difference for scenario 4. The results for each scenario are discussed in the following sections.

Table 14 - Solution rankings by scenario and condition

		Solution ranking																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Scenario one	list	8	0	1	1	0	4	4	2											
	Graph	13	1	0	0	1	1	0	4											
	Electronic	19	1	0	0	0	0	0	0											
Scenario two	list	0	1	2	1	8	0	0	1	4	2	0	1							
	Graph	3	3	8	0	5	0	0	0	0	1	0	0							
	Electronic	9	2	4	0	1	1	1	0	0	1	1	0							
Scenario three	list	18	2	0	0	0	0	0	0	0										
	Graph	6	6	3	1	1	1	0	1	1										
	Electronic	10	8	0	0	1	0	1	0	0										
Scenario four	list	8	2	1	3	1	1	4												
	Graph	13	0	0	4	0	0	3												
	Electronic	14	2	0	4	0	0	0												
Scenario five	list	9	0	1	0	1	4	1	2	1	1	0								
	Graph	12	1	1	1	0	2	1	0	0	1	1								
	Electronic	20	0	0	0	0	0	0	0	0	0	0								
Scenario six	list	1	0	1	0	3	3	1	1	0	0	0	1	1	2	5				
	Graph	5	0	3	1	4	2	0	0	1	0	0	0	3	3	0				
	Electronic	9	1	5	0	5	0	0	0	0	2	1	0	0	0	0				
Scenario seven	list	0	2	0	0	1	9	1	1	1	2	0								
	Graph	6	5	2	0	0	1	0	0	1	4	1								
	Electronic	14	2	0	1	0	0	0	0	3	0	0								
Scenario eight	list	0	0	0	0	0	0	10	0	1	2	1	1	0						
	Graph	7	0	1	0	0	1	1	1	0	4	3	0	1						
	Electronic	7	2	0	1	1	9	0	0	0	0	0	0	0						
Scenario nine	list	0	0	0	0	0	0	1	0	1	0	2	2	2	0	1	1	1	1	2
	Graph	5	4	0	0	1	1	1	2	0	1	0	1	1	0	1	0	0	0	0
	Electronic	8	0	7	1	0	1	0	0	1	1	0	0	0	1	0	0	0	0	0
Scenario 10	list	2	0	1	1	0	2	0	2	0	1	1	0	0						
	Graph	8	0	0	0	1	4	1	0	1	0	0	1	1						
	Electronic	19	1	0	0	0	0	0	0	0	0	0	0	0						

<u>Scenario 1</u>

"Train 2N25 due to arrive in platform 6 at 10:29 is now a 6 car instead of a 3 car train".

The most desirable solution in this case was to put the train into platform four from platform six.

Table 15 shows eight different solutions were given to the scenario with the list condition producing the most variability with six different solutions, the graph condition with five different solutions and the electronic condition with only two different solutions.

Table 15 - Scenario 1 solutions

Scenario	Solution	description	Rank	Delay minutes	No moves	Trains affected	incorrect moves	platforms removed	Graph	Elec	List
1	A	Put 2N25 in 4	1	0	1	0	0	2	13	19	8
1	B	Put 2N25 in 5, 2J07 in 6	2	0	2	0	0	2	1	1	0
1	E	Put 2N25 in 5, 2J07 in 4	3	0	2	0	0	2	1	0	0
1	D	Put 2N25 in 10	4	3	1	2	0	4	0	0	1
1	C	Put 2N25 in 9	5	6	1	1	0	3	0	0	1
1	F	Leave 2N25 in 6	6	100	0	0	1	0	2	0	3
1	H	Put 2N25 in 5	7	100	1	0	1	1	4	0	2
1	G	Put 2N25 in 7	8	100	1	0	1	1	0	0	4

The solution ranked number two required two trains to be moved and was only given as a solution by two participants. There was only one more answer given for this scenario that required two trains to be moved which was solution E, ranked number three. This, interestingly, was selected by one participant using the list condition. Three of the solutions included illegal moves (not possible with the error detection of the electronic condition) as the participants were attempting to put a train into a platform where it would not fit either because it was too big for the platform or another train was on the platform already meaning that train would not fit. These three solutions were chosen by a total of nine participants in the list condition and six participants in the graph condition. One of these answers was to leave the train where it was as the participants could not see a problem. The problem was that the platform was only a four car platform and the train had now doubled in size from a three-car to a six car train. Three participants in the list condition and two participants in the graph condition chose this answer. This was a similar situation for solution G which required the train to be put into platform seven which is a four car platform. This was chosen by four participants in the graph condition and two participants from the list condition.

Tests of the three a priori hypotheses were conducted using Bonferroni adjusted alpha levels of 0.017 per test (.05/3). Results indicated that the solution rankings for the list condition was significantly lower than in the electronic condition ($U=84.00$, $N1=20$, $N2=20$, $p=0.001$). The pairwise comparisons of the list condition with the graphical, and the graphical with the electronic condition were non-significant.

Scenario 2

"There has been a mix up with the catering contractor and all of the supplies for train 1Y77, due to arrive in platform 3 at 10:59 have been delivered to platform 6 instead and no-one is available to move them. These supplies must go on 1Y77"

Platform six was occupied at the time by another two-car train that arrived two minutes prior to 1Y77, and was due to leave two minutes prior to 1Y77s departure. So in order to satisfy the scenario adequately 1Y77 must go on platform six, in which case the other train will be affected so a change is required. Table 16 summarises the solution results.

Table 16 - Scenario 2 solutions

Scenario	Solution	description	Rank	Delay minutes	No moves	Trains affected	incorrect moves	platforms removed	Graph	Elec	List
2	B	Put 1Y77 in 6, 2J29 in 7	1	0	2	0	0	4	3	9	0
2	E	Put 1Y77 in 6, 2J29 to 5	2	0	2	0	0	4	3	2	1
2	A	Put 1Y77 in 6, 2J29 in 3	3	0	2	0	0	6	8	4	2
2	L	Put 1Y77 in 6, 2J29 in 8	4	0	2	0	0	5	0	0	1
2	F	Put 1Y77 in 6	5	4	1	1	0	3	5	1	8
2	G	Delay 1Y77 to 11 and put in 6	6	6	1	2	0	3	0	1	0
2	D	Put 1Y77 in 6 and delay	7	16	1	1	0	1	0	1	0
2	K	Put 1Y77 in 6, 2J29 in 11	8	17	2	1	0	8	0	0	1
2	I	Put 1Y77 in 5	9	2	1	1	0	2	0	0	4
2	C	Put 1Y77 in 7	10	2	1	1	0	4	1	1	2
2	H	Put 1Y77 in 4, 2R01 to 3	11	0	2	0	0	2	0	1	0
2	J	Put 2J29 in 5	12	0	1	0	0	1	0	0	1

The solution ranked number one for this scenario meant moving 1Y77 to platform six and moving the train out of platform six into platform seven. The solution ranked number two was similar; the train already on platform six was moved to platform five. This platform is adjacent to platform six but the move meant putting the train behind another one which could lead to delays later on.

Nine participants from the electronic condition selected the highest ranking solution, as did three from the graphical condition. No one in the list condition chose this solution. The third-ranked solution was to swap trains in platform six and three. This solution was chosen by eight participants in the graphical condition, four for the electronic and two for the list condition. Six out of the twelve possible solutions involved accruing delay minutes of between two and seventeen minutes. Two of the twelve solutions did not sufficiently solve the scenario.

Tests of the three a priori hypotheses were conducted using Bonferroni adjusted alpha levels of 0.017 per test (.05/3). Results indicated that the solution rankings for the list condition was significantly lower than in the electronic condition ($U=78.00$, $N1=20$, $N2=20$, $p=0.001$) and the graphical condition ($U=75.50$, $N1=20$, $N2=20$, $p<0.001$). The pairwise comparisons of the graphical with the electronic condition were non-significant.

Scenario 3

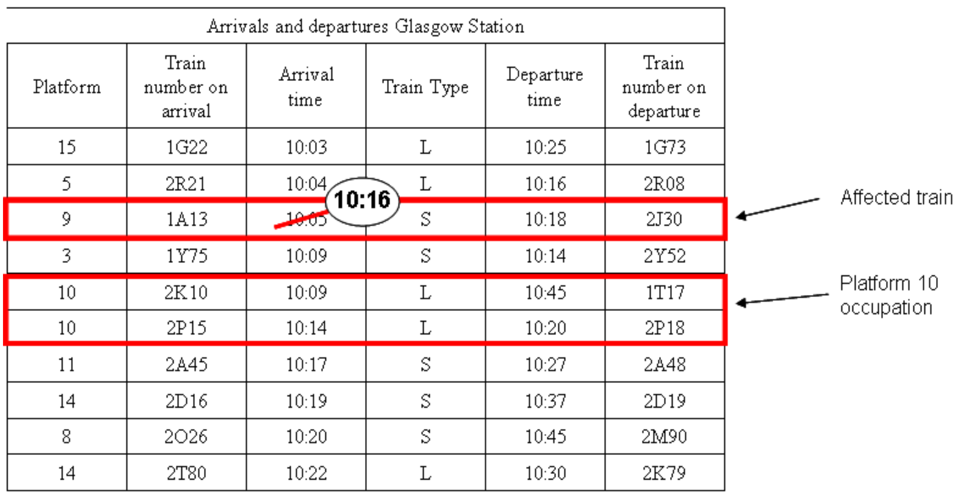
"Train 1A13, due to arrive in platform 9 at 10:05 is running late, and will not arrive until 10:16. As a result, it has missed its clear route into the platform and can no longer get into platform 9. It is currently 10:04 and all of the passengers are already on platform 9. As the train will only be in the station for 2 minutes you need to ensure that all of the passengers can board the train on the new platform in this short space of time".

The scenario in this case gave additional information effectively implying the 'use the closest platform' rule was important here. Table 17 summarises the results for this scenario.

Table 17 - Scenario 3 solutions

Scenario	Solution	description	Rank	Delay minutes	No moves	Trains affected	incorrect moves	platforms removed	Graph	Elec	List
3	A	Put 1A13 in 10	1	0	1	0	0	1	6	10	18
3	C	1A13 to 8	2	0	1	0	0	1	6	8	0
3	G	1A13 to7	3	0	1	0	0	3	3	0	0
3	I	1A13 to 6	4	0	1	0	0	3	1	0	0
3	B	Put 1A13 in 10, 2P15 to 9	5	0	2	0	0	2	1	1	2
3	H	1A13 to 10, 2P15 to 7	6	0	2	0	0	4	1	0	0
3	D	1A13 to 10, 2K10 to 14, 2P15 to 9	7	0	3	0	0	5	0	1	0
3	E	1A13 to 10, 2K10, 2P15, 2G24 to 4	8	0	4	0	0	19	1	0	0
3	F	1A13 to 11	9	3	1	0	0	2	1	0	0

The most desirable answer in this case is to put the train 1A13 into platform ten. This answer was selected by eighteen participants in the list condition, ten in the electronic and six in the graphical condition. This answer involved docking the train behind another one and having three trains in the platform at one time. One explanation for the high number of list condition answers could be the close proximity with which the trains arrive into platform ten; one arrived at 10:09 with the second one arriving at 1014. These two trains were easy to spot when the participant was searching through the time based list for 1016 (see Figure 39). They were both on the same page and it was easy to see that they were double docked and that the train in question could slot easily behind them and not affect them.



Arrivals and departures Glasgow Station					
Platform	Train number on arrival	Arrival time	Train Type	Departure time	Train number on departure
15	1G22	10:03	L	10:25	1G73
5	2R21	10:04	L	10:16	2R08
9	1A13	~~10:05~~	S	10:18	2J30
3	1Y75	10:09	S	10:14	2Y52
10	2K10	10:09	L	10:45	1T17
10	2P15	10:14	L	10:20	2P18
11	2A45	10:17	S	10:27	2A48
14	2D16	10:19	S	10:37	2D19
8	2O26	10:20	S	10:45	2M90
14	2T80	10:22	L	10:30	2K79

Figure 39 - List Docker with scenario 3 highlighted

Participants in the electronic condition after shortening the train to only remain in the station for 2 minutes were instinctively looking for an empty space. They were moving the train around until it went green and eight of the participants moved the train to platform eight. Six participants in the graphical condition also move the train to platform eight. The graphical condition however, did attract a higher number of moves with two answers requiring two moves and one answer requiring four moves. The highest number of moves for the list condition was two.

Tests of the three a priori hypotheses were conducted using Bonferroni adjusted alpha levels of 0.017 per test (.05/3). Results indicated that the solution rankings for the list condition was significantly higher (better) than in the Graphical condition ($U=72.00$, $N1=20$, $N2=20$, $p<0.001$). The pair wise comparisons of the list condition with the electronic, and the graphical with the electronic condition were non-significant.

Scenario 4

> **"Train 2O26, due to arrive in platform 8 at 10:20 can no longer use that platform as the train before it is running late. Due to this train being a diesel train, it can only use platforms 7 and 8".**

If the train was moved to platform seven this would mean the train booked in there could no longer use that platform. Table 18 shows the results for scenario 4.

Table 18 - Scenario 4 solutions

Scenario	Solution	description	Rank	Delay minutes	No moves	Trains affected	incorrect moves	platforms removed	Graph	Elec	List
4	A	2O26 to 7, 2I27 to 6	1	0	2	0	0	2	13	14	8
4	C	2O26 to 7, 2I27 to 9	2	0	2	0	0	3	0	2	2
4	G	2O26 to 7, 2I27 to 8	3	2	2	1	0	2	0	0	1
4	B	2O26 to 7, delay 2I27	4	3	1	1	0	1	4	4	3
4	E	2O26 to 7, 2I27 to 10	5	3	2	1	0	4	0	0	1
4	F	2O26 to 8	6	100	0	1	1	0	0	0	1
4	D	2O26 to 7	7	100	1	1	1	1	3	0	4

The most desirable solution in this case was to move the train to platform seven, and the train on platform seven to platform six. This solution was selected by fourteen participants in the electronic condition, thirteen participants in the graphical condition, and eight using the list condition. The second ranked solution, and the only other solution not accrue any delay minutes, was to move the change to platform seven and then the train on platform seven to platform nine. This required one additional platform move than the highest ranked solution.

Two of the solutions involved making incorrect or illegal moves. These were chosen by five participants in the list condition, and three in the graphical condition. Another solution, solution B, was to move the train to platform seven and actively delay the train already on platform seven by three minutes. This was chosen by four users in the graphical condition, four in the electronic and three in the list condition.

Scenario 5

"Train 1K16 arriving in platform 10 at 11:36 will now not be departing until 12:33"

The platform in question, platform ten, was at the time extremely busy with many double docked trains. 1K16 arrived in the platform at 1136 and was initially due to leave at midday. Table 19 summarises the ranked results for scenario 5.

Table 19 - Scenario 5 solutions

Scenario	Solution	description	Rank	Delay minutes	No moves	Trains affected	incorrect moves	platforms removed	Graph	Elec	List
5	A	Leave 1K16 in 10	1	0	0	0	0	0	12	20	9
5	K	1K16 to 6, 1A19 to 5, 2P23 to 4	2	2	3	1	0	7	1	0	0
5	D	1K16 to 14	3	3	1	1	0	3	1	0	1
5	J	1K16 to1	4	8	1	1	0	9	1	0	0
5	F	2A41 to 11	5	10	1	1	0	1	0	0	1
5	B	1K16 to 11	6	14	1	1	0	1	2	0	4
5	G	1K16 to 3	7	16	1	2	0	7	0	0	1
5	C	1K16 to 9	8	17	1	1	0	1	1	0	2
5	E	1K16 to 8	9	100	1	2	1	2	0	0	1
5	H	1K16 to 5	10	100	1	1	1	5	1	0	1
5	I	1K16 to 7, 2N31 to 9	11	200	2	2	2	5	1	0	0

The desired solution in this case was to leave the train where it was. Other trains could come in and dock behind it and leave without this train having any effect on them. All twenty participants in the electronic condition chose this solution. They were aided by the ability to change the departure time easily and have instant notification as to if the move was possible by the train turning green, or not possible if the train turned red. Twelve participants in the graphical condition also chose this solution. This was the only solution out of the eleven observed solutions, to not accrue any delay minutes. The solution ranked number two which was only chosen by one participant from the graph condition, involved moving three trains. This led to two delay minutes and also meant the trains were a total of seven platforms away from their original ones.

Three of the solutions involved incorrect moves, one of which involved two incorrect moves. This was chosen by a participant in the graphical condition.
Tests of the three a priori hypotheses were conducted using Bonferroni adjusted alpha levels of 0.017 per test (.05/3). Results indicated that the solution rankings for the list condition was significantly lower than in the electronic condition (U=90.00, N1=20, N2=20, p=0.002). The pairwise comparisons of the list condition with the graphical, and the graphical with the electronic condition were non-significant.

Scenario 6

> **"Platform 8 will be out of use from 11:50 until 12:50. All trains in platform 8 between these times must be moved. The station manager has indicated that he would like to put the trains in platform 7 instead".**

Scenario 6 was the first of the 10 scenarios that encouraged the participants to use not only the rules they had been given, but also their own judgement on whether to follow the orders given directly in the scenario if it meant breaking some of these rules or to disobey orders. By moving the trains to platform seven, following the request, there were then other knock-on effects to deal with. The solution that followed the station manager's request required four or five moves in order to not accrue any delay minutes. Table 20 shows the results for scenario 6.

Four out of the fifteen possible solutions did not accrue any delay minutes. These were chosen by fourteen participants in the electronic condition, 2 in the list condition, and eight in the graphical condition. Four participants in the electronic condition who followed the station manager's request accrued delay minutes by design, i.e. they chose to delay trains to require fewer moves. Four other electronic participants selected a solution that did not follow the station manager's rules, required only two moves and did not accrue any delay minutes. This particular solution was also chosen by one graphical participant and one list participant.

Table 20 - Scenario 6 solutions

Scenario	Solution	description	Rank	Delay minutes	No moves	Trains affected	incorrect moves	platforms removed	Graph	Elec	List
6	A	2M91, 2O34 to 7, 2I31 to 9, 2N33 to 6	1	0	4	0	0	5	6	9	1
6	B	2m91, 2O34 to 7, 2I31, 2N33 to 6, 1A19 to 5	2	0	5	0	0	5	0	1	0
6	C	2M91 to 4, 2O34 to 7	3	0	2	0	0	5	1	4	1
6	O	2M91 to 1, 2O34 to 7	4	0	2	0	0	8	1	0	0
6	F	2M91 and 2O34 to 7, 2N33 to 6	5	2	3	1	0	3	4	2	3
6	J	2M91 to 9, 2O34 to 7	6	5	2	1	0	2	2	0	3
6	M	2M91 to 9, 2O34 to 4	7	5	2	1	0	5	0	0	1
6	I	2M91 and 2O34 to 9	8	7	2	2	0	2	0	0	1
6	N	2M91 to 6, 2O34 to 2	9	10	2	2	0	8	1	0	0
6	D	2M91, 2O34 to 7 and delay	10	19	2	1	0	2	0	3	0
6	E	2M91 and 2O34 to 7, delay both	11	33	2	2	0	2	0	1	0
6	K	2O34 to 7	12	60	1	1	0	1	0	0	1
6	L	2M91 and 2O34 to 7, 2I31 to 9	13	100	3	1	1	4	2	0	1
6	H	2M91 and 2O34 to 7	14	100	2	1	1	2	3	0	2
6	G	2M91 to 6, 2O34 to 7	15	100	2	1	1	3	0	0	5

Tests of the three a priori hypotheses were conducted using Bonferroni adjusted alpha levels of 0.017 per test (.05/3). Results indicated that the solution rankings for the list condition was significantly lower than in the electronic condition ($U=50.00$, $N1=20$, $N2=20$, $p<0.001$). The pairwise comparisons of the list condition with the graphical, and the graphical with the electronic condition were non-significant.

Scenario 7

> **"Train 1G28 due to arrive in platform 11 at 11:03 is running 6 minutes late"**

A total of eleven solutions were used for this scenario in which a train was running six minutes late. By running late this train will make another train nine minutes late if it were to stay where it is. The summarised results are shown in Table 21.

Table 21 - Scenario 7 solutions

Scenario	Solution	description	Rank	Delay minutes	No moves	Trains affected	incorrect moves	platforms removed	Graph	Elec	List
7	A	1A17 to 9	1	0	1	0	0	2	6	14	0
7	B	1G28 to 9	2	0	1	0	0	2	5	2	2
7	K	1G28 to 10, 2A49 to 9	3	0	2	0	0	2	2	0	0
7	D	1A17 to 10, 2A49 to 9, 2K14 to 11	4	0	3	0	0	3	0	1	0
7	E	1G28 to 10, 2K14 to 11	5	4	2	1	0	2	0	0	1
7	F	1G28 to 10	6	5	1	2	0	1	1	0	9
7	H	1A17 to 14	7	5	1	2	0	2	0	0	1
7	I	1A17 to 15	8	5	1	1	0	3	0	0	1
7	C	Delay 1A17	9	6	0	1	0	0	1	3	1
7	G	leave 1A17 where it is	10	6	0	1	0	0	4	0	2
7	J	1G28 to14	11	8	1	1	0	2	1	0	0

The optimum solution for this scenario was to move the train that 1G28 would be blocking in (1A17) to platform nine where it would sit behind the Voyager train. The second ranking solution would be to move 1G28 to platform nine. The majority of people in the electronic condition and the graphical condition chose either the first or the second ranking solution. However, nobody in the list condition chose the first ranking solution and only two chose the second ranking solution. The most popular solution for the list condition was to move 1G28 to platform ten. This solution leads to two trains being affected by a total of five minutes delay. This solution was only chosen by one other participant, in the graphical condition.

Of the eleven solutions observed in total, the list condition used seven, the graphical condition used seven, and the electronic condition used only four different solutions, three of which did not accrue any delay minutes. Only two participants in the list condition chose a solution that did not accrue any delay minutes compared to thirteen in the graphical and seventeen in the electronic condition.

Out of the eleven solutions only four did not accrue any delay minutes. The other seven gathered delay minutes ranging from four minutes to eight minutes. For the solutions that involved moving trains, only three involved moving more than one train. The one solution that required three moves was chosen by one participant in the electronic condition and did not accrue any delay minutes. Three participants in the electronic condition chose the solution that accrued six delay minutes. This was a tactical purposeful decision (based on the commentary during the experiment) which meant that no trains needed to be moved. This solution was chosen by one participant in each of the other conditions.

Tests of the three a priori hypotheses were conducted using Bonferroni adjusted alpha levels of 0.017 per test (.05/3). Results indicated that the solution rankings for the list condition was significantly lower than in the electronic condition ($U=47.50$, $N1=20$, $N2=20$, $p<0.001$). The pairwise comparisons of the list condition with the graphical, and the graphical with the electronic condition were non-significant.

Scenario 8

> **"Train 2K18, due to arrive in platform 10 at 12:07, will now be arriving at the station at 12pm"**

This scenario dealt with the early arrival of a train. This situation was not dealt with at all by either the pre-task presentation, or the rules that were briefed prior to the task. This meant that the participants had to create their own rules regarding early arrival of trains. This scenario was designed to cause disruption by the train arriving early. The participants could therefore work around the disruption, or not except the early arrival. For the purposes of scoring, if a solution required the train to arrive later than planned, (despite arriving earlier anyway), it was still classed as a delay as it was deviating from the planned time. Table 22 shows the summarised results for scenario 8.

Table 22 - scenario 8 solutions

Scenario	Solution	description	Rank	Delay minutes	No moves	Trains affected	incorrect moves	platforms removed	Graph	Elec	List
8	C	2K18 to 14	1	0	1	0	0	3	7	7	0
8	L	1K16 to 1	2	0	1	0	0	9	0	2	0
8	F	2K18 to7, 2N33 to 6	3	0	2	0	0	4	1	0	0
8	K	1K16 to 6, 1A19 to 5	4	0	2	0	0	5	0	1	0
8	M	2K18 to 6, 2P23 to 7	5	0	2	0	0	5	0	1	0
8	A	Arrive 2 minutes later than scheduled	6	2	0	1	0	0	1	9	0
8	B	Leave it	7	2	0	1	0	0	1	0	10
8	G	2A53 to 14	8	6	1	1	0	3	1	0	0
8	J	Get it to arrive at original planned time (7 mins later)	9	7	0	1	0	0	0	0	1
8	D	2K18 to 9	10	11	1	3	0	1	4	0	2
8	E	2K18 to 11	11	18	1	1	0	1	3	0	1
8	I	2K18 to 7	12	100	1	0	1	3	0	0	1
8	H	2K18 to 6, 1A23 to 5	13	100	2	0	1	5	1	0	0

The top-ranked solution in this case was to move the early train to platform fourteen. This was chosen by seven participants in both the graphical and the electronic condition. The second ranked solution was to move the affected train (1K16) to platform one. This was only chosen by two participants in the electronic condition.

The option of making the train arrive at the original planned time of 12:07 was favoured by eleven participants in the list condition and only one in the graphical condition. Nine participants in the electronic condition chose to delay the train by two minutes, to arrive five minutes early rather than seven. This was also chosen by one participant in the graphical condition. Four of the thirteen solutions accrued over ten minutes delay. Eight of these were selected by people in the graphical condition, and four by participants in the list condition.

Tests of the three a priori hypotheses were conducted using Bonferroni adjusted alpha levels of 0.017 per test (.05/3). Results indicated that the solution rankings for the list condition was significantly lower than in the electronic condition ($U=0.00$, $N1=20$, $N2=20$, $p<0.001$). The pairwise comparisons of the list condition with the graphical, and the graphical with the electronic condition were non-significant.

Scenario 9

> **"Platform 15 needs to be closed for some planned maintenance. No trains will be able to use this platform between 10:39 and 10:47am. You are being given this information at 8am".**

This scenario attracted the most variation in solutions, with nineteen solutions being selected. Unlike the other scenarios where the participants were led to assume that the situation was rather urgent, this scenario made the participant aware that they were being given the information in advance. This was designed to encourage planning. Table 23 summarises the results for scenario 9.

The list condition showed great variation in the solutions selected, utilising ten of the nineteen. The graphical condition only used eight, and the electronic condition, seven.

Table 23 - scenario 9 solutions

Scenario	Solution	description	Rank	Delay minutes	No moves	Trains affected	incorrect moves	platforms removed	Graph	Elec	List
9	A	1K12 to 9, 1W34 to 6	1	0	2	0	0	13	7	8	0
9	Q	1K12 to 9, 1W34 to 4	2	0	2	0	0	15	4	0	0
9	D	1K12 to 2, 1W34 to 9	3	0	2	0	0	17	0	7	0
9	F	1K12 to 7, 2I27 an 2P19 to 6, 1W34 to 9	4	0	4	0	0	14	0	1	0
9	S	1G22, 1K12 and 1W34 to 14, 2D16, 2T80 to 15	5	0	7	0	0	7	2	0	0
9	B	1K12 to 14, 1W34 to 9	6	3	2	1	0	6	0	1	0
9	P	1K12 and 1W34 to 4	7	3	2	1	0	10	1	0	1
9	R	1K12 to 3, 1W34 to 6	8	3	2	1	0	19	1	0	0
9	E	1K12 to 9, 1W34 to 14	9	4	2	2	0	6	0	1	1
9	G	1K12 to 9, 1W34 to 11	10	6	2	2	0	8	1	1	0
9	K	1K12 to 14, 1W34 to 10	11	7	2	3	0	5	0	0	2
9	H	1K12 and 1W34 to 14	12	9	2	3	0	2	1	0	2
9	I	1K12 to 14, 1W34 to 11	13	9	2	3	0	4	0	0	2
9	C	Delay 1K12, 1W34 to 14	14	17	1	3	0	1	0	1	0
9	M	1K12 to 10, 1W34 to 11	15	29	2	5	0	7	0	0	1
9	L	1W34 to 14	16	100	1	2	1	1	1	0	1
9	N	1K12 to 11, 1W34 to 14	17	100	2	2	1	4	0	0	1
9	O	1W34 to 9	18	100	2	0	1	5	0	0	1
9	J	1K12 to 6, 1W34 to 6	19	100	2	0	2	16	0	0	2

Only five out of the nineteen solutions did not accrue any delay minutes. These were chosen by thirteen participants in the graphical condition, sixteen participants in the electronic condition and none in the list condition. The four lowest ranking solutions accrued 100 delay minutes each. A total of five participants in the list condition chose these and one participant in the graphical condition.

This was one of only two scenarios where the list condition showed considerable differences with both the graph and electronic conditions. This is also the only scenario where the electronic condition gathered more delay minutes.

Tests of the three a priori hypotheses were conducted using Bonferroni adjusted alpha levels of 0.017 per test (.05/3). Results indicated that the solution rankings for the list condition was significantly lower than in the electronic condition (U=11.50, N1=20, N2=20, p=0.001) and the graphical condition (U=27.00, N1=20, N2=20, p<0.001). The pairwise comparisons of the graphical with the electronic condition were non-significant.

Scenario 10

> **"Train 1S39 due in platform 5 at 11:16 is now a 6 car train. Train 2R03 due in platform 4 at 11:35 cannot access platform 4 due to a signalling failure".**

This scenario was designed to test the participants learning throughout the task. The participant had to be aware of train lengths, platform lengths, and the other occupation rules. Although there was a change in length in this scenario from a four car to a six car train, the train did not require moving to an alternative platform. Train 2R03 however, did require moving with the optimum solution being to move this train from platform four to platform two. Table 24 summarises the results for scenario 10.

Table 24 - scenario 10 solutions

Scenario	Solution	description	Rank	Delay minutes	No moves	Trains affected	incorrect moves	platforms removed	Graph	Elec	List
10	A	2R03 to 2	1	0	1	0	0	2	8	19	2
10	M	2R03 to 3, 2J09 to 2	2	0	2	0	0	2	0	1	0
10	J	2R03 to 3, 2J09 to 4	3	0	2	0	0	2	0	0	1
10	K	2R03 to 6, 2R01 to 3, SE96 to 2, 1S39 to 4	4	1	1	1	0	2	0	0	1
10	F	2R03 to 8	5	3	1	1	0	4	1	0	0
10	C	2R03 to 3	6	6	1	1	0	1	4	0	2
10	B	2R03 to 5, 1S39 to 3	7	7	2	1	0	3	1	0	0
10	I	2R03 to 5, 1S39 to 4	8	11	2	2	0	2	0	0	2
10	D	2R03 to 6, 2R01 to 3, SE96 to 2, 1S39 to 4	9	35	4	3	0	6	1	0	0
10	H	2R03 to 5	10	100	1	0	1	1	0	0	1
10	L	2R03 to 5, 1S39 to 6	11	100	2	1	1	2	0	0	1
10	E	2R03 to 5, 1S39 to 1	12	100	2	0	1	5	1	0	0
10	G	2R03 to 4, 1S39 to 1	13	100	23	0	1	4	1	0	0

Only ten participants (50%) in the list condition completed this scenario. 70% of all participants chose solutions that accrued delay, with two participants choosing solutions that accrued 100 delay minutes each. Even though only ten participants from the list condition completed this scenario, this condition accounted for seven of the thirteen solutions. The seventeen participants in the graphical condition accounted for seven solutions, and the twenty participants in the electronic condition accounted for only two.

Only three of the thirteen possible solutions for this scenario did not accrue any delay minutes. All the participants in the electronic condition chose from these three solutions. With nineteen participants choosing the optimum solution and the other participant choosing the solution ranked number two. Eight participants in the graphical condition chose the optimum solution and only two participants in the list condition chose the optimum solution.

Tests of the three a priori hypotheses were conducted using Bonferroni adjusted alpha levels of 0.017 per test (.05/3). Results indicated that the solution rankings for the list condition was significantly lower than in the electronic condition (U=21.00, N1=20, N2=20, p<0.001) and the graphical condition significantly lower than the electronic condition (U=84.00, N1=20, N2=20, p=0.008). The pair wise comparisons of the graphical with the list condition were non-significant.

6.3.2 Time taken

The participants were given 30 min to complete all of the scenarios. This timing included completing the post scenario questionnaires. Each scenario was also timed individually. Timing started when the experimenter finished reading the scenario aloud, and ended when the participant verbally said that they had come up with a solution. Figure 40 shows the average completion times for each scenario by condition.

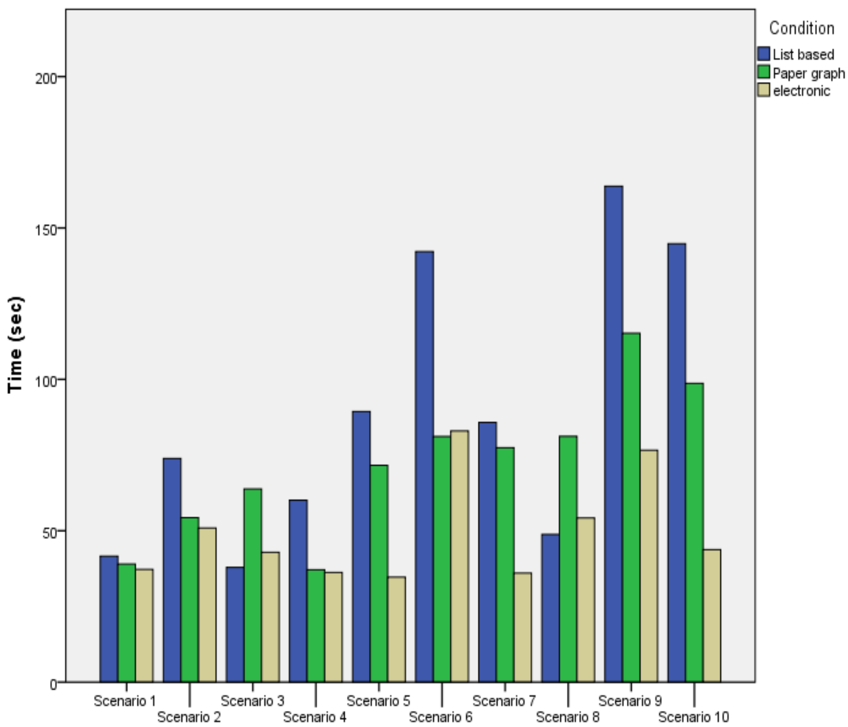


Figure 40 – Mean completion time results by scenario and condition

With the exception of scenarios 3 and 6, the electronic condition participants typically took less time to complete the scenarios than the other conditions. Scenario six was the scenario that involved the participants choosing whether to take orders or not, and scenario 3 required a train to be moved that only had 2 minutes in the station to board all passengers.

Figure 40 shows the difference between different conditions based on mean values (see note 1, p122). High standard deviations were reported for many of the values. This is seen in particular for scenarios 6, 9 and 10 and is most pronounced for the list condition. This indicates that there is a greater range of time values associated with these scenarios, and can be explained due to the complex nature of the list based task, and the wider variation in solutions produced, particularly for the list condition.

A Kruskal Wallis test showed that the effect of display type was significant across scenarios 1, 2, 3, 4, 5, 6, 7, 9 and 10 with regard to time taken. There was no significant difference for scenario 8.

Tests of the three a priori hypotheses were conducted using Bonferroni adjusted alpha levels of 0.017 per test (.05/3). The results can be seen in Table 25.

Table 25 - Pairwise comparisons for completion time

Scenario	Significant at p<0.017 (blank cells indicate non-significant comparisons)								
	List longer than Elec			List longer than Graph			Graph longer than Elec		
	U	N1	N2	U	N1	N2	U	N1	N2
1	96.5	20	20						
2	72	20	20						
3									
4				77.5	20	20			
5	22.5	20	20	112.5	20	20	67.5	20	20
6	54	19	20	73.5	20	20			
7	26	17	20				80	20	20
8									
9	33	14	20				82.5	18	20
10	12	10	20				53.5	17	20

6.3.3 Re-Platforming Performance

This section will focus on the results regarding re-platforming performance, such as delay minutes, number of moves taken, platforms moved, trains affected and number of illegal moves.

[1.] *Care must be taken in interpreting these graphs as the underlying data is non-parametric and non-normal. A mean value was taken as the collective measure of a given performance metric, in order to collate all the participant results into an easy to view summary plot. A mean is a useful term to use here to indicate relative performance between the different conditions, but it must be noted that this is not the same as a traditional normal distribution mean. It is only a performance metric for comparison, and in this data often biased with zero measures for successful performance (e.g. zero delay minutes) and sometimes biased by penalties on illegal moves (e.g. 100 delay minutes).*

6.3.3.1 Delay

With the exception of scenario 5, participants in the list based condition accrued more delay minutes than any other condition. With the exception of scenario 2, participants in the electronic condition accrued fewer delay minutes on average than participants in the other two conditions. This can be seen in Figure 41(see note 1, p122).

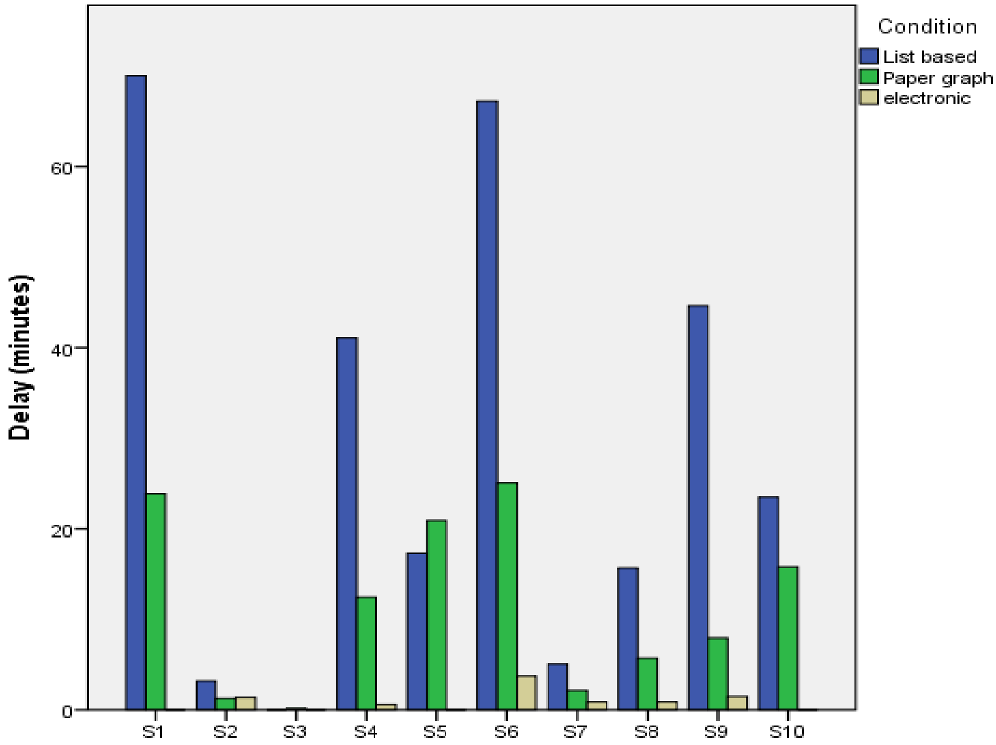


Figure 41 – Mean delay minutes by scenario and condition

A Kruskal Wallis test showed that the effect of display type was significant across scenarios 1, 2, 5, 6, 7, 8, 9 and 10 with regard to time taken. There was no significant difference for scenarios 3 and 4.

There are high standard deviations associated with certain scenarios and mainly the list and graphical based conditions. This can be explained by the fact that the majority of delay minutes were zero or close to zero, so the data is centred around that. Scenarios with a high standard deviation tended to have a high number of incorrect moves, incurring a time penalty of 100 minutes which heavily bias the variation. Scenario 4 for example had 39 scores of 0 minutes (mainly for the electronic condition), 8 scores of 100 minutes and 13 at 2 or 3 minutes. There is a trend in more variation in solutions for the more complex scenarios, particularly for the list and paper graph conditions in relation to the electronic condition.

Tests of the three a priori hypotheses were conducted using Bonferroni adjusted alpha levels of 0.017 per test (.05/3). The results can be seen in table 26.

Table 26 - Pairwise comparisons for delay minutes

Scenario	Significant at p<0.017 (blank cells indicate non-significant comparisons)								
	List more than elec			List more than graph			Graph more than Elec		
	U	N1	N2	U	N1	N2	U	N1	N2
1	90	20	20						
2	101	20	20						
3									
4									
5	90	20	20						
6	52	19	20				112.5	20	20
7	63.5	17	20						
8	45	15	20						
9	12	14	20	29.5	14	18			
10	30	10	20				80	17	20

6.3.3.2 Number of trains affected by delay

With the exception of scenarios 1 and 3, more trains were affected by delay in the list condition than in the graphical and electronic conditions and the graphical more than the electronic condition (see Figure 42: see note 1, p122). Aside from the two exceptions (Scenarios 1 and 3), the list condition performed consistently the worst, and the electronic condition the best.

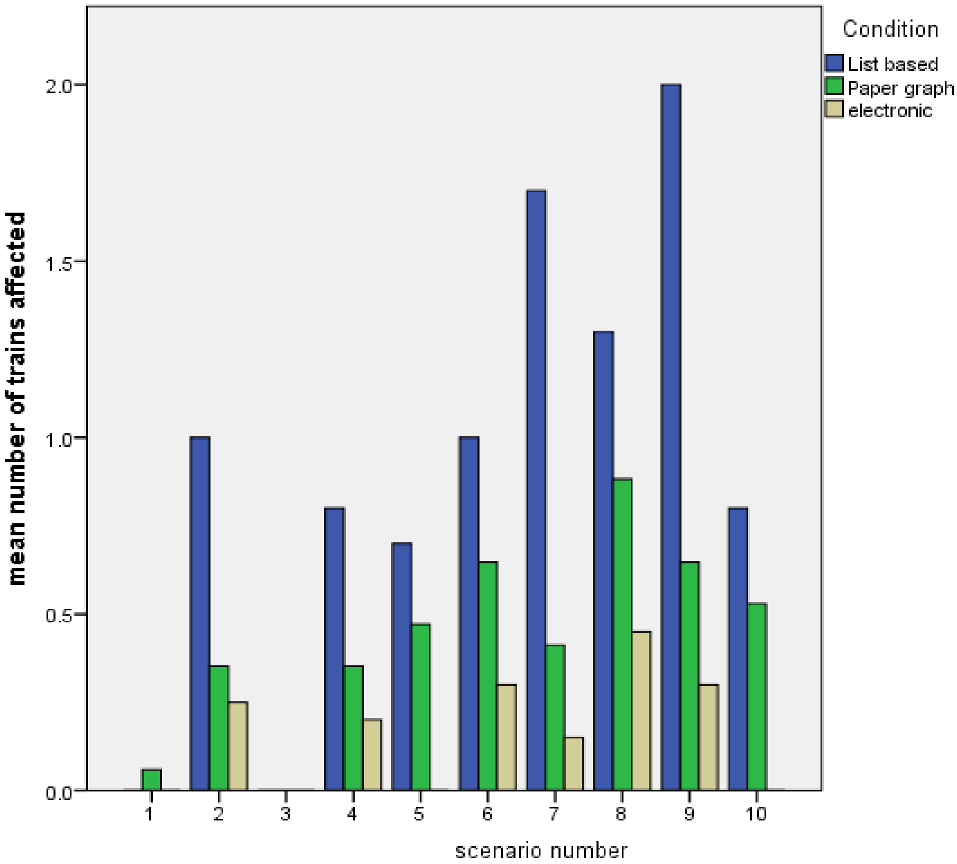


Figure 42 – Mean number of trains affected by delay, by scenario and condition

A Kruskal Wallis test showed that the effect of display type was significant across scenarios 2, 5, 6, 7, 8, 9 and 10 with regard to time taken. There was no significant difference for scenarios 1, 3 and 4.

Tests of the three a priori hypotheses were conducted using Bonferroni adjusted alpha levels of 0.017 per test (.05/3). The results indicate that in scenario 2 the list condition had significantly more trains affected by delay than the graphical condition (U=110.00, N1=20, N2=20, p=0.007), and the Electronic condition (U=97.50, N1=20, N2=20, p=0.003). This was also the case for scenario 7 where the graphical condition (U=52.00, N1=17, N2=20, p<0.001), and the electronic condition (U=68.5, N1=15, N2=20, p=0.003), outperformed the List condition. For scenarios 5, 6, 8, 9 and 10, the electronic condition affected fewer trains by delay than the list condition. There were no significant differences between the graphical and electronic conditions.

6.3.3.3 Number of incorrect moves

The mean number of incorrect moves by condition is shown in figure 43(see note 1, p122). All participants across all scenarios in the electronic condition did not perform any incorrect or illegal moves. No illegal moves were performed by any participants in scenarios two, three or seven. In all of the remaining scenarios, with the exception of scenario five, participants in the list based condition performed more illegal moves than those in the graphical condition.

A Kruskal Wallis test showed that the effect of display type was significant across scenarios 1 and 6 with regard to number of illegal moves. There was no significant difference for the other eight scenarios.

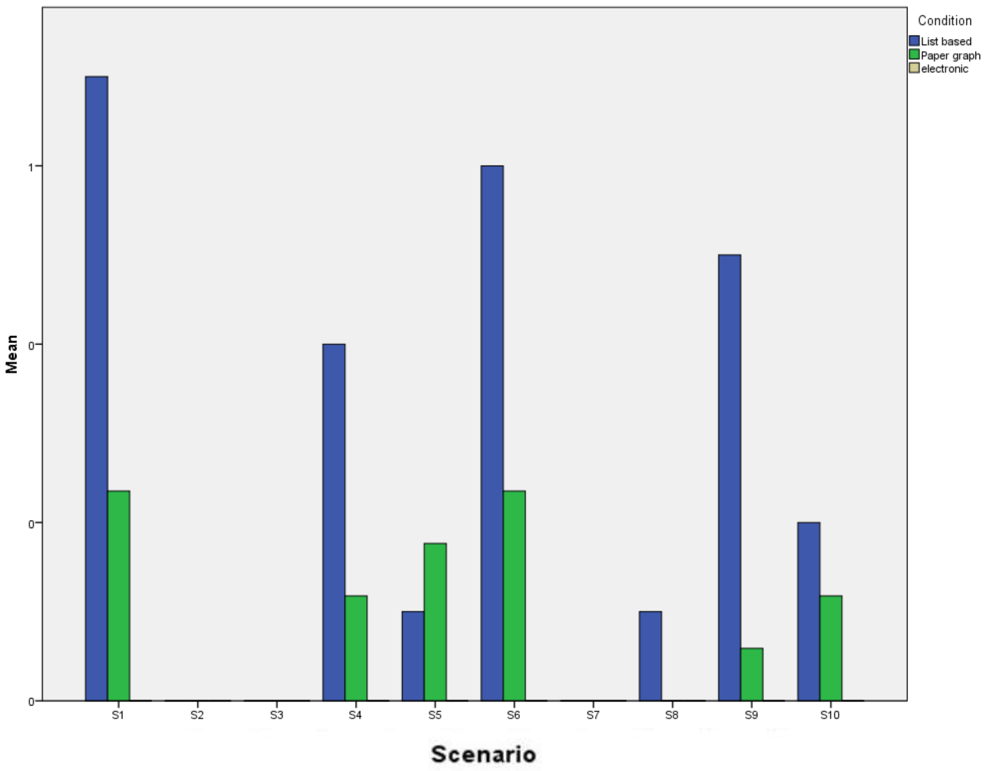


Figure 43 - Number of incorrect moves by condition

Figure 43 shows a graph of the mean number of incorrect moves by condition. Many of the values are zero. For example for scenario 5, for the graphical condition one participant made 2 incorrect moves. All of the other participants in this condition scored zero. For the list condition, only 2 participants made one incorrect move, all the rest scored zero.

Tests of the three a priori hypotheses were conducted using Bonferroni adjusted alpha levels of 0.017 per test (.05/3). The results indicate that in scenarios one and six, participants in the list condition performed significantly more incorrect moves than in the electronic condition (U=100.00, N1=20, N2=20, p=0.003) and (U=110.00, N1=19, N2=20, p=0.012) respectively.

6.3.3.4 Distance moved from original platform

Figure 44 (see note 1, p122) shows the mean distance moved from the original platform for each scenario. These results showed a great amount of variability but the list condition performed consistently better than the graphical and the electronic conditions across all scenarios with the exception of scenario five.

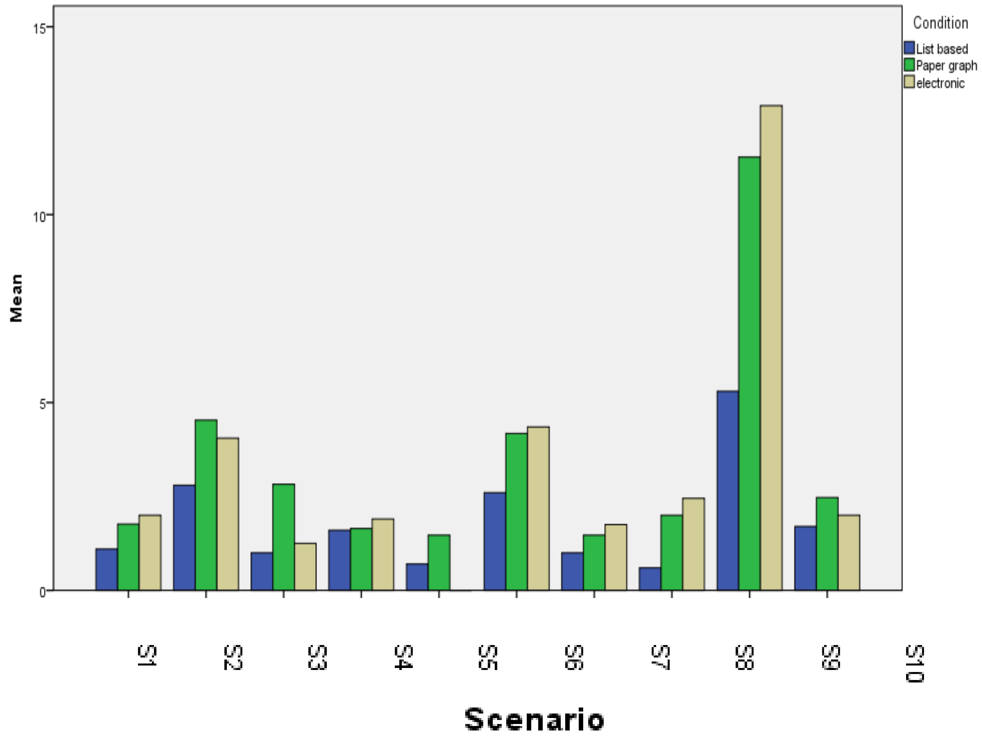


Figure 44 - Mean distance moved from original platform across scenarios

A Kruskal Wallis test showed that the effect of display type was significant across scenarios 1, 2, 3, 5, 6, 7, 8, 9 with regard to number of platforms moved from the original. There was no significant difference for scenarios 4 and 10. This can be explained by there being a small amount of different values, but some considerably higher outliers. For example in scenario 3, one participant in the graphical condition moved four platforms. All other participants in this condition moved one.

Tests of the three a priori hypotheses were conducted using Bonferroni adjusted alpha levels of 0.017 per test (.05/3). The results can be seen in table 27.

Figure 45 shows the favoured solutions for scenario 9 for the electronic Docker condition.

Table 27 - Pairwise comparisons for platforms moved

Scenario	Significant at p<0.017 (blank cells indicate non-significant comparisons)											
	List fewer platforms than elec			List fewer platforms than graph			Elec fewer platforms than List			Elec fewer platforms than Graph		
	U	N1	N2	U	N1	N2	U	N1	N2	U	N1	N2
1	110	20	20									
2				109.5	20	20						
3				120	20	20						
4												
5							90	20	20	120	20	20
6	83.5	19	20									
7	95	17	20									
8				40.5	15	19						
9	43.5	14	20	70.5	14	18						
10												

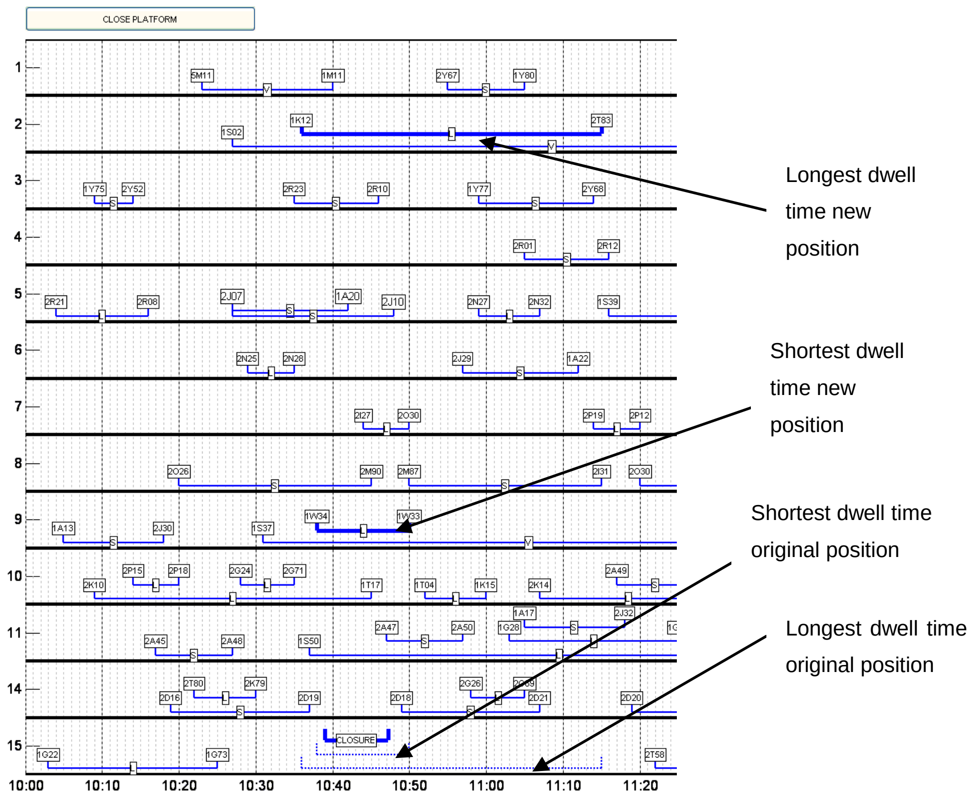


Figure 45 - Scenario 9 electronic condition favoured solutions

Scenario five was the only scenario where the list condition did not out-perform the other two. This scenario required no moves to be undertaken in order to complete. However, eleven participants in the list condition and eight participants in the graphical condition moved one or more trains.

6.3.4 Interactivity and use of scrap paper

The level of interactivity between the participant and the tool varies in both frequency and type depending on the type of tool. For both the list and graphical conditions, participants were told that they could mark the tools as they wished and were given a pen and pencil. For the electronic condition all interaction with the tool was carried out using the mouse and the drag-and-drop facility. All participants regardless of condition were given access to scrap paper.

The majority of participants in the list and graph conditions annotated the tool. Scrap paper was not used as widely (see Figure 46). There was no correlation between the two different conditions.

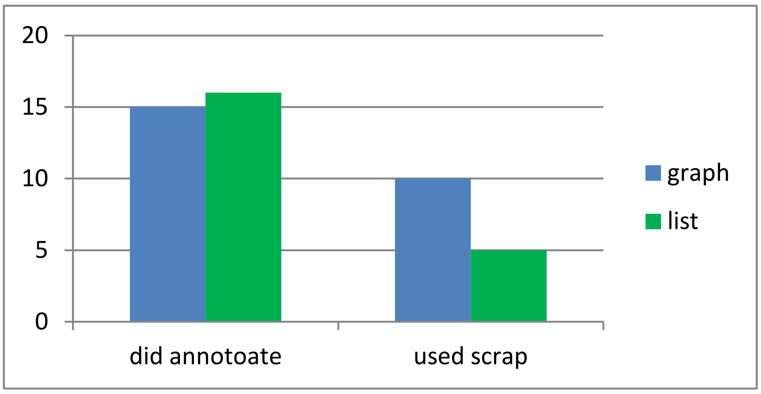


Figure 46 - Annotation of tool & use of scrap for list and graph conditions

For the List and Graphical conditions, there were no significant differences between those that did annotate their tools and those that did not, or those that used scrap and those that did not for any variable.

The favoured annotation type for the graphical condition was arrows, and drawing the trains as they were drawn already (U shaped lines). Examples can be seen in Figures 47 and 48.

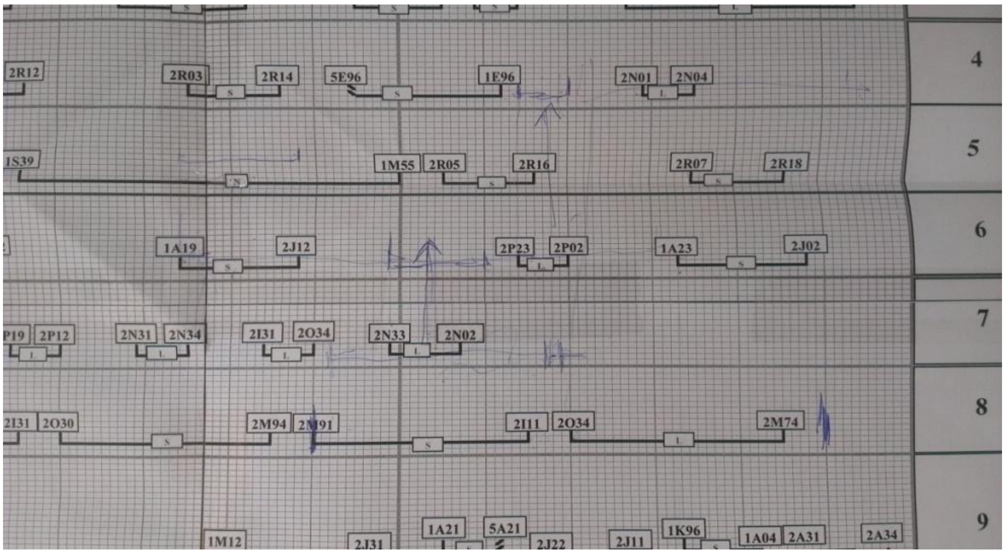


Figure 47 - Participant 8 graph annotations

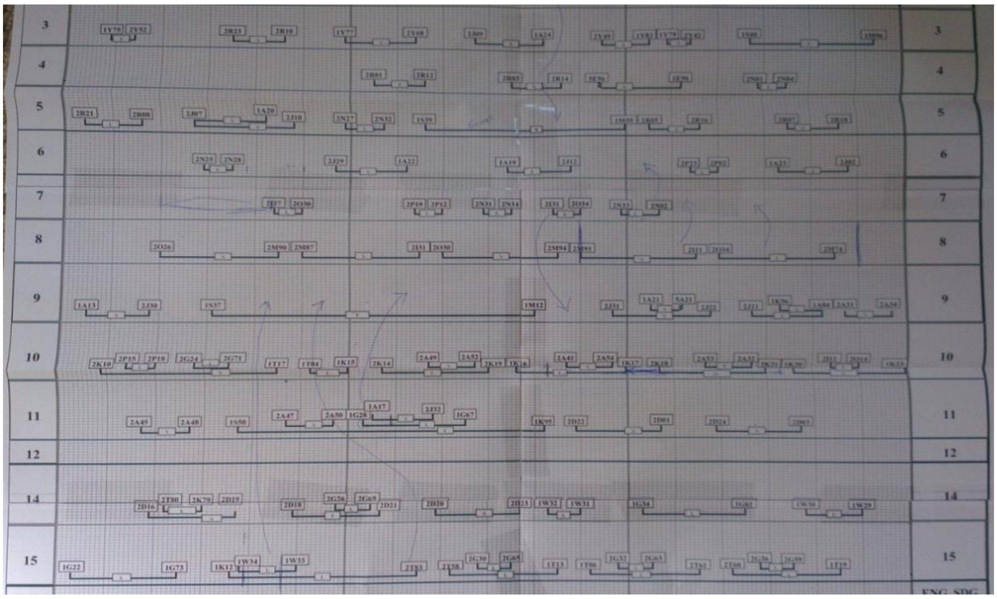
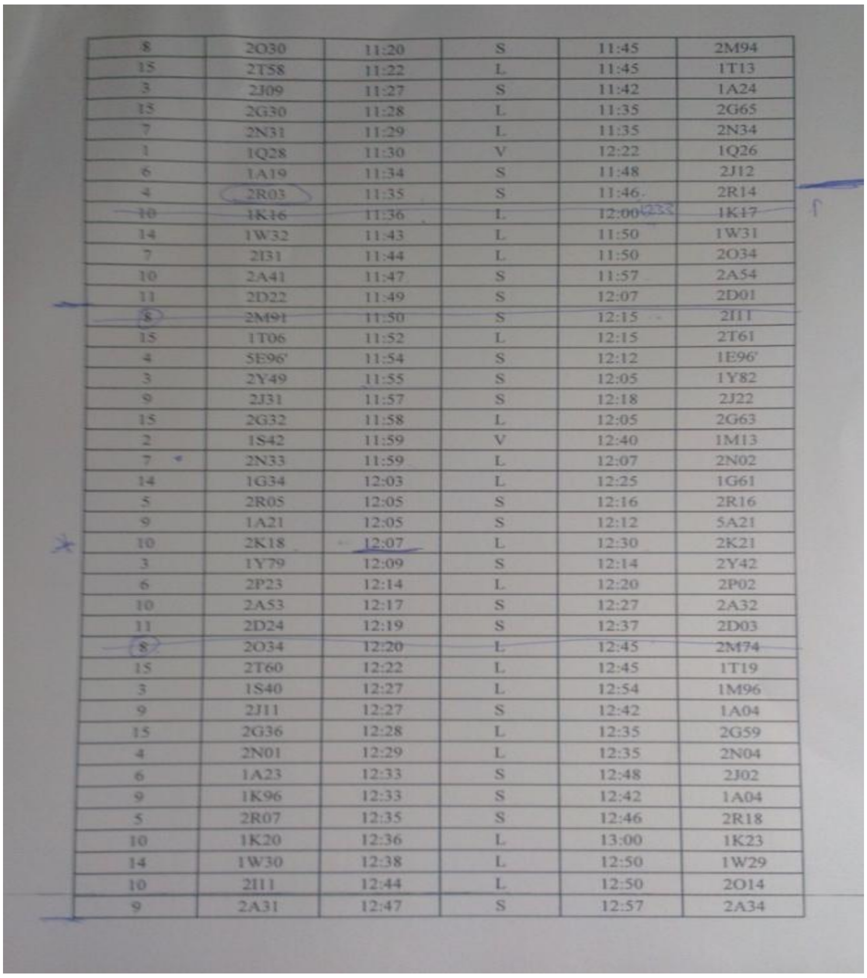


Figure 48 - Participant 59 graph annotations

Participants in the list condition annotated the tool mainly with numbers, and crossing out of trains that had changed. Circling affected trains was also a strategy (see figure 49).



8	2O30	11:20	S	11:45	2M94
15	2T58	11:22	L	11:45	1T13
3	2J09	11:27	S	11:42	1A24
15	2G30	11:28	L	11:35	2G65
7	2N31	11:29	L	11:35	2N34
1	1Q28	11:30	V	12:22	1Q26
6	1A19	11:34	S	11:48	2J12
4	2R03	11:35	S	11:46	2R14
10	1K16	11:36	L	12:00	1K17
14	1W32	11:43	L	11:50	1W31
7	2I31	11:44	L	11:50	2O34
10	2A41	11:47	S	11:57	2A54
11	2D22	11:49	S	12:07	2D01
8	2M91	11:50	S	12:15	2I11
15	1T06	11:52	L	12:15	2T61
4	5E96'	11:54	S	12:12	1E96'
3	2Y49	11:55	S	12:05	1Y82
9	2J31	11:57	S	12:18	2J22
15	2G32	11:58	L	12:05	2G63
2	1S42	11:59	V	12:40	1M13
7	2N33	11:59	L	12:07	2N02
14	1G34	12:03	L	12:25	1G61
5	2R05	12:05	S	12:16	2R16
9	1A21	12:05	S	12:12	5A21
10	2K18	12:07	L	12:30	2K21
3	1Y79	12:09	S	12:14	2Y42
6	2P23	12:14	L	12:20	2P02
10	2A53	12:17	S	12:27	2A32
11	2D24	12:19	S	12:37	2D03
8	2O34	12:20	L	12:45	2M74
15	2T60	12:22	L	12:45	1T19
3	1S40	12:27	L	12:54	1M96
9	2J11	12:27	S	12:42	1A04
15	2G36	12:28	L	12:35	2G59
4	2N01	12:29	L	12:35	2N04
6	1A23	12:33	S	12:48	2J02
9	1K96	12:33	S	12:42	1A04
5	2R07	12:35	S	12:46	2R18
10	1K20	12:36	L	13:00	1K23
14	1W30	12:38	L	12:50	1W29
10	2I11	12:44	L	12:50	2O14
9	2A31	12:47	S	12:57	2A34

Figure 49 - Participant 16 List annotations

The use of scrap paper varied and saw participants sketch out the problem in many different ways. These were often unordered and messy and in the case of the list participants often detailed the train head code, the time of arrival and departure and the details of any changes, for example late arrival time (see Figure 50). Arrows were also popular for both the list and graphical conditions. Participants in the electronic condition did not use scrap paper.

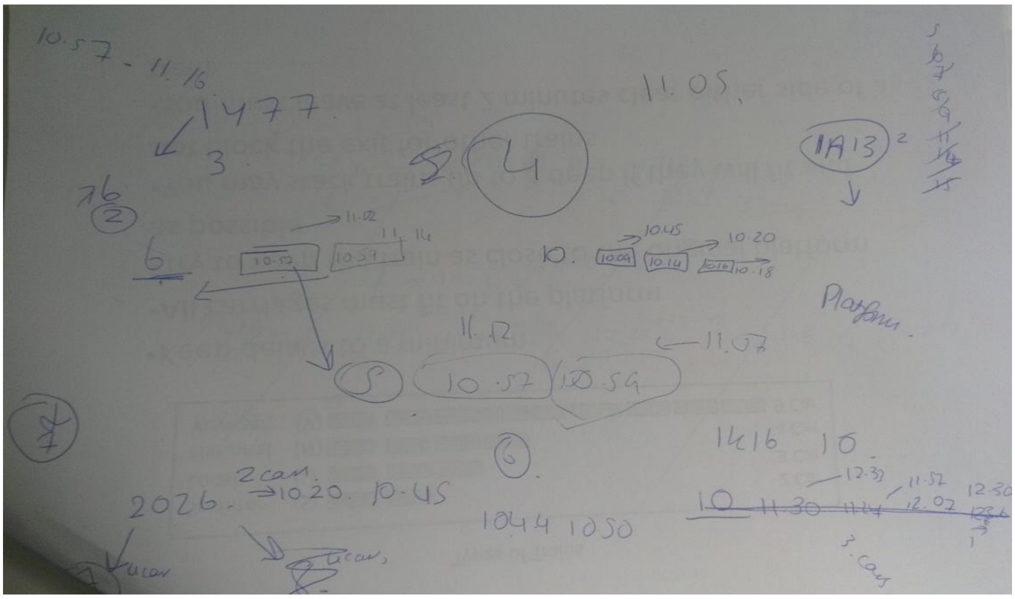


Figure 50 - Participant 34 scrap paper sketches (List condition)

6.3.5 Questionnaire Scores

The questionnaire scores for mental effort, pressure and difficulty were taken at the end of each scenario. The list based and graphical conditions consistently scored higher scores than the electronic condition for all three measures indicating higher workload. Figure 51 shows the total counts for each score, by condition, regardless of scenario.

The list based condition had the most counts for extensive mental effort required. Nine participants chose ‘extensive mental effort required’. Three participants in the electronic condition chose this statement. For pressure, the list condition again scored the highest for intense pressure with a total of five compared to two for the electronic condition. Difficulty was scored on a seven-point scale from very easy to extremely difficult. A total of twenty participants in the list condition ranked very difficult and extremely difficult. This is compared to twenty four in the graphical condition and four in the electronic condition.

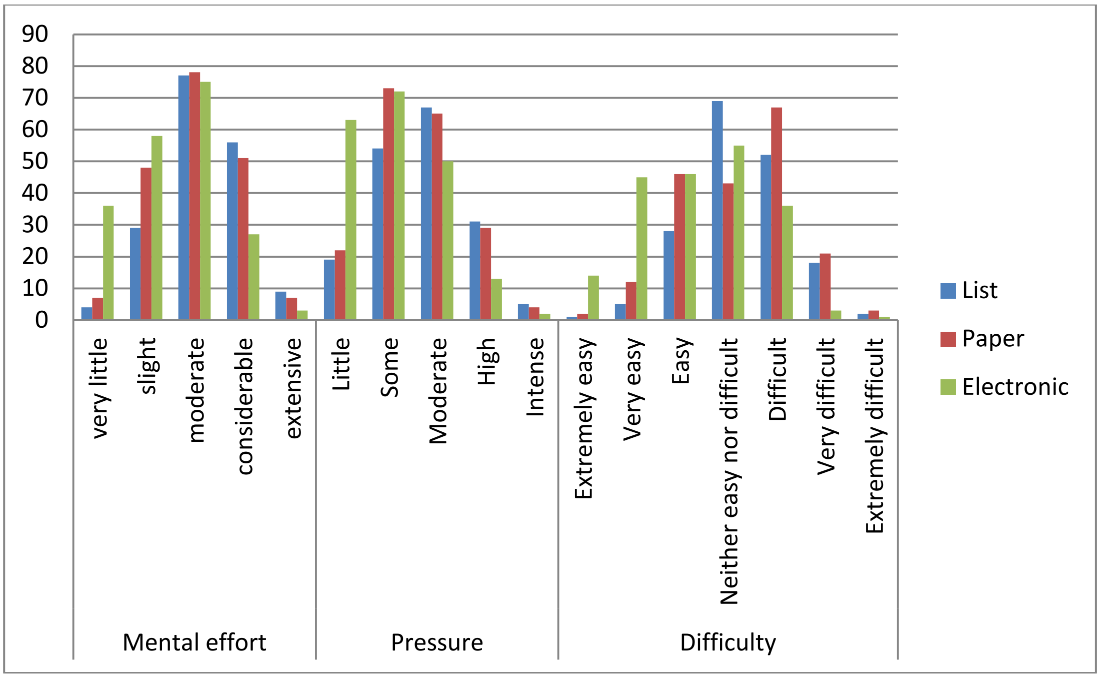


Figure 51 - total scores for each section by condition

A Kruskal Wallis test showed that the effect of display type was significant across scenarios 2, 3, 4, 5, 6, 8 and 10 with regard to mental effort, pressure and difficulty scores. There was no significant difference for scenarios 1, 7 and 9.

Tests of the three a priori hypotheses were conducted using Bonferroni adjusted alpha levels of 0.017 per test (.05/3). The P values of these tests can be seen in table 28.

Table 28 - Pairwise comparisons of mental effort, pressure and difficulty

		List vs Graph			Graph vs Electronic			List vs Electronic		
		Mental Effort	Pressure	Difficulty	Mental Effort	Pressure	Difficulty	Mental Effort	Pressure	Difficulty
Scenario	1									
	2	0.012						0.012	0.003	0.007
	3						0.013			
	4							0.006	0.009	0.004
	5				0.000	0.000	0.000	0.000	0.000	0.000
	6									0.006
	7									
	8			0.017						
	9									
	10					0.013				

Table 28 indicates that the list users found the task more challenging than the other two conditions, and significantly more so than the electronic condition, leading to higher scores on the questionnaires.

6.4 Discussion

6.4.1 Task Performance – Scenario Ranking

The highest ranked solutions were chosen most frequently by the participants in the electronic condition, with the exception of scenario 3 where eighteen participants in the list condition chose the highest ranking solution. This would indicate that the preferred method of searching in this condition was to look to the closest proximity platform first, before considering the location of the trains. The list on this occasion listed both trains within close proximity of the problem train (and both together), so the information was easily accessible.

Scenario 8 saw the electronic condition and the graphical condition perform equally well. Participants in both the list and the electronic condition however mostly chose solutions that accrued two delay minutes. Ten participants in the list condition chose to leave the train where it was, indicating that the participants were unaware that there was a train already in the platform. Nine participants in the electronic condition chose to leave the train where it was, but delay its arrival by two minutes. This conscious decision to delay the arrival of the train was only chosen by one other participant. The electronic format with the instant colour coded feedback made it easier in this instance to look to other avenues for solutions rather than just moving trains straight away; cognitively, it was easier to process additional decisions (conscious decision to delay the arrival) using the electronic Docker. This could suggest that the format and semi-automation of the electronic condition enabled the participant to choose a solution that had benefits in the future (i.e. did not incur additional delays).

6.4.2 Time Taken to complete Scenario

Time taken to complete the scenario was significantly different for all scenarios apart from scenario eight, and it typically took longer for participants in the list condition to complete the scenarios than the graphical condition, which in turn took longer than the electronic condition. None of the three display types provided any additional base information. The only difference was the additional error identification functionality on the electronic tool, but this did not tell the participants anything that was not available on the other two conditions; it just alerted them. Participants in the list condition took time to understand the problem, and took time to identify all of the trains affected. For the graphical and electronic conditions, participants may have been able to understand the problem relatively quickly due to the pictoral representation of the station area and were also able to identify the problem trains quickly. However this assumption could not be made for all scenarios. In Scenarios 3, 6 and 8 the electronic tool did not yield the fastest solution completion time. For scenarios 3 and 8 the list based tool proved to be fastest.

In scenario 3 the information required by the participant was grouped very close together in the list condition. The two trains were visible on the same page and their arrival and departure times quite close together. This supports Larkin and Simon’s (1987) view that information grouped close together can improve problem-solving. This, coupled with the fact that there was increased mental effort required to solve scenarios using the list tool, meant that the participants in this condition understood the task (specifically this scenario) a lot more than the other two conditions. Similarly, scenario eight required participants to develop their own rules regarding dealing with an early running train. The increased cognitive effort required by the list users to obtain information may have led to an increased understanding of the task. This meant that instead of focusing on the train that was affected, the list users thought around the problem and considered other trains and how these will be affected first. This led to half the list participants choosing a solution that meant leaving the train where it was requiring no additional moves but accruing two delay minutes.

While in some situations the list format enabled the participants to solve the scenarios more quickly, the electronic tool proved faster generally. The electronic tool with the automatic conflict detection enabled participants to make effective decisions quickly.

6.4.3 Re-Platforming Performance – Delay

With the exceptions of scenarios three and five, participants in the list based condition accrued more delay minutes than in the other two conditions. With the exception of scenario two, participants in the electronic condition accrued the fewest delay minutes compared to the other two conditions. Participants using the list Docker were observed to systematically go through different options and attempt to accrue as few delay minutes as possible. Despite the extra care taken, they often accrued the most delay minutes. This was not a result of an error on their planning strategy, or an indication that they misunderstood the task, it was more likely to be an issue with finding the right information at the right time. In many of the scenarios observed, the list participants would systematically work through and identify different trains and different moves that they believed worked. However, they would often fail to notice another train due to enter that platform for example, or a train was already in the platform. This again supports Larkin and Simon's theory that information grouped close together can support problem-solving.

6.4.4 Number of Trains Affected by Delay

The number of trains affected by delay was consistently higher for the list condition than the other two conditions with the exception of scenarios one and three. The participants in the electronic condition were made aware of any clashes and potential issues when they attempted to make a move. With this in mind it could have been hypothesised that the electronic condition would score perfectly on all counts, however this condition still resulted in some trains being affected. This was largely down to the scenarios, some of the scenarios required trains to be moved and accruing delay was unavoidable. But, was it always the case that the participants were aware that their moves were affecting other trains? For the electronic condition this answer is almost certainly yes. The software would alert the user to the fact that their move was affecting another service and the user (armed with this new information), can then decide how best to use this information. In the graphical condition, the participants were more likely to notice if they were using the graph in an interactive way (drawing on it). The participants who were drawing directly onto the graph were aware of the impact that their moves would have on the rest of the service as they were interacting directly with the train plan and drawing over existing services. Likewise with the list condition, the participants who drew on the list by scribbling out trains and drawing lines adjoining services were more aware of the impact their move was having on other trains as the participants who did this made fewer mistakes. Again, this only worked if the users were utilising all of the correct information. If information was missing (for instance if they did not spot an affected train) or incomplete (if three trains were involved in the scenario and they only recognised two of them) or incorrect (for example if the user thought the train was a three-car not a six car) then interactivity made no difference. In this instance the participant was utilising the information to the best of their abilities, and the result may not have been because of lack of understanding necessarily, but that the user was building up an incomplete picture due to not being able to access and process the information easily.

6.4.5 Number of Incorrect Moves

No one in the electronic condition utilised a solution that included incorrect (illegal) moves. Much like for delay minutes, the electronic tool alerted the participant if they were attempting to perform a move that included an illegal move. With the exception of scenario five, participants in the list condition performed more illegal moves than participants in the graphical condition. The optimum solution for scenario five was to leave the train in its original platform. This was the only solution that did not accrue any delay minutes. This was chosen by twelve people in the graphical condition, nine people in the list condition and every participant in the electronic condition. By being alerted to the fact a move was illegal, the electronic users could instantly rectify and choose an alternative solution. All of the participants observed in the electronic condition, picked up the train dragged it along all of the platforms and shortly after realising that it was not a simple move dropped it back on its original platform and realised that that was acceptable. By being able to try moves and getting instant feedback about what was and was not possible, participants were able to choose the optimum solution. Users in the graphical condition did this to some degree, but they had to use their existing knowledge and limited experience of using the graph to articulate the information that was being given to them. It was then up to the user to interpret this information. Where the electronic condition made this fool proof, the need for human intervention and a degree of decision-making in the graphical condition meant it was possible to miss information, or misinterpret it. In the list condition the lack of any ability to visualise the state of the station resulting from moves meant that solutions were perhaps less obvious.

6.4.6 Distance from Original Platform

Scenario nine involved a platform closure and required two trains on that platform to be moved. Of the five possible 'optimum' (did not accrue any delay) solutions for this scenario the distance moved from the platform ranged from 7 to 17 platforms. No-one in the list condition picked any of these solutions; thirteen participants did in the graphical condition; and sixteen did in the electronic condition. Of these, 100% in the graphical condition moved the train with the longest dwell time first. Only 50% did this in the electronic condition. The other 50% moved the train with the shortest dwell time first. Seven participants in the electronic condition chose a solution that led to the trains being 17 platforms away from their original platform (see Figure 45). This was not chosen by anyone in the graphical condition. By moving the train with the shortest dwell time first, the options became limited for where to platform the train was the longest dwell time. The strategy utilised by all of the electronic condition participants, was to grab the train on top first (the one with the shortest dwell time), then drag it up to the graph until it went green. They then released the train and grabbed the train remaining (the train with the longest dwell time). All of the participants in the graphical condition set about moving the train with the longest dwell time first. By doing this they were able to find more efficient solutions. The ability of the electronic condition participants to drag a train until it goes green meant that they were less aware of the task. They did not have to fully understand the impact their moves were having on the rest of the station area as the system did it for them. By having to think about the impact moves were having and not being automatically made aware, the list and graphical condition participants were much more aware of the whole situation.

6.4.7 Interactivity and Use of Scrap Paper

By annotating the graphs and lists, the users were creating up to date, current pictures of the state of the station area. By making notes and annotating the original plan they were building on our awareness of the situation. This is in contrast to participants in the electronic condition who were utilising the drag-and-drop and instant feedback facility to obtain information about the predicted state of the system. The electronic users were essentially missing out a step: they did not have to predict the future state of the station area, as the system was doing it for them. Therefore they were less aware of the impact their changes would have on the station. The electronic users did not utilise the scrap paper, whereas the graph and list users did.

6.5 Conclusions

The benefits of being able to physically create an updated plan on the graphical Docker and 'try out' moves before carrying them out can assist greatly when developing a strategy to overcome disruption. The users are able to manage complex situations and get the stations back to normal operation quickly with benefits for disruption management and workload. An experiment was next carried out in order to measure the cognitive benefits of using the graphical Docker compared to the list based one, when learned knowledge and experience have been stripped away.

All three of the display types assisted the participants when solving the scenarios. However all three behaved very differently. Although the electronic Docker appeared to perform the best, the users gained less knowledge throughout the experiment about how station areas are managed and the techniques and strategies that can be used than the list and graphical users did. By having to use more mental effort, the list and graph users had an increased understanding of the task (O'Hara and Payne, 1998). However the external representations in the form of the graphs, for example the paper graph or the electronic graph, provided the user with tools necessary to be able to utilise their existing knowledge to predict the future state of the railway (Xiao et al., 1997). Even though some of the computational effort was offloaded by the electronic version (Scaife and Rogers, 1996), the outcome had the potential to be the same: an updated version of the current state of the railway. The ability to glance at the graph and instantly see solutions meant that the users were able to predict the future state well into the future and fairly accurately (Cheng et al., 2001). The extra preparatory activities required by the graphical users in order to find a solution to the scenario meant that they were able to anticipate the future state of the railway more accurately (Xiao et al., 1997). And while the list users appeared to understand the task a lot more, the format was so abstract from the actual situation (the actual layout of the station area) that the increased mental effort they utilised often had a negative impact (Larkin and Simon, 1987a). This was due to the extensive mental effort required to pull the information they required from the list. This information was incorrect or incomplete a lot of the time meaning any predicted future state was inaccurate (Nemeth et al., 2003).

In an environment such as a signalling centre, the ability to make decisions quickly and accurately is essential in maintaining the safe operation of the railway. While the awareness the graphical and list users appeared to have of the state of the station area appeared to be superior to the electronic users, the electronic format outperformed the other two formats in nine out of ten of the scenarios with the users consistently picking the most effective, efficient solution. It proved the quickest in seven out of the ten scenarios, and accrued the fewest delay minutes with the exception of one scenario. The electronic users also found the tool easier to use compared to the graphical and list options, and stated that they felt it required less mental effort to operate than the other two tools. It is to be remembered that the participants in this experiment had no prior railway signalling knowledge. Having established from the previous chapter that knowledge and experience influence decision-making, the assistance the electronic tool can provide in terms of alerting the signaller to potential mistakes could, when coupled with prior knowledge and experience, be a considerable benefit in an unpredictable high-pressure environment such as signalling.

7. CASE STUDY 2: REGULATING AND PLANNING

7.1 Introduction

This chapter details a study carried out assessing at a new tool called the Train Graph. This tool was developed over many months by the early traffic management team at Network Rail, and the signallers were instrumental in aiding the design in the latter stages. This case study will help to fulfil all four of the main objectives of this thesis, but in particular it will address research aim three directly, and in understanding how successfully the tool was integrated into the signalling environment it will also address research aim four:

3. Explore the implications of introducing new tools into signalling environments to support proactive control.
4. Develop recommendations for the development, integration and acceptance of decision support tools into existing and future rail signalling systems.

The case study was carried out as part of support work for Network Rail on the larger "early traffic management" project.

7.2 Background

The Train Graph is a tool that shows the routes taken by trains using information from existing signalling information systems (TRUST), and displays a line based representation of the train's path. Figure 52 shows an example of Train Graph in operation. The line representation itself is a plot of the train's position with key route locations against time. The tool provides a quick visualisation of the train's past, current, and projected future position relative to other trains and route locations. When trains are running late, the Train Graph will flag up potential conflicts and also provide regulating options to aid the signaller in their decisions.

Figure 52 - Train Graph example in use (rollout phase 2).

Part of a larger project called Early Traffic Management, the Train Graph was initially rolled out along the East Coast Mainline in December 2010 ("rollout 1"). The Train Graph was made available to Shift Signalling Managers (SSMs) and Train Running Specialists (TRSs) to assist with regulating tasks. The SSMs are responsible for their area of control (i.e. the area covered by their signal box). The TRSs are essentially Train Running Controllers (TRCs) and are responsible for the regulation of the entire route (their TRS title is unique to the East Coast mainline). Following initial training given at the end of 2010, the Train Graph was introduced in five signal boxes and one control centre along the East Coast Mainline.

In 2011 the Train Graph was also rolled out across the West Coast Mainline ("rollout 2"). Five control centres and signal boxes were visited to obtain their views and opinions about Train Graph. The Train Graph was introduced as a way to encourage pro-active, rather than reactive planning and dealing with incidents. If operators are able to look to the future and see what potential problems there might be, they will be able to commit more effort to sorting them out.

Following the implementation of the Train Graph on the East Coast mainline an in service review was carried out, the findings of which are used in this chapter. These findings informed some design changes that were later made to the Train Graph before it was rolled out nationally. The Train Graph was rolled out nationally in 2011 and currently used in signal boxes and control centres across the UK. A questionnaire was used to obtain the views of other roles that also have access to Train Graph, such as Route Control Managers (RCMs) and Incident Controllers (ICs).

The Train Graph is based on a format widely used in planning (Kauppi et al., 2006) but was not used previously in UK railway operations. The main concept of the Train Graph is to interact with the visualisation itself to change train paths and send information to the Automatic Route Setting (ARS). The Train Graph used in the rollouts described in this chapter had limited functionality compared to this and could only be used for identifying conflicts and suggesting regulating solutions. The idea of the rollout process was to introduce the concept of Train Graph and introduce the layout and general principles throughout operations as a precursor to proposed traffic management systems.

This chapter presents the results of a study investigating the uptake rates associated with Train Graph across the East Coast (rollout 1), West Coast (rollout 2) and national rollout. It presents results from a number of different studies; where three different methods were used to investigate what affects the uptake of new technology and how it can best be integrated into existing environments. The three methods used were observation, interviews and a questionnaire. The details of these methods are discussed in the following study design section.

7.3 Study Design

7.3.1 Study Aims

The aims of the study were dictated to a certain degree by the needs of the wider Network Rail project. Hence the methods and approaches used for this case study reflect the real working environment and critical nature of this system rollout. The main goal of the case study was to gather feedback on the Train Graph from operators in order to inform the larger traffic management program. The specific case study aims were as follows:

- To investigate the uptake rate across different roles.
- To measure the operators' trust in the system with regard to data quality.
- To establish whether the Train Graph is viewed as both usable and useful.
- To gauge the operators' expectations of the Train Graph and whether it operates as promised.
- To establish if the system is consistent with the operators' existing approach to regulation.

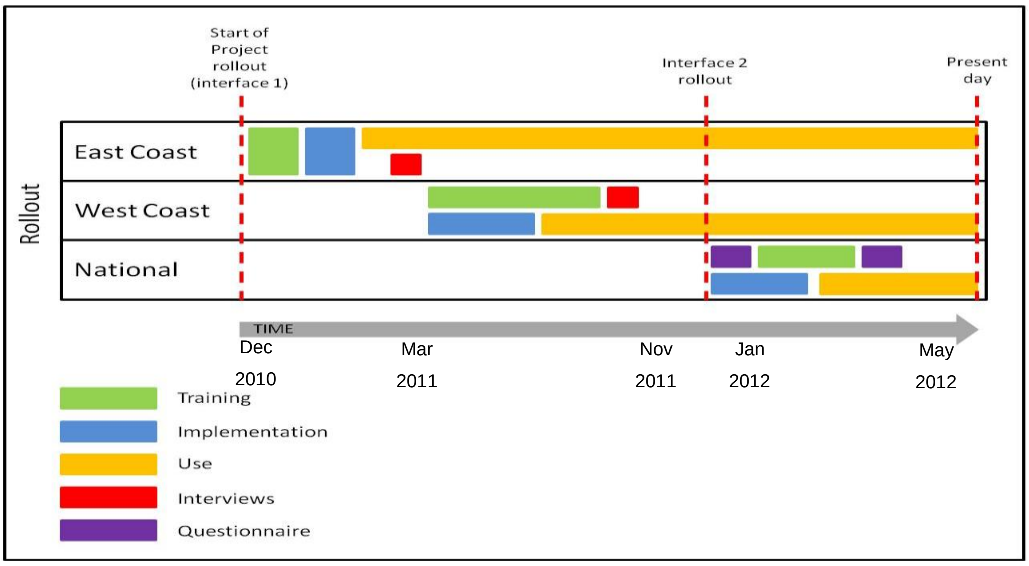


Figure 53 – Case study 2 project plan

The study spanned the three different rollout phases and two different interface designs. Figure 53 shows a project plan for the study. The three stages of system rollout are clearly depicted along with the review of the interface carried out prior to the national rollout. The functionality and interface differences between the rollouts are shown in table 29.

Table 29 - Functionality and interface differences between rollouts

Feature	Phase 1	Phase 2
Menus	Six dropdown menus with inefficient groupings	Three menus with information grouped more intuitively
Menus	Right clicks required to access hidden functionality	The most used items were placed in icons on the tool bar. Others put in drop down menus
Tool Icons	All of the icons at the top of the page were the same colour	The icons were given different colours based on their functionality
Zoom function	The zoom function was on a dropdown menu	The zoom function was given an icon at the top of the screen and when selected an overlaid panel was visible
Zoom Function	The zoom zoomed both axis at the same rate	Separate zooms for each axis
current timeline	The line indicating the current time remained static	The line location could be set by the user
Train associations	No associations (e.g. a joining service) were shown.	These were shown using a white line
Interaction with line	Line cannot be manipulated	Line can be manipulated
Conflict resolution	The conflicts were just shown on the graph	Conflicts were shown, and when they were clicked on, different solutions were shown with predicted delay outcomes shown for each.

Interviews were carried out during the East Coast and West Coast line rollout phases, and questionnaires were used post training after all three rollout phases were completed. Observations were made throughout all three phases, but mainly during the first two phases.

7.3.2 Interview and Observation Method

The interview and observation method was the same for the East and West Coast rollouts, so these routes will be discussed together for the remainder of this section.

7.3.2.1 Participants

A total of 20 participants were interviewed and observed across 11 sites spanning the East and West Coast mainline (detailed in table 30).

Table 30- Participants for Train Graph interviews

Line	Box ref	Type	Personnel	Number of participants
East	a	IECC	SSM	1
East	b	ICC	TRC	1
East	c	IECC	SSM	2
East	d	PSB	SSM	2
East	e	PSB	SSM	2
East	f	PSB	SSM	2
West	g	ICC	TRC	2
West	h	IECC	SSM	2
West	i	PSB	SSM	2
West	j	PSB	SSM	2
West	k	PSB	SSM	2

7.3.2.2 Apparatus

A list of questions was developed in order to assist with data collection, which also included aspects of interest to the larger traffic management project. The data were then analysed using NVivo software. A list of observation triggers was also used in order to guide the observations and also the questioning, derived from the literature and guided by the needs of the project team. This can be found in Appendix D.

7.3.2.3 Procedure

The Local Operations Manager (LOM) was contacted for each of the 11 sites (the LOM may be responsible for more than one box) and visits were arranged in advance. Sometimes this would then involve contacting the SSM directly to organise the visit, so some SSMs had prior warning of the visit and some did not. Sampling was opportunistic depending on who was on shift at the time of the visit. Generally, visits were arranged to coincide with shift handover so that two participants could be interviewed in one visit, however the nature of the real world situation meant that there had to be some flexibility with timing.

In order to obtain entry to a control centre, the Operations Manager (OM) was contacted in the first instance who often gave details of a local contact within the control centre. Again, sampling was opportunistic based on who was on shift at the time.

Upon arrival and after initial meetings the purpose of the visit was explained to the SSM. It was also explained at this point that all interview responses would be anonymous, each participant would have the participant number assigned to them and they were informed that the data would only be used for the purposes of an internal Network Rail report and this research. They were also given the opportunity to withdraw from the study at this point. Prior to the commencement of the interviews participants were asked if the interviews may be recorded. All but two participants consented to the interviews being recorded. Interviews typically lasted between an hour and an hour and a half for each participant. Immediately following the interview, where possible, the LOM was given a debrief about the general use patterns and attitudes towards Train Graph. No individual responses were disclosed. When the interviews were recorded they were typed immediately following the interview and inputted into NVivo where they were analysed using theoretical thematic analysis (Boyatzis, 1998). For the two interviews that were not recorded, hand written notes were made during the interview and observation phase, which were also analysed using NVivo.

7.3.3 Questionnaire method

7.3.3.1 Participants

The participants for this phase of the study were identified through the Train Graph project. They fell into two groups: existing Train Graph users who had access to Train Graph currently, and new Train Graph users undergoing initial training that had not seen Train Graph before and did not have access to it currently.

7.3.3.2 Apparatus

A questionnaire was developed that utilised questioning techniques from established models of technology acceptance and usability testing. There were originally 32 questions developed. These stemmed from 3 main theories: The Technology Acceptance Model (Venkatesh and Davis, 2000), Innovation Diffusion Theory (Rogers, 1995), and the Theory of Planned Behaviour (Brown et al., 2002). Chapter 4 discusses these theories in depth. These three were chosen as a framework for the study as all have been well used and tested within industrial and commercial environments to assess the uptake of technology (Moore and Benbasat, 1991). Since this piece of research was part of a larger project carried out within Network Rail, the research had to be in line with the project objectives. Using a framework that was well established and had been used commercially ensured that the project team would have good quality data and the researcher would be able to utilise existing frameworks for data collection and analysis. Table 31 shows the selected questions and the source of each one. It also outlines the question groupings used which were based on the existing research drawn from literature of the three theories discussed above. The 32 questions were shown to the project team, who selected the ones they saw as important to the project along with input from the researcher (Those chosen for this case study are highlighted in yellow). A likert 7 point scale was used to answer the questions, consist with existing work in this field (see Figure 54).

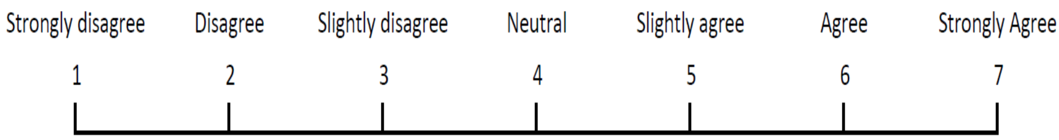


Figure 54 - Likert scale used for questionnaires

Two forms of the questionnaire were used, these were an electronic version of the questionnaire developed using Survey Monkey for the existing users, and a paper-based version of the questionnaire for new users. The questionnaires used can be seen in Appendix E.

Table 31 - Question development for Train Graph Research

NEW USERS			
	Question	Source	Theory
Experience	How long have you worked in the railway industry?		
	What is your current job role? (SSM / TRS/TRC)		
	How long have you worked in your current role?		
Relative advantage	Using Train Graph will enable me to accomplish tasks more quickly	(Moore and Benbasat, 1991)	IDT (Rogers)
	Using Train Graph will improve the quality of work I do	(Moore and Benbasat, 1991)	IDT (Rogers)
	Using Train Graph will make it easier to do my job	(Moore and Benbasat, 1991)	IDT (Rogers)
	Train Graph will be advantageous to my job	(Moore and Benbasat, 1991)	IDT (Rogers)
	Using Train Graph will give me greater control over my job	(Brown et al., 2002)	TPB
	Train Graph will provide more information than existing systems	researcher	
	Using Train Graph will enhance existing systems	researcher	Adapted from IDT - compatability
Trust / output quality	The information the Train Graph provides is of good quality	researcher	Adopted from TAM2
	I trust the information the Train Graph provides	Researcher	Adopted from TAM2
	I trust the data that is used to produce the train graph	Researcher	Adopted from TAM2
Usefulness	Using Train Graph will Improve my job performance	(Venkatesh and Davis, 2000)	TAM2
	Using Train Graph in my job will increase my productivity	(Venkatesh and Davis, 2000)	TAM2
	Using Train Graph will enhance my effectiveness in my job	(Venkatesh and Davis, 2000)	TAM2
	Train Graph will be useful in my job	(Venkatesh and Davis, 2000)	TAM2
	The information Train Graph provides is more useful than existing systems	researcher	
Ease of use	My interaction with Train Graph is clear and understandable	(Venkatesh and Davis, 2000)	TAM2
	Interacting with the Train Graph does not require a lot of mental effort	(Venkatesh and Davis, 2000)	TAM2

	Question	Source	Theory
	I find Train Graph easy to use	(Venkatesh and Davis, 2000)	TAM2
	I find it easy to get the Train Graph to do what I want it to do	(Venkatesh and Davis, 2000)	TAM2
	Learning to operate Train Graph is easy for me	(Moore and Benbasat, 1991)	IDT
Voluntariness	My use of Train Graph is voluntary	(Venkatesh and Davis, 2000)	TAM2
	My supervisor does not require me to use Train Graph	(Venkatesh and Davis, 2000)	TAM2
	Although it might be helpful, using Train Graph is certainly not compulsory in my job.	(Venkatesh and Davis, 2000)	TAM2
Job relevance	In my job, usage of the Train Graph is important	(Venkatesh and Davis, 2000)	TAM2
	In my job, usage of Train Graph is relevant	(Venkatesh and Davis, 2000)	TAM2
Observability	I would have difficulty explaining why using Train Graph may or may not be beneficial	(Moore and Benbasat, 1991)	IDT
	The results of using Train Graph are apparent to me.	(Moore and Benbasat, 1991)	IDT
Behavioural intention	I intend to use Train Graph for the next 6 months	(Brown et al., 2002)	TPB
	I intend to use Train Graph to perform my job functions in the next 6 months	(Brown et al., 2002)	TPB
	I intend to use Train Graph frequently in the next 6 months	(Brown et al., 2002)	TPB

7.3.3.3 Procedure

The questionnaire was administered as part of the familiarisation training that ran alongside the national rollout of Train Graph. As part of the implementation programme, all new and existing users of Train Graph were given training on the new Train Graph interface and design. Working closely with the project manager, the questionnaire formed part of the training programme. All existing users of the Train Graph who attended the familiarisation training were sent an electronic link to the Survey Monkey questionnaire after they had attended the training session. This link was sent to around 200 users and the users were invited to complete the questionnaire in their own time. The new users of Train Graph were asked to complete the questionnaire directly following their training session. These were paper-based questionnaires that were administered by the trainers and passed back to the researcher upon completion.

7.3.4 Analysis method

7.3.4.1 Qualitative

Data were collected in the form of transcripts, or written notes. Using TAM (Davis, 1989a) as a theoretical base, the two overarching themes, specifically usefulness and ease of use were utilised as an initial starting point for data sorting, then theory led thematic qualitative analysis was used to analyse the data.

7.3.4.2 Quantitative

Upon completion of the questionnaires, the Survey Monkey responses were downloaded directly into Microsoft Excel and the paper responses were input manually. These were then imported into SPSS for analysis, ensuring the columns were correctly aligned.

The data, based on a likert scale has been treated as ordinal data. Therefore non-parametric tests were used as it did not meet the assumptions for parametric data.

7.4 Results

7.4.1 Interview results

It became clear during coding that there were two main topics in the data that these themes fell within. These were the Train Graph itself (including the qualities associated with it) and the existing job role. The grouped data are shown in table 32.

Table 32 – Thematic qualitative analysis of the interview data

	Interviews (X if yes)	Observations (X if yes)	Freq (comment from interviews)
Existing Job Role			
Signaller Qualities			
Experience	X		31
Knowledge	X		36
Role	X	X	24
Physical attributes of signalling task			
Infrastructure	X	X	14
Existing technology	X	X	36
Train Graph			
Use of Train Graph			
Accessibility	X		11
Functionality	X		60
Usefulness	X		78
Relative advantage	X		52
Usage	X	X	34
Acceptance	X		15
Data Quality			
Input quality	X		17
Output quality	X	X	36
Trust of TG	X		24
Interaction with Train Graph			
Usability	X	X	61
Interface	X	X	14

7.4.2 Questionnaire results

A total of 138 responses were gathered from the questionnaire. 90 of these responses (65%) were gathered from new users via paper-based forms at the training sessions, and 48 responses were gathered from existing users by the electronic questionnaire. Most of the respondents were currently working as SSMs (n=47) or train running controllers or specialists (n=47). The remaining respondents were signallers or other roles. Over half of the respondents (58%) had been working in the rail industry for over 20 years, but most respondents (54%) had only been working in their role for less than five years.

The 20 Likert scale questions were interpreted and explored using SPSS . The scores for question 12, which is a negatively worded question, were reversed to reflect the direction of the other questions. With the exception of questions 12 and 13, the scores for new users were consistently higher than those of existing users.

7.4.2.1 Descriptive statistics

New and existing users

Figure 55 shows the mean scores for the 20 Likert questions asked to each participant. These are displayed for all users, new users and existing users. The graph clearly shows differences between the two user groups. The mean was used to demonstrate the differences between the average user in each category.

A Mann-Whitney U test was carried out to compare the new and existing user groups. Table 33 shows that there are significant differences between new and existing users for all but four of the questions.
This would suggest that the new users are in general more positive about Train Graph. It may also suggest that many of the issues evolve with use. The new users were less positive than the existing users for just 2 questions. These were question 12; I would have difficulty explaining why using Train Graph may be beneficial, and question 13; learning to operate Train Graph is easy for me. This may indicate that the users learn how to operate the Train Graph more effectively through use, and as a result, could explain the benefits more effectively.

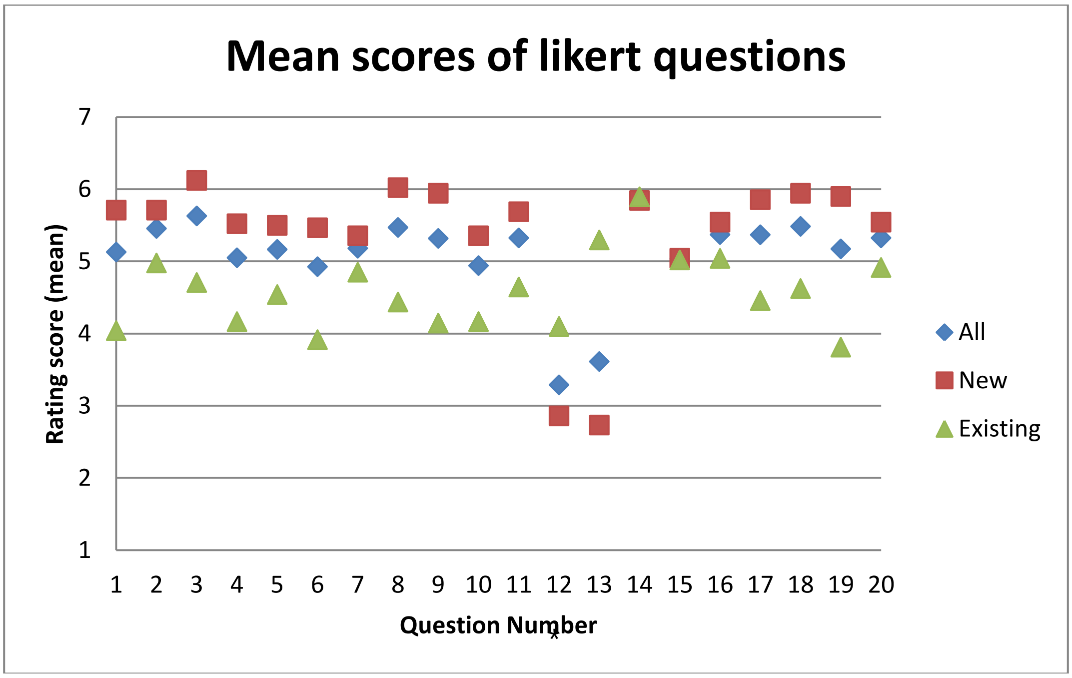


Figure 55 - Graph to show the mean scores of the Likert data (* the data for question 12 has been reversed to reflect the direction of the other data – i.e. a higher score meaning a positive attitude)

Table 33 - Mann Whitney test results for new and existing users

Question		Mann-Whitney U	Sample size	p value
1	Using Train Graph enables me to accomplish tasks more quickly	992.000	n1 =90 n2 = 48	.000
2	The information Train Graph provides is of good quality	1672.000	n1 =90 n2 = 48	.019
3	Train Graph provides more information than existing systems	1071.000	n1 =90 n2 = 48	.000
4	Using Train Graph improves the quality of work I do	1217.500	n1 =90 n2 = 48	.000
5	I trust the information Train Graph provides	1584.500	n1 =90 n2 = 48	.007
6	Using Train Graph improves my job performance	1146.500	n1 =90 n2 = 48	.000
7	Train Graph is clear and understandable	1877.000	n1 =90 n2 = 48	.264
8	I find Train Graph to be useful in my job	1125.000	n1 =90 n2 = 48	.000
9	The information Train Graph provides is more useful than existing systems	832.000	n1 =90 n2 = 48	.000
10	Overall, I find Train Graph to be advantageous to my job	1445.500	n1 =90 n2 = 48	.001
11	Interacting with the Train Graph does not require a lot of mental effort	1389.500	n1 =90 n2 = 48	.000
12	I would have difficulty explaining why using Train Graph may be beneficial	1320.500	n1 =90 n2 = 48	.000
13	Learning to operate Train Graph is easy for me	405.500	n1 =90 n2 = 48	.000
14	My use of Train Graph is voluntary	1990.000	n1 =90 n2 = 48	.392
15	I find it easy to get the Train Graph to do what I want it to do	1987.500	n1 =90 n2 = 48	.423
16	I find Train Graph easy to use	1743.000	n1 =90 n2 = 48	.073
17	In my job, using Train Graph is relevant	1260.000	n1 =90 n2 = 48	.000
18	I intend to continue using Train Graph for the next six months	1393.000	n1 =90 n2 = 48	.000
19	In my job, using Train Graph is important	847.500	n1 =90 n2 = 48	.000
20	I trust the data that is used to produce the Train Graph	1705.500	n1 =90 n2 = 48	.035

<u>Job role</u>

A Kruskal Wallis test was carried out to identify if there was any significant effect of job role on any of the Likert scale questions. Job role was found to have a significant effect on 10 of the 20 questions. The significant results are summarised in table 34. The degree of freedom in all the tests was df=5.

Fifteen pairwise comparisons were then carried out using Mann-Whitney U tests to identify exactly where the effects could be found. These pairwise comparisons are shown in table 35.

Table 34 – Significant Kruskal Wallis test results for new and existing users

Significant Questions		X^2	Sample size	p value
4	Using Train Graph improves the quality of work I do	11.909	138	<0.05
6	Using Train Graph improves my job performance	18.290	138	<0.05
8	I find Train Graph to be useful in my job	18.416	138	<0.05
9	The information Train Graph provides is more useful than existing systems	12.919	138	<0.05
10	Overall, I find Train Graph to be advantageous to my job	11.060	138	<0.05
13	Learning to operate Train Graph is easy for me	13.214	138	<0.05
14	My use of Train Graph is voluntary	14.941	138	<0.05
16	I find Train Graph easy to use	12.193	138	<0.05
17	In my job, using Train Graph is relevant	12.109	138	<0.05
19	In my job, using Train Graph is important	14.035	138	<0.05

Table 35 - Pairwise comparisons for job role effects

SSM v TRS				
SSM v TRC	TRS v TRC			
SSM v RCM	TRS v RCM	TRC v RCM		
SSM v IC	TRS v IC	TRC v IC	RCM v IC	
SSM v OTHER	TRS v OTHER	TRC v OTHER	RCM v OTHER	IC v OTHER

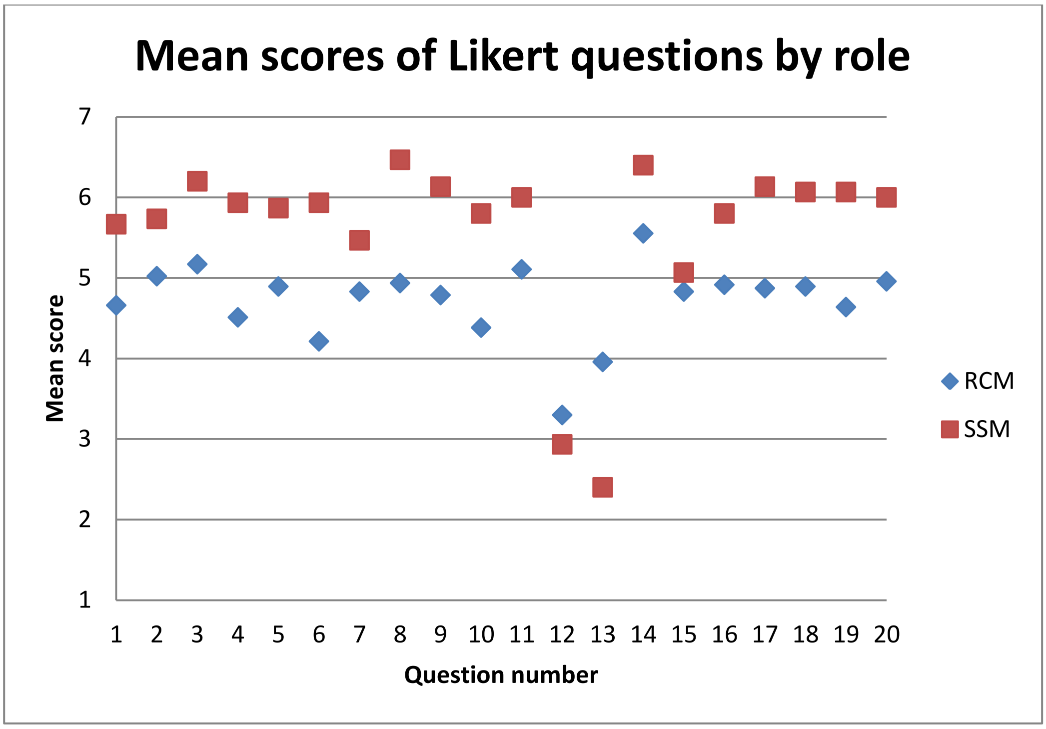


Figure 56 - Mean scores of Likert questions by role

Figure 56 shows a graphical representation of the mean scores of the RCM and SSM.

Using a Bonferroni correction based on the 15 a priori hypotheses of a significance level of 0.003 (0.05/15), differences were observed between the SSM and the RCM for 7 of the 10 questions where an effect was observed. With the exception of question 13, the SSM scored higher than the RCM role. One significant result was found between the SSM and another role. Table 36 shows the pairwise comparison for SSM, RCM and other roles. The differences in opinion between the RCM and SSM cover all of the usefulness questions, one ease of use and voluntariness question and two of the four relative advantage questions.

Table 36 - pairwise comparisons for SSM, RCM and other roles

			SSM v RCM		SSM v OTHER	
Question number	Question text	Grouping variable	Mann-Whitney U	p	Mann-Whitney U	p
1	Using Train Graph enables me to accomplish tasks more quickly	relative advantage				
3	Train Graph provides more information than existing systems	Relative advantage				
4	Using Train Graph improves the quality of work I do	Relative advantage	179.500	.003		
10	Overall, I find Train Graph to be advantageous to my job	Relative advantage	177.500	.003		
2	The information Train Graph provides is of good quality	trust				
5	I trust the information Train Graph provides	Trust				
20	I trust the data that is used to produce the Train Graph	Trust				
6	Using Train Graph improves my job performance	Usefulness	154.500	.001		
8	I find Train Graph to be useful in my job	Usefulness	138.000	.000		
9	The information Train Graph provides is more useful than existing systems	Usefulness	180.500	.003		
7	Train Graph is clear and understandable	Ease-of-use				
11	Interacting with the Train Graph does not require alot of mental effort	Ease-of-use				
13	Learning to operate Train Graph is easy for me	Ease-of-use	156.000	.001		
15	I find it easy to get the Train Graph to do what I want it to do	Ease-of-use				
16	I find Train Graph easy to use	Ease-of-use				
12	I would have difficulty explaining why using Train Graph may be beneficial	Observability				
14	My use of Train Graph is voluntary	Voluntariness	174.000	.001	262.000	.002
17	In my job, using Train Graph is relevant	Job relevance				
19	In my job, using Train Graph is important	Job relevance				
18	I intend to continue using Train Graph for the next six months	Behavioural intention				

Length of time worked in the railway

A Kruskal Wallis test was carried out to identify if there was any significant effect of length of time worked in the railway on any of the Likert scale questions. Length of time worked in the railway was found to have a significant effect on 4 of the 20 questions. Table 37 summarises the significant results – the degree of freedom for these tests was df=8.

Table 37 – Significant Kruskal Wallis test results for length of time working in the railway

Significant Questions		X^2	Sample size	p value
2	The information Train Graph provides is of good quality	17.239	138	<0.05
5	I trust the information the Train Graph provides	18.585	138	<0.05
12	I would have difficulty explaining why using Train Graph would be beneficial	16.385	138	<0.05
16	I find Train Graph easy to use	15.810	138	<0.05

Figure 57 shows the mean scores for the Likert data. Questions 2 and 5 concerned trust; question 12 concerned observability; and question 16 ease of use. All of the groups followed a similar pattern of scoring slightly lower for question 12 for each of the four questions, with the exception of the 6 to 10 year group for question 12 "I would have difficulty explaining why using Train Graph may be beneficial".

Length of time worked in current role

There were no significant effects observed for length of time worked in current role.

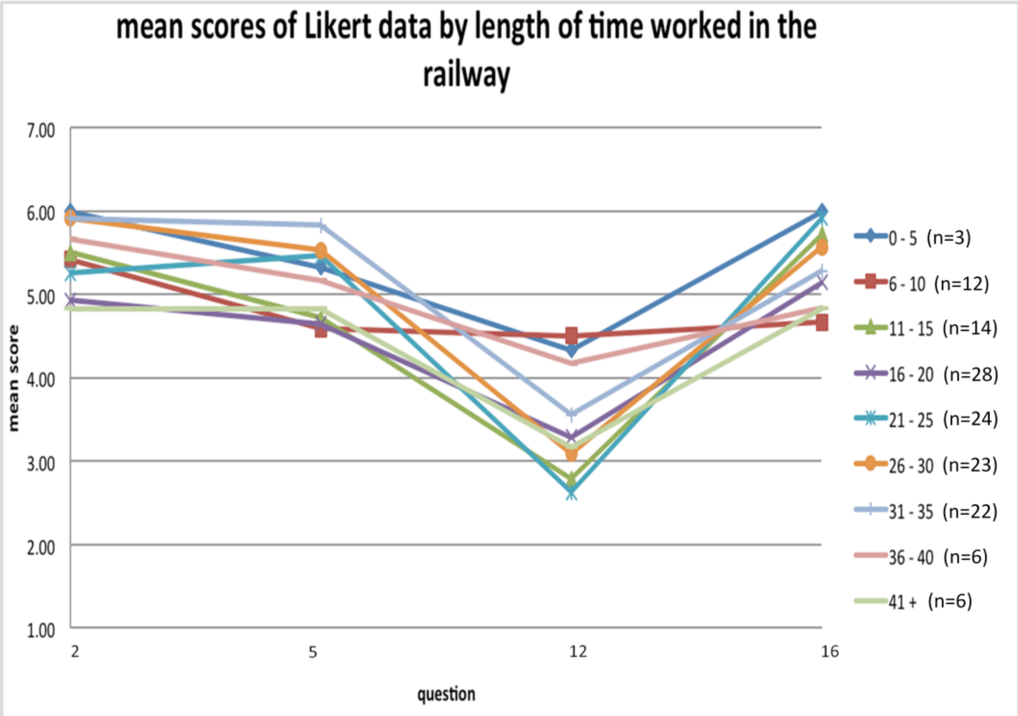


Figure 57 – Mean scores of Likert data by length of time worked in the railway

7.4.3 Correlations

A series of Spearman's nonparametric correlations were carried out on the Likert scale data. These were carried out for all of the dataset, and correlations were also carried out on the new user data sets and existing user dataset separately. The results are shown in Table 38.

Table 38 - Correlation matrix

				Relative advantage				Trust			Usefulness			Ease of Use					Observability	Voluntariness	Job Relevance		Behavioural intention
				1	3	4	10	2	5	20	6	8	9	7	11	13	15	16	12	14	17	19	18
				Using Train Graph enables me to accomplish tasks more quickly	Train Graph provides more information than existing systems	Using Train Graph improves the quality of work I do	Overall, I find Train Graph to be advantageous to my job	The information Train Graph provides is of good quality	I trust the information Train Graph provides	I trust the data that is used to produce the Train Graph	Using Train Graph improves my job performance	I find Train Graph to be useful in my job	The information Train Graph provides is more useful than existing systems	Train Graph is clear and understandable	Interacting with the Train Graph does not require alot of mental effort	Learning to operate Train Graph is easy for me	I find it easy to get the Train Graph to do what I want it to do	I find Train Graph easy to use	I would have difficulty explaining why using Train Graph may be beneficial	My use of Train Graph is voluntary	In my job, using Train Graph is relevant	In my job, using Train Graph is important	I intend to continue using Train Graph for the next six months
Relative advantage	1	Using Train Graph enables me to accomplish tasks more quickly	Correlation Coefficient		.329**	.320**	.314**	.322**	.475**	.399**	.196	.259*	.551**	.408**	.576**	-.365**	-.055	.231*	-.211*	.216*	.195	.353**	.502**
			Sig. (2-tailed)		.002	.002	.003	.002	.000	.000	.063	.014	.000	.000	.000	.000	.607	.029	.046	.041	.065	.001	.000
	3	Train Graph provides more information than existing systems	Correlation Coefficient	.455**		.350**	.226*	.329**	.293**	.325**	.403**	.474**	.410**	0.139534	.225*	-.243*	.199	.594**	-.316**	.385**	.428**	.463**	.330**
			Sig. (2-tailed)	0.001143		.001	.032	0.001562	.005	.002	.000	.000	.000	.190	.033	.021	.060	.000	.002	.000	.000	.000	.001
	4	Using Train Graph improves the quality of work I do	Correlation Coefficient	.875**	.572**		.670**	.320**	.573**	.342**	.492**	.311**	.324**	.357**	.507**	-.249*	.088	.424**	-0.17411	.245*	.290**	.232*	0.128155
			Sig. (2-tailed)	4.28E-16	.000		.000	0.002091	.000	.001	.000	.003	.002	.001	.000	.018	.411	.000	.101	.020	.006	.028	.229
	10	Overall, I find Train Graph to be advantageous to my job	Correlation Coefficient	.854**	.580**	.911**		.314**	.535**	.525**	.444**	0.192144	.379**	.389**	.586**	-0.19214	.068	.322**	-.296**	0.186266	.263*	.319**	.299**
			Sig. (2-tailed)	1.27E-14	.000	.000		0.002592	.000	.000	.000	.070	.000	.000	.000	.070	.522	.002	.005	.079	.012	.002	.004
Trust	2	The information Train Graph provides is of good quality	Correlation Coefficient	.691**	.637**	.698**	.720**		.475**	.399**	.196	.259*	.551**	.408**	.576**	-.365**	-.055	.231*	-.211*	.216*	.195	.353**	.502**
			Sig. (2-tailed)	5.44E-08	.000	.000	.000		.000	.000	.063	.014	.000	.000	.000	.000	.607	.029	.046	.041	.065	.001	.000
	5	I trust the information Train Graph provides	Correlation Coefficient	.620**	.600**	.588**	.544**	.596**		.543**	.417**	.400**	.600**	.662**	.648**	-.367**	-.007	.277**	-.230*	0.196574	.281**	.280**	.448**
			Sig. (2-tailed)	2.57E-06	.000	.000	.000	7.76E-06		.000	.000	.000	.000	.000	.000	.000	.944	.008	.029	.063	.007	.007	.000
	20	I trust the data that is used to produce the Train Graph	Correlation Coefficient	.488**	.577**	.566**	.504**	.621**	.762**		.407**	.335**	.647**	.531**	.630**	-.381**	.129	.385**	-.401**	.381**	.442**	.510**	.611**
			Sig. (2-tailed)	0.000433	.000	.000	.000	2.51E-06	.000		.000	.001	.000	.000	.000	.000	.226	.000	.000	.000	.000	.000	.000
Usefulness	6	Using Train Graph improves my job performance	Correlation Coefficient	.826**	.572**	.933**	.863**	.663**	.612**	.511**		.309**	.417**	.327**	.264*	-.270*	.142	.521**	-.224*	.294**	.232*	.262*	.260*
			Sig. (2-tailed)	4.99E-13	.000	.000	.000	2.9E-07	.000	.000		.003	.000	.002	.012	.010	.181	.000	.034	.005	.028	.012	.013
	8	I find Train Graph to be useful in my job	Correlation Coefficient	.826**	.450**	.876**	.887**	.701**	.457**	.440**	.849**		.524**	.275**	.362**	-.369**	.132	.336**	-.253*	.444**	.523**	.367**	.318**
			Sig. (2-tailed)	4.75E-13	.001	.000	.000	2.86E-08	.001	.002	.000		.000	.009	.000	.000	.215	.001	.016	.000	.000	.000	.002
	9	The information Train Graph provides is more useful than existing systems	Correlation Coefficient	.720**	.687**	.744**	.699**	.690**	.643**	.618**	.776**	.663**		.598**	.674**	-.477**	.026	.384**	-.358**	.520**	.501**	.576**	.725**
			Sig. (2-tailed)	7.76E-09	.000	.000	.000	5.9E-08	.000	.000	.000	.000		.000	.000	.000	.808	.000	.001	.000	.000	.000	.000
Ease of use	7	Train Graph is clear and understandable	Correlation Coefficient	.649**	.584**	.642**	.634**	.717**	.534**	.523**	.629**	.674**	.695**		.595**	-0.20712	-.015	.209*	-0.15956	0.098202	.149	.247*	.527**
			Sig. (2-tailed)	8.26E-07	.000	.000	.000	1.45E-08	.000	.000	.000	.000	.000		.000	.050	.885	.048	.133	.357	.162	.019	.000
	11	Interacting with the Train Graph does not require alot of mental effort	Correlation Coefficient	.410**	.649**	.367*	.418**	.585**	.647**	.445**	.386**	.411**	.524**	.579**		-.489**	.042	.336**	-.345**	.383**	.378**	.463**	.604**
			Sig. (2-tailed)	0.003772	.000	.010	.003	1.27E-05	.000	.002	.007	.004	.000	.000		.000	.694	.001	.001	.000	.000	.000	.000
	13	Learning to operate Train Graph is easy for me	Correlation Coefficient	0.277	.359*	.315*	.305*	.378**	.319*	.322*	.288*	.391**	.447**	.516**	.527**		.023	-.272**	.272**	-.500**	-.425**	-.442**	-.416**
			Sig. (2-tailed)	0.05663	.012	.029	.035	0.008084	.027	.026	.047	.006	.001	.000	.000		.832	.010	.009	.000	.000	.000	.000
	15	I find it easy to get the Train Graph to do what I want it to do	Correlation Coefficient	.531**	.485**	.624**	.605**	.593**	.522**	.387**	.635**	.678**	.653**	.664**	.605**	.567**		.373**	-.333**	.271**	.277**	0.099231	-0.00246
			Sig. (2-tailed)	0.000103	.000	.000	.000	9.01E-06	.000	.007	.000	.000	.000	.000	.000	.000		.000	.001	.010	.008	.352	.982
	16	I find Train Graph easy to use	Correlation Coefficient	.430**	.529**	.513**	.502**	.564**	.539**	.462**	.510**	.557**	.624**	.713**	.622**	.783**	.809**		-.489**	.621**	.666**	.446**	.259*
			Sig. (2-tailed)	0.002536	.000	.000	.000	3.71E-05	.000	.001	.000	.000	.000	.000	.000	.000	.000		.000	.000	.000	.000	.014
Observability	12	I would have difficulty explaining why using Train Graph may be beneficial	Correlation Coefficient	.494**	.458**	.496**	.540**	.570**	.476**	.498**	.439**	.497**	.577**	.618**	.433**	.292*	.474**	.417**		-.489**	-.528**	-.262*	-.234*
			Sig. (2-tailed)	0.000363	.001	.000	.000	2.35E-05	.001	.000	.002	.000	.000	.000	.002	.044	.001	.004		.000	.000	.013	.027
Voluntariness	14	My use of Train Graph is voluntary	Correlation Coefficient	0.083	.378**	0.104688	0.108913	0.164621	0.19574	0.160159	.040	0.065349	0.251372	.302*	.322*	0.23816	.330*	.342*	0.220895		.761**	.520**	.412**
			Sig. (2-tailed)	0.57342	.008	.479	.461	0.263519	.182	.277	.786	.659	.085	.039	.025	.103	.022	.019	.131		.000	.000	.000
Job Relevence	17	In my job, using Train Graph is relevant	Correlation Coefficient	.551**	.412**	.687**	.697**	.522**	0.261364	.420**	.605**	.699**	.552**	.559**	.289*	.321*	.451**	.462**	.364*	0.13256		.552**	.395**
			Sig. (2-tailed)	4.87E-05	.004	.000	.000	0.000143	.073	.003	.000	.000	.000	.000	.046	.026	.001	.001	.011	.369		.000	.000
	19	In my job, using Train Graph is important	Correlation Coefficient	.738**	.619**	.801**	.751**	.638**	.604**	.601**	.736**	.702**	.718**	.540**	.506**	.348*	.528**	.487**	.474**	0.087543	.722**		.593**
			Sig. (2-tailed)	2.15E-09	.000	.000	.000	1.09E-06	.000	.000	.000	.000	.000	.000	.000	.015	.000	.001	.001	.554	.000		.000
Behavioural intention	18	I intend to continue using Train Graph for the next six months	Correlation Coefficient	.758**	.572**	.844**	.823**	.770**	.567**	.587**	.850**	.834**	.766**	.701**	.415**	.458**	.721**	.656**	.567**	0.157073	.710**	.779**	
			Sig. (2-tailed)	4.57E-10	.000	.000	.000	1.62E-10	.000	.000	.000	.000	.000	.000	.003	.001	.000	.000	.000	.286	.000	.000	

NEW USERS

EXISTING USERS

Following existing research, the questions were correlated when they were grouped into their main constructs. These were relative advantage, trust, usefulness, ease-of-use, observability, voluntariness, job relevance and behavioural intention. There were some strong correlations observed between the questions. There did not appear to be a clear pattern for the new users; however for the existing users there were some very strong correlations and some very clear patterns observed. Most notable was a strong correlation between relative advantage and trust and usefulness. Although ease-of-use shows some strong correlations with relative advantage, trust, usefulness, behavioural intention and observability there were some clear gaps. These were notably between question 13 “learning to operate the Train Graph is easy for me" and observability, voluntariness, job relevance, relative advantage, trust, and usefulness. Question 14 relating to voluntariness "my use of Train Graph is voluntary" did not correlate with any other construct, which would be expected.

7.4.4 Factor Analysis

In order to determine any association between the different variables an exploratory factor analysis was carried out. The data were analysed by means of principal component analysis, with varimax rotation. Using an initial extraction criterion of selecting factors with an eigenvalue greater than one, it was revealed that four components accounted for 71.5% of the variance. However there is some debate in the literature over whether a cut-off point of an eigenvalue of one as recommended by Kaiser (1960) is too restrictive. Jolliffe (1972) recommends adoption of retaining all factors with an eigenvalue greater than 0.7. In this instance the inclusion of these extra factors led to one additional group, with five components accounting for 75.7% of the variance (see Table 39 and Figure 58). Therefore the factor analysis was re-run specifying an eigenvalue greater than 0.7 as the selection criterion. Figure 58 shows that the scree plot evens out from the 6th component onwards.

Table 39 - Extraction sums of squared loadings of total variances

Component	Initial Eigenvalue		
	Total	% of Variance	Cumulative %
1	10.078	50.388	50.388
2	1.635	8.177	58.565
3	1.445	7.226	65.790
4	1.148	5.740	71.530
5	.836	4.182	75.712
6	.690	3.448	79.160
7	.593	2.964	82.124
8	.543	2.713	84.836
9	.469	2.344	87.181
10	.465	2.324	89.505
11	.385	1.923	91.428
12	.328	1.639	93.067
13	.283	1.417	94.484
14	.235	1.177	95.661
15	.213	1.064	96.725
16	.185	.924	97.649
17	.145	.727	98.376
18	.134	.672	99.048
19	.111	.556	99.604
20	.079	.396	100.000

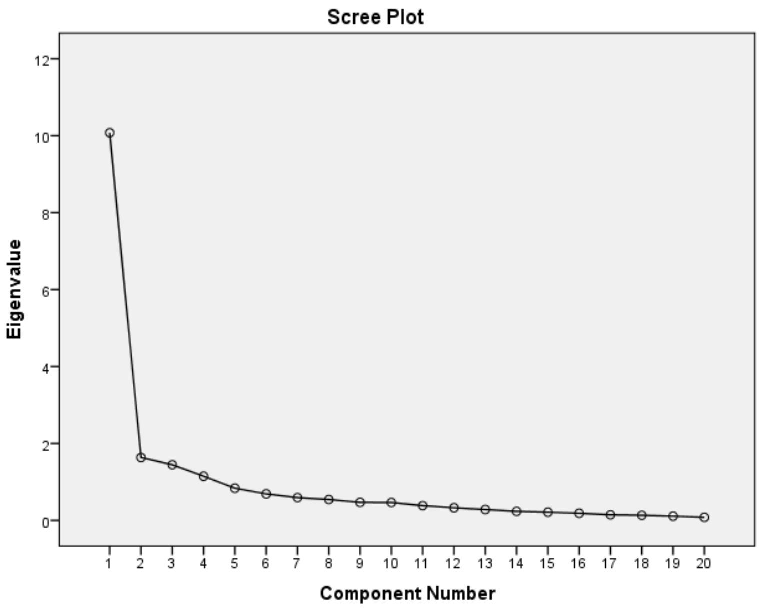


Figure 58 – Scree plot for factor analysis

Table 40 - Component matrix - before rotation

	Component				
	1	2	3	4	5
Relative advantage 1	.835	-.116	-.307	-.032	.057
Relative advantage 2	.781	-.051	.094	.139	.014
Relative advantage 3	.835	-.014	-.143	-.221	-.096
Relative advantage 4	.832	.038	-.138	-.195	-.052
Trust 1	.758	.136	-.249	.177	.180
Trust 2	.733	.043	-.057	.365	-.343
Trust 3	.639	-.013	.096	.361	-.313
Usefulness 1	.823	-.024	-.078	-.324	-.109
Usefulness 2	.841	-.052	-.116	-.296	.098
Usefulness 3	.893	-.083	-.028	.070	.021
Ease of use 1	.684	.393	-.078	.203	-.027
Ease of use 2	.737	.112	.147	.397	-.099
Ease of use 3	-.363	.785	-.006	-.102	.011
Ease of use 4	.297	.438	.503	-.378	-.304
Ease of use 5	.591	.316	.488	-.134	-.003
Observability 1	-.039	.671	-.474	.116	.294
Voluntariness 1	.300	-.003	.647	.309	.493
Job Relevence 1	.762	-.150	.189	-.253	.299
Job Relevence 2	.820	-.190	.012	-.040	.068
Behavioural intention 1	.868	.048	-.103	-.064	.157

The component matrices before and after rotation are shown in Table 40 and Table 41 respectively. Prior to the rotation, 16 of the 20 factors appear to load onto factor 1. The rotated component matrix shows several different variables loading onto each of the five factors. All of the factor loadings are above 0 .5 which would indicate a meaningful relationship between the factor and the item (cliff, 1987).

Table 41 - Component matrix - after rotation

	Component				
	1	2	3	4	5
Relative advantage 1	.810	.374	-.116	.005	-.012
Relative advantage 2	.560	.497	.087	-.098	.251
Relative advantage 3	.794	.324	.179	-.046	-.075
Relative advantage 4	.782	.328	.180	.013	-.034
Trust 1	.637	.456	-.109	.260	.160
Trust 2	.371	.805	.066	-.049	-.030
Trust 3	.267	.734	.105	-.145	.068
Usefulness 1	.809	.250	.264	-.096	-.078
Usefulness 2	.874	.181	.139	-.034	.054
Usefulness 3	.722	.499	.045	-.085	.177
Ease of use 1	.434	.564	.178	.344	.118
Ease of use 2	.351	.729	.118	.010	.277
Ease of use 3	-.353	-.170	.378	.674	-.092
Ease of use 4	.129	.089	.861	.011	.036
Ease of use 5	.357	.263	.613	.025	.364
Observability 1	.035	.005	-.117	.871	-.061
Voluntariness 1	.045	.156	.110	-.086	.895
Job Relevence 1	.765	.069	.166	-.166	.384
Job Relevence 2	.723	.349	.036	-.185	.189
Behavioural intention 1	.794	.344	.073	.087	.180

The factor groupings after rotation, would suggest that the initial groupings of question themes were fairly representative.

Eleven factors load on to the first component. All of the original groups are kept together in this first component with the exception of trust. The factor analysis has grouped the first trust question “the information Train Graph provides is of good quality" with this first component. This would seem logical as the quality of the information could indicate how useful and advantageous the operators find the system rather than being explicitly about trusting the system.

Four factors loaded onto component 2. These refer to the two remaining trust questions and two of the five ease-of-use questions relating to Train Graph being clear and understandable and not requiring a lot of mental effort to interact with the Train Graph. It seems sensible to conclude that an inherent trust of the data and information provided by the Train Graph would mean less mental effort is required so these for factors sit well together.

The two factors that load onto component 3 both relate to ease-of-use and interactivity of the Train Graph. The grouping of these two factors suggest that if operators feel the Train Graph is easy to manipulate and easy to get it to do what they wanted to do they would perceive it is easy to use.

The one question relating to observability "I would have difficulty explaining why using Train Graph may be beneficial" was loaded onto component four along with an ease of use question "learning to operate Train Graph is easy for me". If learning to use the Train Graph is easy then the benefits of using it would also be easier to obtain and therefore conveying this to others would be easier.

There was one factor loaded onto component 5 which was "my use of Train Graph is voluntary". The fact that this is on its own is an interesting finding but was somewhat expected: It is the only question that is heavily reliant on external influences and was the only question in the voluntariness category, thus backing up the original groupings even further. That is the ability for the operator to perceive the use of Train Graph is voluntary or not is largely down to the organisation rather than the individual themselves or the Train Graph itself.

The final components and groupings can be seen in Table 42.

Table 42 - Final components

	Question	Grouping	Component	Final component
1	Using Train Graph enables me to accomplish tasks more quickly	RA1	1	Perceived benefit and job enhancement
3	Train Graph provides more information than existing systems	RA2	1	
4	Using Train Graph improves the quality of work I do	RA3	1	
	Overall, I find Train Graph to be advantageous to my job	RA4	1	
	The information Train Graph provides is of good quality	Trust 1	1	
6	Using Train Graph improves my job performance	Useful 1	1	
8	I find Train Graph to be useful in my job	Useful 2	1	
9	The information Train Graph provides is more useful than existing systems	Useful 3	1	
17	In my job, using Train Graph is relevant	JR 1	1	
19	In my job, using Train Graph is important	JR 2	1	
18	I intend to continue using Train Graph for the next six months	BI 1	1	
7	Train Graph is clear and understandable	EOU 1	2	Information provision
11	Interacting with the Train Graph does not require a lot of mental effort	EOU 2	2	
5	I trust the information Train Graph provides	Trust 2	2	
20	I trust the data that is used to produce the Train Graph	TRUST 3	2	
15	I find it easy to get the Train Graph to do what I want it to do	EOU 4	3	Ease of use
16	I find Train Graph easy to use	EOU 5	3	
12	I would have difficulty explaining why using Train Graph may be beneficial	OBS 1	4	Understand-ability

	Question	Grouping	Component	Final component
13	Learning to operate Train Graph is easy for me	EOU 3	4	Understand-ability
14	My use of Train Graph is voluntary	VOLUN 1	5	Voluntariness

7.4.5 Qualitative data from questionnaires

Two questions were asked at the end of each questionnaire where respondents were invited to write their own comments. These questions were "what do you use the Train Graph for" (or "what would you use the Train Graph for" for new users) and "do you have any improvement suggestions for Train Graph?" The results for the first question can be seen in table 43.

The only negative comments received were from the existing users, with 10 people saying that they "do not use it for anything" and "it's not useful". The new users focused more on regulating decisions and conflict detection and resolution and also predicting future conflicts. The existing users focused more on general regulating monitoring, and prevention of off area delays.

The responses from the second question will be discussed in section 7.5 (and will be clearly marked as having evolved from the questionnaire data).

Table 43 - Frequency of comments by new and existing users

		Frequency of comment	
		existing	New
Signalling task	Regulating decisions		19
	Regulation monitoring	11	11
	Identify conflicts	4	11
	Predicting conflicts		9
	Conflict resolution		8
	late running monitoring	2	4
	Checking paths for VSTPs	2	1
	General monitoring	1	1
Information provision	Junction clashes	3	2
	Inquiring about a particular train rather than using TRUST	1	1
	Delay attribution		7
	Using for blockages and planned works		3
	Train running info	1	3
	Where no CCF coverage	1	2
General opinion of Train Graph	To understand what it can offer my staff	1	
	Check my TRCs are doing their job!	1	1
	Looking impressive	1	
	Nothing	10	
	Too early to say		2

7.5 Discussion

The discussion will be structured utilising the coding structure for the interview data identified and reported in the results section. When quotes from interviews held in the signal boxes are used these will clearly be labelled boxes A to K. When quotes from questionnaires are used these will be labelled QP1 – QP158 (questionnaire participant 1 to 158).

7.5.1 Existing Job Role

7.5.1.1 Signaller qualities

Experience

The staff that took part in this study had varied experience ranging from 5 to 45 years working on the railway. Although this only affected certain questions in the questionnaire, during the interviews it became apparent that experience, in particular working in different roles on the railway, affected how the operators perceived the Train Graph.

Experience in this sense refers to the depth and breadth of railway knowledge the operators had. This could be anything from this being their first and only job, to having worked in various roles within the railway industry from train driving to maintenance to signalling and management roles. Their level of experience may have affected how the Train Graph was perceived with many longest serving operators resisting the introduction of new technology. One SSM remarked:

> "I have worked this panel for 20 years. No clever graph is going to tell [me] what I don't already know". (Box E)

This opinion was not a lone one and many operators believed that their experience was superior to the graph. One operator however seem to appreciate that the introduction of Train Graph was not so black and white:

> "you can't help but gather knowledge and experience to work in the railway but we're only human; we can't spot everything and anything that gives you a helping hand in my opinion and enhances your experience is a good thing". (Box I)

Experience is a key factor in the TAM2 model (Venkatesh and Davis, 2000). Venkatesh hypothesises that experience will influence subjective norm, which in turn will affect perceived usefulness and intention to use. Experience in a more local sense could be identified with new and existing users. Existing users had experience of using the Train Graph in the setting it is intended to be used where as the new users had only had access to the Train Graph in a training environment. This did have an effect on the scores for the Likert questions relating to usefulness and behavioural intention. The new users scored these four questions significantly higher than the existing users. This may suggest that experience with the system, specifically a negative experience, impacts on how useful the system is perceived to be and also the usage patterns moving forward. Experience also appears to directly affect trust. The operators would use their prior knowledge and experience to establish whether or not the information the Train Graph provided was accurate.

> “That's showing a conflict there. But I know that's a freight that is not running, so the conflict is non-existent. Someone who didn't know the timetable wouldn't know that”. (Box B)

This would suggest that rather than being a modifier that the TAM2 model suggests, prior experience and knowledge is a key foundation to technology acceptance.

Knowledge

Knowledge is very closely tied to experience, but in this instance it is referring more to route and local knowledge rather than general railway knowledge and experience. Many of the operators interviewed had extensive knowledge of not only their area but their neighbouring areas as well. This meant that any issues, conflicts or problems they could often foresee before they arrived on the panel.

In the interviews the role of knowledge was referred to 36 times by operators making it the fifth most mentioned theme.

All SSMs are managers and oversee all of the signalling activity that is carried out under their control area. They are all experienced signallers and have often worked in signalling and the railway industry for many years.

When observing the existing operators in situ, particularly the first phase East Coast station of Train Graph, the operators were very quick to point out conflicts that would not exist by the time the trains actually arrived on that panel and would spend time explaining how the trains would be regulated before they reach their area.

Roles

The questionnaire data clearly shows that there are differences in operators’ opinions of Train Graph according to role. The analysis of the questionnaire results indicated that there was a significant effect of job role on 10 of the Likert questions. These included all of the usefulness questions, all of the job relevance questions and some relative advantage and ease-of-use questions. Seven of the 10 questions found to be affected by job role were loaded onto the first component of the factor analysis. This would indicate that role has significant impact upon this factor. When pairwise comparisons were carried out on significant results three significant differences were found between the

RCM and the SSM role. These were for questions 6, 8 and 9 which accounted for all three of the usefulness questions, questions four and 10 with related to relative advantage, question 13 relating to ease-of-use and question 14 which related to voluntariness.

The difference between the RCM and SSM role response for the voluntariness question may have been due to the different managerial styles in place in control and signalling. The RCMs felt that their use of Train Graph was more voluntary than the SSMs did. The results of the questionnaire analysis also indicate that the SSMs felt that the Train Graph was more useful than the RCMs. This finding was backed up further during the interviews and observations when the SSMs indicated that Train Graph would be beneficial for regulating purposes.

The topic of job relevance was mentioned several times during the interviews and in contrast to the questionnaire results the RCMs appeared more open to the use of Train Graph than the SSMs.

7.5.1.2 Physical attributes of signalling task

Infrastructure

The layout of the infrastructure appeared to have an impact on whether the operators thought of the Train Graph as being useful or not. The observed operators, particularly during the first phase, commented on the Train Graph being more useful in less complex areas.

> "It's very easy to regulate a single-track railway. It's very easy to show this on the graph and very easy to read this. Get a more complicated area like the throat of a busy station and the graph is useless". (Box B)

When the area was complex, there were more regulating opportunities than were necessarily apparent on the graph. These needed interpretation and local knowledge in order to carry out changes using the graph.

> "If I was a new starter and I looked at that I wouldn't have a clue what was going on". (Box F)

The infrastructure also impacted how the graph looked. More stations and stops meant that the Train Graph looked busier and the lines were more stretched out. If there were small sections of railway that came onto their area and left rather quickly this would mean that trains would quickly appear and disappear as they moved through and on to the next area.

The graph had limited usefulness in station areas. Although the platforms were visible in Train Graph, when expanded to show all the platforms the mixture of vertical and horizontal lines meant that it was not clear to the operator how many trains were in the platform at one time. Gaps were not immediately obvious and so for re-platforming the graph was not very useful. The Docker tool discussed in the previous two chapters provided an 'at a glance' view of the station area enabling the operators to identify quickly any gaps and aid re-planning.

Existing technology

Currently signallers use TRUST and CCF along with their overview and detail screens in order to regulate the railway (see Chapter 2). The Train Graph was introduced alongside this existing technology so the use of the Train Graph was on the whole voluntary. Although many could see a benefit with the Train Graph they commented that they would still continue to use the existing technology that was currently in the box.

> "CCF is all we need here. You can glance at it really quick and it'll tell you what the service is doing". (Box D)

Although the Train Graph could provide all of the information that the existing systems provided, familiarity with the existing system led to them still being used over the Train Graph. One SSM commented:

> "I don't use it [the Train Graph] now, no. I'll have it up, but I just use CCF and TRUST and the graph doesn't really add anything extra... Mind you, I can remember when they first put CCF in here. Everyone thought it was useless and we didn't need it; now we couldn't do without it. Maybe the same'll happen with this?" (Box D)

Conversely, the questionnaire results revealed that the users had a positive attitude towards the question "Train Graph provides more information than existing systems" with the mean score for all users being 5.6. The mean score of existing users were slightly lower at 4.7 and significantly higher for new users at 6.1. This may have been due to the redesign of the Train Graph between gathering information for new and existing users. Also the questionnaire for the new users was administered during the training session when functionality was at the forefront of their minds. The second rollout of Train Graph provided additional features and functionality over the first. This may have led the users to believe that it provided additional information over existing systems; in reality however, the information was just easier to access.

Familiarity with the Train Graph was certainly an issue, particularly at the first rollout sites. It also became apparent that anyone who had not worked as a planner or been subject to planning role was not familiar with the layout of the Train Graph. The SSMs in particular found it difficult to read the graph in the first instance:

> "it's so different anything we used to. That [pointing at the NX panel] shows everything in relation to the infrastructure. I can do that; that makes sense. This [gesturing towards the Train Graph] is taking a bit of getting used to. It's like you're turning the panel through 90°. But more than that, it then keeps moving". (Box I)

Operators who had worked in control environments were more comfortable with the time-based display which was common to many planning tools. This may have been due to signallers operating the railway using a map based representation whereas controllers generally use TRUST a lot more than CCF to query trains so this time based representation may have been more familiar to them.

7.5.2 Train Graph

7.5.2.1 Use of Train Graph

Accessibility

Accessibility of the system was not a frequently mentioned issue; however, if it was seen as an issue this is often fundamental to the overall attitude towards the Train Graph. One of the main facets of TAM is that the interaction between usefulness and ease-of-use will influence behavioural intention leading to use of the system (Venkatesh et al., 2003). In this instance something as straightforward as not having enough screens to display their existing systems and Train Graph on led to users perceiving the Train Graph as not useful.

Operators who mentioned the accessibility of the Train Graph always perceived the Train Graph to be not useful and not advantageous to their job. In fact it led to a negative attitude towards the Train Graph and many felt that issues surrounding screen availability and the overall speed of the system meant that it was not worth persevering with:

> "Currently I can't use it as our PC is not powerful enough to run all the applications we require". (QP 118)
>
> "Until we get TG on a separate standalone computer as far as I am concerned it can stay switched off, as it slows everything down, and as we have more than 3 applications running at once TG is a hindrance, by the time we get a standalone computer, version 10 will be out and we will require more training". (QP 76)
>
> "It takes up a lot of space. You need a whole screen. It wouldn't be so bad if you could just have the vital information i.e. a list of conflicts that you could minimise and drag around so you could put it where you want". (Box B)

Functionality

The graph predicts what is going to happen to the train service in the future. It gets this information from real time data and flags up any conflicts to the operator in the form of a yellow star.

Many operators, particularly in the first phase rollout, were disappointed with the lack of interactivity that the Train Graph possessed.

> "I was expecting to be able to drag parts of the graph and that would signal the trains for me. As it is, it's totally pointless. It tells you where conflicts are then we have to go out of the graph and re-plan trains". (Box B)

This frustration was documented and observed at several of the sites visited. Operators were often expecting the Train Graph to do more than it did and as a result did not see any benefits over existing systems.

Functionality was coded in the interview data 60 times. Usefulness was mentioned 78 times and usability 61. In the interviews, when a specific functional issue was raised it was often accompanied by an issue relating to the usability of perceived usefulness of that function. This was a comment made by an SSM at a box that had the first phase rollout of Train Graph:

> "I have no idea what all these buttons are at the top. When you press on them they don't do anything, or, you can't really tell what it's done. You'd want it to tell you surely? And why can you not just hover over it, the line and it'll pop up all of the train running information?" (Box F)
>
> "As it is I can't use it. I want to be able to filter out certain trains; you can't do that. You can only look at one direction or another. This doesn't really help me, especially when trying to look at the platform areas. (Box D)

After the second rollout when certain aspects of functionality changed, for instance buttons were more obvious and there was less hidden functionality, attitudes were more positive towards the Train Graph.

> "It looks good, I know what all the buttons do: it's just getting used to it. It's still a shame it doesn't do more though, it's essentially just a graphical form of TRUST". (Box H)

<u>Usefulness</u>

Usefulness was a topic that was well covered in the interviews, with 78 separate comments relating to it across all of the interviews. There was a significant difference observed between SSMs and RCMs for all three of the usefulness questions in the questionnaire with the SSM scoring consistently higher than the RCMs; their mean scores being at least one point higher for each of the three questions. These questions relate to 'the graph is improving job performance', 'the Train Graph being useful to their existing job' and 'the Train Graph providing more useful information than existing systems'. This does not mean however that the RCMs had a negative opinion of Train Graph, specifically whether it will be useful in their job. The mean score for SSM for this question was 5 compared to 6.5 for the RCMs. There was also a considerable difference in the mean scores of these three questions for new and existing users with the new users scoring consistently higher than the existing users. The largest difference was for the question 'the information Train Graph provides is more useful than existing systems' where the mean scores for the new users were almost 2 points higher than for the existing users.

During the interviews, the general opinion among the participants was that CCF and TRUST are useful systems. SSMs at three locations felt that it was easier to spot late runners at a glance using CCF, rather than Train Graph. This may be that CCF is consistent with other signalling displays and the late trains are shown in their geographical location, colour coded by lateness. If the SSMs are aware of their area, it is easy to glance at CCF, see where trains are and if they are running late. It is then easy to assess regulating options. The SSMs also believe that the Train Graph does not allow for recovery time, whereas CCF does, and so they tend to trust CCF more in terms of predicting conflicts due to late runners.

The usefulness questions showed some strong correlations with the questions relating to relative advantage, trust, observability and behavioural intention; however these were only for existing users. Interestingly the existing users showed extremely strong results for ‘the information Train Graph provides is more useful than existing systems’ when correlated with all of the questions specifically relating to trust and relative advantage. This would indicate that the users who felt that the Train Graph is useful and beneficial also trusted its outputs. The relationship between usefulness and trust was further strengthened in the factor analysis, when the trust question “The information train graph provides is of good quality” was grouped with all three of the usefulness questions. The usefulness questions relate to job performance, being useful in your job, and being more useful than existing systems. It would stand to reason, then, that the correlations between these two categories would be stronger for the existing users, as they have had the opportunity to use the train graph and explore the real meanings to the questions. Only having a short training session, the new users may be able to get a feel for the train graph and its use, but trust is a concept that develops through everyday use.

Six of the SSMs said that they had interrogated TRUST after they had spotted a white conflict box on the graph when it was first installed but said that they were usually aware of conflicts anyway and felt their knowledge and expertise would have given this information. This was especially the case in NX boxes where the large display is visible at a glance.

One SSM also commented that seeing conflicts before arriving in your area does not help because you do not know how the trains will be regulated before arriving on the panel and one SSM even went on to say that they felt the task of regulating over a wide area was best left to the TRS:

> “I don’t want to step on the toes of the Train Running Specialists. At the end of the day, he or she makes a decision that is based on the bigger picture, so we try our best to carry out their request”. (Box A)

The TRS commented that for his particular job role:

> “The at a glance view that the Train Graph provides is really useful. It allows you to see what is likely to happen and where there could be possible clashes throughout the whole of its journey. To do all this in TRUST would take ages. The graph just allows you to see it very quickly and easily”. (Box A)

They still refer primarily to the CCF late running list, and focus on those particular trains on the graph, but seem to have no problem in switching between the two and accessing the necessary information quickly.

In terms of use for the regulating task, the TRS stated that the Train Graph is now used as an extra tool to back up their judgement calls and gives them added confidence in their decisions. The TRS did state however that there may be a possible loss of usefulness during major disruption:

> “When there were only a few running late, it's great. When the service has gone to sh*t, it's not that useful. It looks like a load of red spaghetti”. (Box B)

<u>Relative advantage</u>

The Train Graph can be viewed as an upgrade to the TRUST system. The current TRUST system is not being removed, but the information currently provided by it is represented in a different way via the graph. Relative advantage in this case is the degree to which the Train Graph is perceived as better than the current TRUST system.

The questionnaire asked four questions relating to relative advantage and there was a significant difference observed between the mean scores of new and existing users for all four questions, with the new users scoring consistently higher than the existing users. The questionnaire also asked a direct question regarding existing systems. The question "the information Train Graph provides is more useful than existing systems" saw one of the biggest differences in opinion between new and existing users when the mean scores were considered. The mean score for existing users for this question was 4.1 compared to 6 for the new users.

The general opinion among the SSMs was that they had high hopes for the Train Graph when they attended the training course, but were quite disappointed when it arrived, mainly due to software problems. All of the SSMs said that CCF was currently their preferred tool for regulating. They felt that the display was easy to read and understand at a glance and was sufficient for what they needed. None of the SSMs had used the graph to make a regulating decision, but many stated that when they had used it at all they had used it as a shortcut for accessing TRUST and finding out train data.

The SSMs felt it could be extremely time saving in terms of accessing information, but not necessarily for making regulating decisions. Those who had used it said that they still use TRUST to verify the information but Train Graph is good for accessing this information quickly. The SSMs did recognise that the Train Graph could potentially assist them and maybe even save time due to all of the information being collated:

> "Rather than cross checking across many different information sources all the information is right there, in one place". (Box C)

However, rather than saving time, one signaller commented that he did not see the Train Graph as useful unless he could watch it continually which they were unable to do as the computer is used for other purposes such as fault logs and CCF. Another SSM commented on the fact that the Train Graph does not save information, so data cannot be recovered to support delay attribution. This was seen by this SSM as a major limitation as compared to CCF.

All of the SSMs said they would continue to use CCF as "it is fine for what we need" but can see the benefits of the Train Graph for the controllers (TRS). Their opinion was that the SSM role is more concerned with dealing with the present, over a shorter distance, but in more detail, whereas the TRSs responsibility is the whole route. This led many SSMs to the opinion that the Train Graph was not of relevance to them due to them being more concerned with the present, not what was happening a few hours in advance.

Although the TRC now regard the Train Graph as a valuable extra tool, they felt that experience and prior knowledge is still an important part of interpreting the graph, and knowing which regulating decision to make. For example:

> "On the approach to Peterborough, it is usual for trains to lose a minute. TRUST and the graph may say that trains will clash, for instance if a train is late into Peterborough and then there is a London train, but you know from experience that actually, there probably won't be a clash". (Box G)

One TRC interviewed was extremely enthusiastic about Train Graph and generally pleased with the additional information and aid to their job that it provides;

> "A big view I share and one that is generally thought in Control, is that Train Graph is brilliant for routes that don't have CCF, for routes that do have CCF there is a tendency to use CCF before Train Graph, - might be worthwhile thinking on how the tool can be developed so it become the preferred option - other than CCF". (Box A)

Despite the clear differences in opinion between the SSMs and TRC's there were no significant differences observed between the two roles for the four relative advantage questions on the questionnaire. However, there were significant differences observed for two of the relative advantage questions between the SSM and RCM. This may have been due to a similar reason in that RCMs are more concerned with the overall view of the railway rather than a small section.

Usage

Generally, the Train Graph has been well received by the TRSs and is observed to be displayed on the screen most of the time. When the railway is running well, it is not used (but is still visible on the screen), as no changes need to be made to any running trains and the individual boxes are in control of the short-term regulation. However, when one or two trains are out of PPM (public performance measure - significantly delayed) it allows the TRS to concentrate on those trains, make regulating decisions and contact individual signal boxes accordingly.

Only three of the SSMs that were interviewed had opened the Train Graph more than a few times since it was installed, and only one signal box left it open most of the time. None of the SSMs interviewed used the Train Graph on a daily basis. One of the main reasons for this seemed to be that the screen was used for other purposes. This perception is consistent with the general view of the SSMs that the Train Graph is of more use to the TRS.

Due to the timing of the questionnaire administration, i.e. immediately following training, it was not possible to gain any further insight in to the actual usage of the system from the questionnaire data.

Acceptance

Acceptance was very closely correlated with usefulness and relative advantage. The fact that the operators who did not find it useful did not accept it as part of their working toolkit is consistent with the theory of TAM. The overall results for the questionnaires indicated a medium level of acceptance. The mean score for the question "I intend to continue using Train Graph for the next six months" was 5.5. This score was lower however for the existing users which may indicate that having been used, the benefits are less than expected and therefore the tool becomes less useful.
Many operators saw the Train Graph as a necessary addition to their signalling systems. This was especially apparent if the operators understood the concept of traffic management:

> “I can see it's part of the future of Traffic Management, so I know it's essential to embrace and understand it. Much like ARS etc”. (QP56)

Although generally seen as a necessary addition, operators who were aware of the wider implementation, in particular the Traffic Management project, seemed to accept the Train Graph more readily than those who were not. Some were sceptical about the future of traffic management:

> “Traffic management? That's one of those pie in the sky ideas that will come to nothing”. (Box H)

Consistent with TAM, acceptance is dependent upon many different things. Some users may see Train Graph as advantageous to their job, but may find it difficult to use. This may lead to low user acceptance. Equally, an operator may find it easy to use but may not see as relevant. This may also lead to low acceptance. During the first rollout there was generally low acceptance: Only one operator at the Train Graph up on their screen the time of the visit and some operators did not even know what the password was. This lack of acceptance was largely due to the Train Graph is not being seen as usable. Many operators commented on its lack of usability and lack of relevance to their job. The second rollout saw more operators attempting to use Train Graph and had more belief in its benefits.

7.5.2.2 Data quality

Input quality

The fact that the graph sometimes shows clashes that do not exist was a common theme which was usually caused by inaccurate information being fed to the graph. A particular example given was a freight company running trains to Tyne Docks:

> “The Freight Operating Company (FOC) will book all three potential routes, but only run one a day. The graph may then show clashes based on the other two routes that it is not running on, but the trains will not exist. This leads to the general opinion that the Train Graph is currently not trusted 100% and cannot be relied on solely to make regulating decisions: “everything needs double checking at the moment”. (Box B)

The occasions when incorrect information was provided (and the associated mistrust) could cause a problem with regards to consistent use and see the operators revert back to using TRUST for regulating. Despite the obvious system issues especially in the first rollout, operators still believed that Train Graph could be a good tool if the input data was right:

> “It's only as good as the stuff you put in the end of the day. You put crap in, you get crap out, and we have to filter through that crap to get the good bits. So at the moment is probably less useful than TRUST - at least I know that what that's telling me is right”. (Box C)

The questionnaires asked a direct question about the information used to produce the Train Graph. The question "I trust the data that is used to produce the Train Graph” saw a mean score of 5.3 for all users. This relatively high score would indicate that most of the users accepted the issues as minor bugs rather than fundamental system issues. The fact that all operators interviewed trusted TRUST as a data source currently would also hint towards the fact that the lack of mistrust and scepticism with regard to the information was due to the familiarity of the tool rather than fundamental mistrust of the information.

Output quality

Many operators felt that the information the Train Graph provided was not sufficiently accurate:

> "It can tell you what is going to happen in two hours time, but if that train loses or gains two minutes, that conflict's gone. The two big clashes we have had, it didn't spot, as it didn't know the train was going to leave late, it can't tell you that". (Box C)

At the moment the Train Graph only shows two trains conflicting. The general opinion was that this is rarely the case and other trains will also be affected, and that is not shown. The graph also predicts trains as first come first served, but some conflicts would never be resolved in that manner. One SSM stated that to be more useful, the graph should be able to tell for which conflicts difficult regulating decisions might be required (i.e. the obvious decisions between an early stopper and an on time fast are not difficult to resolve).

> "Train Graph gives you conflicting info and does not report accurately, i.e.: if an early running freight train is held at a regulating point/jcn [junction] and still passes the regulating point/jcn on time it shows the train running late by including the mins it was held even though it is still early or on time". (QP23)

This inconsistency in output quality affected the operators opinions of Train Graph and influenced their trust in the system. The information Train Graph provided was deemed to not be accurate in a lot of cases and conflicts showing were ignored as a result:

> "Link it to CCF rather than TRUST! If it was linked to CCF it would be brilliant as it would be more accurate. At the moment you can see a big white square (i.e. a conflict) and in reality it isn't a conflict because its already rectified itself but the Train Graph only changes at the timing points for the trains rather than every signal berth the same as CCF". (QP56)

There were three questions relating to trust in the questionnaire and the question "the information Train Graph provides is of good quality" gathered a mean score of 5.5 from all users. This is similar to the other two trust questions that were 5.1 and 5.2. This would indicate an alignment between the three questions.

Trust in Train Graph

As a facet, trust is tied very closely to the previous two sections but was coded as separate section due to being mentioned explicitly during the interviews.

The general view is that in its current stage of development, the Train Graph will not be useful to make regulating decisions in the box as all the information is readily available on TRUST and CCF. However, most were of the opinion that it may be more useful in the future when the existing bugs have been fixed and accurate information is being fed to the graph. All of the SSMs mentioned that conflicts had shown up that did not exist, or did not show conflicts that were there. One SSM stated:

> "At the moment the Train Graph is disappointing. We had high hopes for it when we were first introduced to it. 90% of the conflicts are either wrong or don't exist". (Box C)

While it is unlikely that 90% are wrong, the SSM perceives it to be so, therefore showing severe mistrust for the information provided.

As mentioned previously these initial experiences mean that they do not trust Train Graph to provide accurate information, but some stated that when the updated software was introduced they would give it another chance:

> "If it was 100% accurate we would use it. At the moment it isn't and we don't trust it". (Box E)

All of the SSMs suggested that if the information being fed to the graph was more accurate, they would trust it and maybe use it more.

In the factor analysis the three trust questions were loaded onto two separate components. The first question relating to the information Train Graph provides was loaded onto the component consisting of the questions relating to relative advantage, usefulness, job relevance and behavioural intention. This would indicate that the operators who believed the Train Graph provided good quality data would find it advantageous to their job, relevant to their job and useful. The component that contained the other two trust questions only contained four factors in total. Two of these were trust and two ease-of-use. The ease-of-use questions relating to the Train Graph being 'clear and understandable' and 'requiring minimal mental effort' to interact. The trust questions were about trusting the information Train Graph provides and trusting the information used to produce it. This would indicate that the readability and ease-of-use of the system can be influenced by the level of trust in the background data.

All of the operators interviewed trusted the information that TRUST provided but some did not trust the Train Graph even though it was essentially the same information. One reason for this may be that the Train Graph makes the information more visible whereas users have to search for information on TRUST. For example, if a conflict is shown on train graph that does not exist because the input information is wrong, that information is still wrong on TRUST, but the user is not alerted to it in such an abrupt manner: they would have to search for it.

7.5.2.3 Interaction with Train Graph

Usability

Six of the nine SSMs felt that the Train Graph was hard to read and understand at a glance. One reason for this opinion may be the different orientation of the railway network compared to existing tools. An SSM at one location suggested that the Train Graph provided a very different view of the railway compared to existing representations: the route running vertically instead of horizontally.

The first roll-out received a mixed response with regard to usability. Some of the functionality was hidden in drop-down menus and right click menus (see Table 29), and the fact the line could not be manipulated was frustrating many users.

Four SSMs commented that the display was too cluttered and felt that it was not necessary to display the trains that were running to time. The SSMs are only concerned with the conflicts in their area, and felt that displaying all of the trains did not add anything to Train Graph as a tool, or add anything extra to CCF. The SSMs at Box F however stated that the interface “was not too bad” and was easy to use once they had got used to it. Box A were the only signal box to have Train Graph open all the time, so this would imply that the interface is something that users could get used to with regular exposure.

The TRS commented that at times the graph can be very difficult to read, “especially near [a major terminus station] where you’ve got all the local trains coming in”. This is because of the amount of trains on the network. At particularly busy times, this is unavoidable.

Within the questionnaire there were questions relating to usability of the Train Graph. Specifically questions 7, 15 and 16 these were:

- Train Graph is clear and understandable
- I find it easy to get the Train Graph to do what I wanted to do
- I find the Train Graph easy to use

There was no significant difference observed between the scores for these questions between new and existing users. The only other question that did not show a difference was "my use of Train Graph is voluntary". These results would indicate that these issues are not dependent on length of time of use. The operator’s perception of whether the graph is clear and easy to use was developed within minutes of seeing the graph and would not change over time.

Interface

The physical appearance of Train Graph was not mentioned too frequently in the interviews, and of the 14 comments most were made during the first roll-out phase. Unfortunately most of these comments were negative in nature and referred to mainly the readability of the actual information on the graph. Most operators appeared indifferent to the interface and it appeared to be overshadowed by the lack of trust in the information it was providing. No mention was made about font size, and the colours were well received.

These opinions are reflected in the results for the question "Train Graph is clear and understandable" which received a mean score of 5.2. One SSM commented that the Train Graph would be readable if it was on a bigger screen:

> “On the current 17" PC screens the graph is all "squeezed" up which I find difficult to follow & understand. It would probably be more beneficial on a dedicated larger screen. On our current PC's, (of which there are 4,) we are constantly switching between applications in order to do the job”. (QP 5)

One issue with the way Train Graph displays the infrastructure is that for a complex area there are many breaks in the train lines, so in order to view the full path of the train the operator may have to look at several sections of the graph individually:

> “The graphs are not set up very well for our geographical area, and can be very slow to manoeuvre”. (QP 76)
>
> “In Manchester we need more route specific maps. Also, the computers seem to be at their limit running the application which results in sometimes slow performance”. (QP 54)

The layout of infrastructure is a current problem in signal boxes and is often debated at length when designing new signalling areas, as the splitting of the information can have a big impact on the usability of the system.

7.6 Conclusions

The two models that were the driver for this case study are IDT and TAM2 (see Figure 59). Through utilising the facets most relevant to a railway environment, the main drivers of technology acceptance within a rail signalling environment were tested in this chapter.

The key conclusion to be drawn from the findings is that the remaining presence of the existing technology (TRUST and CCF) coupled with inaccurate input information led to the first lot of users being sceptical about Train Graph and its benefits. This along with the limited functionality led to the Train Graph not being used much during the first phase rollout. This attitude changed slightly among the existing users for the second rollout when the interface and functionality was improved slightly, but still the frustration with inaccurate information provided by the graph led to low uptake.

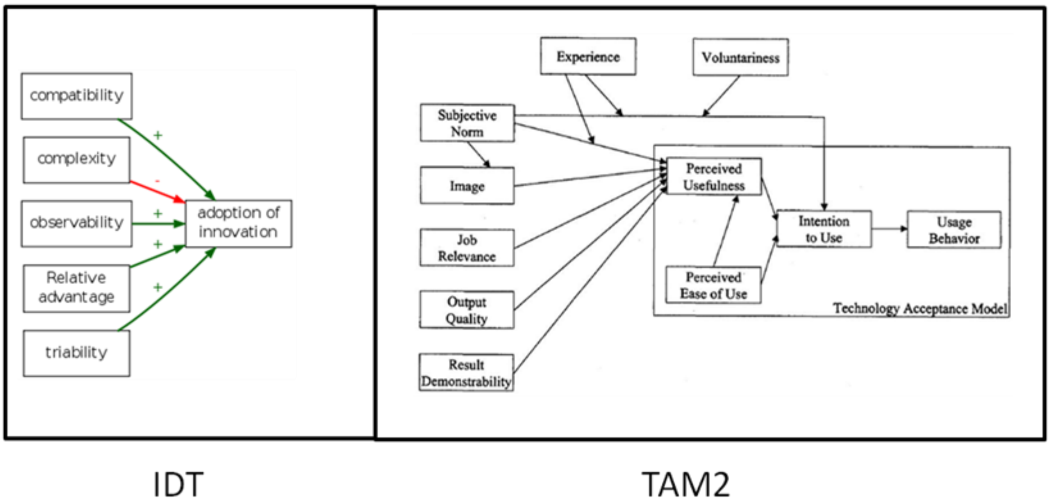


Figure 59 - IDT and TAM2

One of the main findings was the effect that the trust of the information provided by the Train Graph had on the users attitudes. Trust as a concept is not incorporated into TAM2 or the IDT. Output quality however is a facet of the TAM2 model, but the results of this case study have indicated that users with the existing knowledge and experience of the task were also concerned with the input quality. This would suggest that trust, in particular trusting the information used to produce the Train Graph and also trusting the information that Train Graph provides is a key driver of perceived usefulness.

Experience and prior knowledge also appeared to have a greater influence on usage patterns than the TAM2 model would suggest. Far from being a modifier, experience and prior knowledge appear to be a key driver in whether operators see the Train Graph as being relevant to their job and also whether it provides any advantage over the existing tools that they still have access to. Having access to tools that they are already familiar with affected the voluntariness factor, which is also a modifier in the TAM2 model. This did not appear to provide much insight into usage patterns for this case study. The factor analysis loaded it onto its own component, and this may indicate that it may not have been useful to use it to measure the perceived usefulness or ease-of-use of the Train Graph. However this technology was installed as an addition to the technology already used. If TRUST and CCF were taken away and the Train Graph was effectively forced upon users, the concept of voluntariness would have a greater influence upon the usage.

Figure 60 illustrates the proposed rail specific technology acceptance model resulting from the findings of this case study. The overall core of TAM is maintained, but the influencing factors are more specific to this type of technology introduction.

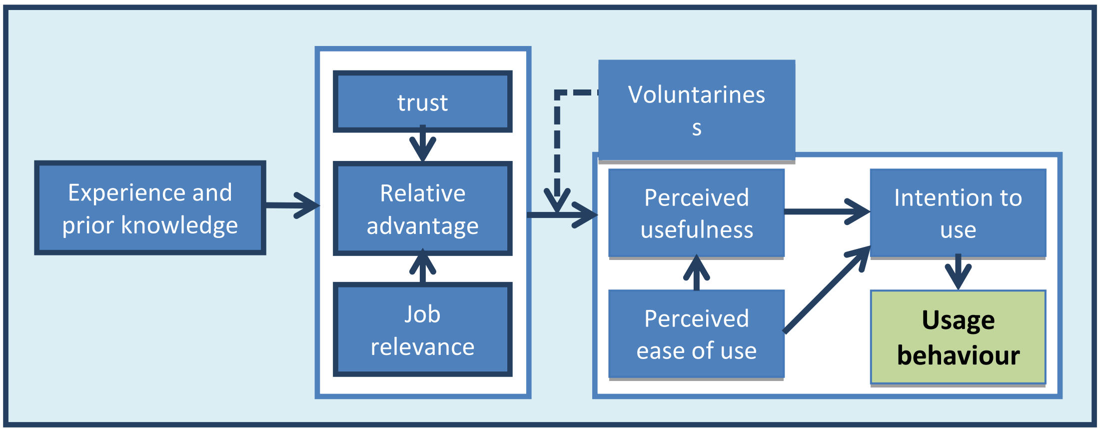


Figure 60 - Technology Acceptance Model based on a rail case study

Experience and prior knowledge is seen as a key driver to the rest of the model. This has the ability to influence users' trust of the technology and also whether they find it relevant or advantageous to their job. Relative advantage is seen as the main influence of perceived usefulness which can be affected by voluntariness.

When considering technology acceptance in an environment such as the railway, there are several key differences between this environment and an application used in banking or web retailing for example. Trust would come into play when considering Internet banking or applications of that nature, but in the case of the railway, operators are using this information to inform safety critical decisions. Therefore trust as a concept has a different meaning: trusting the technology has more serious implications than identify fraud (for instance), as a wrong decision could cost lives.

The case study demonstrated that role affected the usage of the Train Graph, which is a part of job relevance. This was particularly apparent during the first phase rollout where the train running specialists found the graph to be more useful than the SSMs. The train running specialists believed that the Train Graph provided them with additional information that they do not receive currently, therefore being relative to their job and providing them with an advantage over existing technology.

The difference in opinions and attitudes between new and existing users was clear throughout this whole study. Unfortunately it was not possible to retest the new users when they had had an opportunity to interact with the graph in their work environment for a few weeks. It is thought that the same frustrations with data quality and functionality would emerge over time which is indicated by the mean scores for the Likert questions. With the exception of a few questions, the mean scores for new and existing users follow a similar pattern despite the new users scores being slightly higher. This suggests that through use all scores drop which would indicate that use negatively affects opinion in this study.

To conclude, the combination of the IDT and TAM2 models in their current state is not representative of technology introduction into an existing railway environment. This case study has demonstrated that several different factors affect the uptake of new technology and that previous experience and trust in the system have considerable impact on the operators' relationship with the new technology.

8. GENERAL DISCUSSION

This chapter describes the research carried out and discusses the findings in line with the research aims. The findings are collated and related to previous research carried out on cognitive artefacts, decision-making and planning. This is drawn together to present a framework for the design and integration of decision support tools along with some key design principles.

8.1 Introduction

The main aim of this research was to study a real world signalling environment in order to understand the strategies signallers use when re-planning and how decision support tools can be designed and integrated into existing signalling environments to support proactive planning. Figure 2 shows the research framework that was followed in order to develop solid recommendations. This chapter discusses the thesis results in general and focuses back upon the research aims presented in chapter 1.

8.2 Discussion of research findings

A review of the literature was undertaken to identify relevant theories and themes relating to decision-making and planning using cognitive artefacts. The literature review focused on cognitive ergonomics as its overarching theme, and investigated how different representations and artefacts can influence decision-making and the impact this has on planning capabilities. Key themes also included the development of electronic artefacts and the integration and acceptance of these in existing and new environments. The key findings from the literature review are summarised in Table 44.

Table 44 - Summary of findings from Literature review

Theme	Key points	Source
Cognitive artefacts	• Can be used personally or collectively to change and improve cognition within teams and can aid joint planning • Artefacts should be: malleable, ecological, locally owned, widely available, informal and accessible. • Becomes part of the human cognitive system by "remembering" current cases, "displaying" constraints and options, and "simulating" possible solutions.	(Kaptelinin and Nardi, 2006) (Wears et al., 2007) (Xiao et al., 1997)
External representations	• If information is grouped sufficiently a diagram can aid problem-solving • Diagrams can offload cognitive processes from the user • Interpretations of diagrams can depend on the users prior experience and knowledge which influences the ability to predict future situations • External artefacts need to be supported by internal cognition • Computational offloading can occur and takes three forms: re-representation (external representations influencing problem-solving), graphical constraining (constraining interferences made about concept), temporal and spatial constraining (distribution over time and space)	(Larkin and Simon, 1987a) (Larkin and Simon, 1987a) (Cheng et al., 2001) (Zhang and Norman, 1994) (Scaife and Rogers, 1996) external cog – how do graphical reps work
Problem solving and planning	• Problem-solving is distributed across internal and external representations and there is often a trade-off between planning (internal) and acting (external) • Increased implementation costs (mental effort) can result in more efficient solutions and an increased understanding of the task • Preparatory planning activities utilising prior knowledge and experience can help anticipate future tasks • Interruptions, if similar to the primary task on more disruptive • Planning is not sequential and is a	(Zhang and Norman, 1994) (Scribner et al., 1984) (O'Hara and Payne, 1998) (Xiao et al., 1997) (Nystrom et al., 2010) (Nystrom et al., 2010)

	process of enriching resources	
Planning, decision making and artefacts	• Transferring tools and systems from paper to digital should not be approached in a linear manner: if hard to navigate the users can "get lost" and become unaware • Artefacts should be capable of supporting system recovery • Artefacts that support collaboration are informed by three factors: the Taylor ability, their ecological flexibility, and restrictions on the movement of personnel • Computerising one individual part of the process could aid collaboration and make information sources more robust • In order for an artefact be useful it should be: accurate, efficient, reliable, informative, and malleable	(Elm and Woods, 1985) (Elm and Woods, 1985) (Luff et al., 1992) (Rogers and Brignull, 2003) (Nemeth et al., 2003)
Situation awareness	• A good level of situation awareness should be maintained in the external environment, the system and the individual task is existing experience and knowledge • Mental models can be used to evaluate and predict the outcome of potential decisions	(Wickens and Carswell, 1995) Blandford et al 2010
Automation and electronic tools	• Tools Should be viewable from different locations, and should record any changes that have been made • Designers must consider "why the information is needed"when designing electronic tools • Perceived ease-of-use and perceived usefulness influence behavioural intention which influences system use • Rate of adoption of a particular system can be influenced by the user's perception of its: relative advantage, compatibility, complexity, trialability, and observability	(Wears et al., 2007) (Jenkins et al., 2010) (Atoyan et al., 2006) (Rogers, 1995) (Rogers, 1995)
Adoption of technology	• When considering the speed of uptake of new technology users can be divided into five categories: innovators, early adopters, early majority, late majority, and laggards • Many tools used to measure	(Rogers, 1995) (Moore and Benbasat, 1991)

	adoption of technology do not consider long-term use	
Trust	• When considering trust in system or technology, past history and experience should be considered as an important influence • Faults and poor reliability can undermine the trust in the system and outweigh any potential benefits • Intermittent faults affect trust more than an expected fault which can lead to workarounds which become the norm • Operators should be able to access the origin data at all times. If the system bypasses this the operator is less likely to trust the system • Users should be aware of why the automation is there and feel it has a purpose. They should also be aware of data is incomplete or missing. • Automation should adapt and be able to coincide with the existing mental models and theories that the operator possesses	(Lee and Moray, 1992) (Lee and Moray, 1992) (Lee and Moray, 1992) (Atoyan et al., 2006) (Atoyan et al., 2006) (Atoyan et al., 2006)

8.2.1 Cognitive Artefacts and External Representations

The discussion in the following section mainly addresses objective 2:

> *Evaluate existing decision support tools and their use and integration into signalling environments*.

8.2.1.1 Properties of cognitive artefacts

The cognitive artefacts studied for this research took three forms: list based, graphical based and electronic. Currently the signallers mainly use list based representations when planning and replanning, although moving towards traffic management, graphical based representations will become more common when replanning. Wears et al (2007) presented six properties that cognitive artefacts must have in order to be useful. Although malleable to some degree, the list Dockers were often messy and difficult to read when they have been altered. This is also the case for the graphical based paper representations. These are highly malleable, but the alterations do not update the plan entirely: a new plan appears on top of the old. During the experiment the list and paper-based graph users who annotated their tools, were generally more successful in completing the scenario than those who did not.

This reinforces the finding of Reisberg (1997) who states that annotating or altering external representations could increase their effectiveness. The list and paper-based graph users were also more aware of the impact the changes they were trying to make would have on the rest of the service. The electronic Docker was extremely malleable, and very easy to manipulate. Users could drag and drop and alter the plan fast and easily. However, they did not have to actively think about the impact the alterations were having on the rest of the service as the tool did this for them. The electronic tool and the results demonstrated from the experiment were supportive of Xiao et al's (2002) theory that the tool can become part of the human cognitive system when it remembers current cases, displays constraints, and simulate possible solutions. By combining malleability and automation, the electronic Docker successfully achieves this. When it was studied, the Train Graph was in the early stages of development and did not offer this level of malleability. Users commented it was clunky to use and was not as easy to use as the existing tools.

In terms of being ecological, the list based Dockers do not fulfil this characteristic. The results from the experiment indicated that it took a great deal of cognitive effort to utilise the information provided in the list based display (demonstrated by the time taken to complete the scenarios), and the representation would often contain incomplete information. The signallers studied who used these tools currently would often not take on changes unless the change was thought to be entirely necessary, suggesting that the effort required must outweigh the benefits from using the tool (Zhang and Norman, 1994). The ecological qualities of the paper-based graphical tool used at Glasgow meant that the tool was used regularly. However, this could also be viewed in a negative way: the operators often had additional workload as it was so quick and easy to make changes, so the TOC would rely on them heavily. The Train Graph was not being used as much as existing systems, and signallers were reverting back to the original systems.

Both the list based Dockers and the paper-based graphical Docker were very much owned by the signallers. They are often responsible for the design of these tools, the upkeep, and printing. They are instrumental in deciding what should be displayed on the tools and how it should be displayed. The original graphical Docker concept was developed by the signallers at Glasgow. By doing this, and these tools being locally owned, the signallers believe in the tool as a concept and trust the information it is providing. This is consistent with Rogers and Brignuls (2003) theory that ownership and input is a key driver towards tool use and performance. As a contrast, the Train Graph was not designed by the signallers and they have little input into its development. They became frustrated about certain features and many could not understand why it had been designed in the way it had. This demonstrates the importance of participation, ownership, and perceived value.

By its nature, the Docker used at Glasgow can be utilised by either an individual or group of individuals. While it is primarily operated by one person, the fact that it is large, the changes are so obvious, and it is quick and easy for a trained individual to interpret the information that is on there means that it could be classed as being widely available, supporting Wears et al's (2007) recommendations. It is often used in conjunction with the TOC, and it is a clear indicator to external parties how efficiently the train service is currently running: if it is covered in China graph pencil, the train service is not running to plan. This information can be ascertained at a distance due to the size of the Docker meaning the signallers do not need to be disturbed in order to gather this information. The list Dockers are not as "widely available". Although they can be used collaboratively, they are often only used and updated by one person. They are generally printed off and annotated by one person. There is not usually a 'master copy' as there is with the graphical Docker. This one-person annotates the tool, and the communication of that information to another party is done verbally. The electronic tools have the ability to be widely available. The Train Graph for example shows the current plan which can then be viewed by anyone who has Train Graph access. Likewise they can then also update the plan.

In terms of informality and accessibility, all of these tools as they currently stand are informal in that they are not required in order to allow the operators to do their job. While they are useful, they are not essential. The signallers have access to all the required information in different forms already. So, unless the new tool provides something additional that is seen as useful, it will not be used. All of the tools require prior knowledge and experience in order to be able to use them. However, this is primarily concerned with the signalling task rather than using the tool itself: the electronic Docker during the experiment proved to be the easiest to use. All of the participants instantly knew how to use it and were successful in its operation. However the participants in the experiment had no prior knowledge of signalling or railway operations. Therefore they have no pre-existing expectations about the functionality of the electronic Docker. In the case of the Train Graph however, the signallers were not being asked to do anything new; they were carrying out the same tasks as previously but the information was presented to them in a different way. Their existing mental models and preconceived ideas may have been influencing their initial reaction and interaction with the tool.

8.2.1.2 The nature of external representations

The experiment demonstrated quite clearly that the diagrammatic (graphical) representations enabled the operators to carry out the task more successfully than the list based users. By requiring less interpretation, the graphical representations enabled the operators to be more proactive when dealing with disruption. By being interactive and allowing the operators to try out moves before they commit to them (Xiao et al., 1997) the graphical Docker became an effective assistant to the signaller. However supporting Cheng et al's 2001 theory, the effectiveness of these tools was influenced by the existing knowledge and experience of the operator. Although the graphical users in the experiment were able to work out efficient solutions, the overall benefits of these tools were amplified when users had an understanding of the existing task and environment.

By requiring the operator to internalise their actions (Larkin and Simon, 1987a), the list based representations were not as effective in assisting the signallers in creating future plans. They were not able to effectively realise how any alterations would affect the existing train plan. For very experienced operators this became easier, however it was still less effective than the graphical representations. The graphical representations provided the user with the tools necessary to be able to utilise their existing knowledge to predict the future state of the railway (Xiao et al., 1997) rather than having to utilise their existing knowledge to interpret the tools as with the list Dockers. Although results from the experiment indicate that the electronic and graphical tools enabled the users to understand the problem relatively quickly, participants in the list condition took time to understand the scenario, and the process of searching for the correct information increased their overall awareness. The list condition did outperform the other two conditions on a few occasions. When the information was grouped together effectively, the information was easy to find and interpret (Larkin and Simon, 1987a). This, coupled with the additional awareness the list users had situation, meant that they were able to realise a solution more quickly in this scenario than the other two conditions. Although grouping information together is good design practice, it is only one piece of good practice in design and this strategy alone should not be relied upon to make an artefact efficient in assisting decision-making.

8.2.2 Problem-Solving, Planning, Decision-Making and Artefacts

This section mainly addresses objective 1:

> *To understand the existing strategies used by signallers to regulate and re-plan.*

When considering the problem-solving, planning and decision-making strategies that signallers use when managing station areas, it became clear that the type of tool used had the largest influence. The clearest conclusion drawn when considering this is that signallers using list based tools were less able to operate in a proactive manner. Their reactions were for the most part reactionary, with the exception of timely provision of information from the TOC which gave them time to plan. When considering strategies, the issues faced and the strategies used to deal with them were largely the same from box to box. However, how these strategies were executed varied considerably. For example all boxes were faced with a number of planned, ad hoc and last-minute changes, and they would deal with late running trains and cancelled services. These were dealt with by utilising a number of strategies such as stepping up sets or re-docking trains. The boxes that used graphical Dockers were more willing to attempt to utilise more complex strategies than those who used list based Dockers. They generally took on more tricky moves, and would try to keep delays to an absolute minimum even if this involved a few moves. This was not the case at the boxes that used list Dockers: they would often accept delays and the subsequent knock on delays due to it being less effort. However, this cannot be isolated from the impact of organisational culture.

During the experiment the list based users generally took longer to find a solution than the other two conditions. O'Hara and Paynes (1998) theory of implementation cost suggests that a higher initial outlay (such as mental effort) could lead to a more efficient solution. While the list based users often developed a better understanding of the task and the overall environment and situation, the solutions were rarely more efficient than for the graphical and electronic condition. The list based users also spent time considering and understanding the task. They would often understand the impact that a certain move or decision could potentially have on the rest of the service and would attempt to ensure the impact was minimised. However, they would often base this decision on an incomplete, incorrect picture: The information (although the same as the other two conditions) proved more difficult to find and interpret. Because of this the list based users would make decisions based on what they believed to be the full picture even when that was not the case. By being able to access the correct information more easily, the graph and electronic users were in control of the situation and were able to use this information to accurately predict the future state of the railway.

The electronic Docker tool was designed to behave functionally identically to the existing paper-based tool but also include instant feedback. It was developed using the five design guidelines put forward by Nemeth et al (2003) and in addition to these five guidelines (accurate, efficient, reliable, informative, malleable), the research also found the importance of supporting knowledge in terms of any alterations being "traceable".

These echo the recommendations made by Wears et al (2007). By ensuring all of these guidelines were adhered to the electronic tool proved to be an efficient and effective tool in assisting replanning. None of these six recommendations were met for the Train Graph, with most users having a very negative opinion of it. In particular the information provided was often not accurate due to inaccurate input information. Therefore it was not reliable, so it was no more efficient than using the existing tools. The users of the Train Graph also felt that they were being somewhat forced into using it. Consistent with Wears et al's (2007) theory, the informative nature of the graphical docking tools meant that users felt in control. They felt it was their choice to use it and as they had designed it, it was extremely relevant to their job.

The addition of some basic error detection to the electronic Docker provided the users with the tools necessary to make accurate effective decisions that would have minimal impact on railway operations. During the experiment the electronic users made no illegal moves. However, by removing the need for the users to fully understand the task the users became unaware of the impact of their decisions. Although the tool was telling them that their action would not impact the rest of the train service, they were not always sure why. One scenario in particular highlighted this when the electronic users did not pick the most efficient solution due to not having to think about the impact their moves would have on the rest of the station area because the tool was only alerting them to any wrong moves.

Xiao et al (1997) identified eight types of preparatory planning activity. These are:

- Planning for contingencies
- Selecting foci of attention
- Reviewing options
- Formulating general guiding rules
- Formulating local rules
- Configuring the workplace
- Placing triggering queues
- Making the workplace failsafe

It was observed that all operators carried out these preplanning activities regardless of tool type. However, some of these were more effective when combined with the graphical interface; the electronic tool especially. For example, when planning for contingencies it was considerably easier to visualise potential troublesome scenarios using the graphical interface. Operators were able to see clearly and easily how a delay or change would impact the rest of the service. This was amplified using the electronic Docker due to the added error detection. But, the best solution could only be found if coupled with existing knowledge and experience. Simply letting the electronic docker show where the trains should be placed may not lead to the most efficient solution, as previously discussed. It is also easier to review options using the graphical tools. As already discussed, the list based users would review the impact their decision was going to have but this was often formed from an incomplete picture. By presenting the information in an accurate way the graphical users could reliably try out moves before implementing them. Probably the largest difference however is the ability to make the workplace failsafe. Currently, decisions are made by the signaller and their existing knowledge and experience alerts them to whether this is an effective or safe move. Unless they actively search for information (using TRUST and other systems), the signallers have to use their existing knowledge in order to identify whether or not a move is possible or it is safe. During the experiment the list users often attempted moves that were impossible or unsafe. By alerting users instantly if a move was not possible or unsafe, the electronic Docker adds a layer of safety currently unseen, and removes liability from the signaller. Although, as observed with the Train Graph this is only an accurate statement if the correct information is being fed to the tool in the first place, and removing knowledge from the signaller may lead to skill degredation over time and may impact performance in emergency situations (Lee and Moray, 1992)

One of the main advantages of making the Docker tool electronic is to enable information to be shared across and between teams. By providing an information source that is easy to update, easy to read and instantly available, it could be more efficient to make decisions. One of the main advantages foreseen with the electronic Docker would be the ability for the TOCs to develop their own plans. This would remove the responsibility from the signallers, and reduce their workload by significantly reducing communication. However this in itself brings its own challenges in that currently by taking full control of the Docker tool and utilising the efficient interface (the at a glance and ability to instantly identify the state of the railway) the signaller is fully aware of the state of the railway at all times. If this responsibility of managing the station area and manipulating the graph is being divided between teams, its efficiency may become reduced. This may be because although the Docker tool makes it easy for signallers to try moves before they carry them out, the individual way this is carried out, the order they make moves, and the individual strategies and rules of thumb are unique to the operator. If two individuals are working on the same plan, their strategies and decision-making capabilities could potentially work against one another. This could potentially minimise the total benefits. Although two situations may be the same, and all the inputs identical, the strategies they use, and the order they complete tasks in could be very different between individuals. Therefore, if the tool is being manipulated by two people to create a plan, the plan may not be accurate or effective due to differing strategies.

8.2.3 Situation Awareness, Automation and Electronic tools

This section mainly addresses objective 3:

> *Explore the implications of introducing new tools into signalling environments to support proactive control.*

Currently, signallers control a relatively small area of railway. They are made aware of the decisions other signallers have made with regards to regulating trains when the trains arrive on their panel. If the train arrives on their panel late, they then have to make a decision about what to do with it. By having to manually route trains, and ensuring their station area is running to plan, the signaller is aware of what is happening in their area. Prior experience and knowledge can also mean they are aware of the impact certain situations will have on the train service. For instance, it was observed that signallers used static objects (such as bridges) to determine how late a train was going to be. They could then also predict what impact that train would have on the rest of the service (Cheng et al., 2001). Eliminate prior knowledge and experience however, and the tool becomes the driving force. This was simulated during the experiment. This makes training extremely important and will be a consideration as NR move towards Traffic Management, where operators (who may not have rail experience) control large areas. The abstract nature of the list based Docker meant that predicting situations was difficult especially (as previously discussed) if the predicted state is incorrect or incomplete. Wickens suggests that situation awareness is vital in three areas:

1. The external environment
2. The system
3. The individual task

The levels of situation awareness observed during this study were influenced by the type of tool. During the experiment, the list based users appeared to have a higher level of situation awareness compared to the other two conditions. However the direct impact their decisions were having on the environment and therefore the individual task was clearer and more obvious when using the electronic tool due to the instantaneous feedback. When the signallers were observed carrying out their day-to-day activities, the signallers were aware of what was happening and when. This is due to existing knowledge and experience. Conversely the Train Graph was considered by many as unnecessary as it was attempting to give the signallers information that through experience and knowledge they were already aware of. They deemed it as unnecessary as they felt the tool did not complement their existing skills.

By semi-automating the electronic Docker tool, certain functions were cognitively offloaded from the user (Scaife and Rogers, 1996). This enabled them to be able to use their knowledge and experience to plan rather than 'waste' cognitive processes on remembering information and knowing when to implement it. This increased their situation awareness of the system by clearly defining every move and making it easy to identify what has changed. The tool instantly fed back the changes to the user and kept up to date, accurate plan of the state of the railway. This also increased the situation awareness around the external environment. By making it clear to the user instantly what impact their decisions were having on the larger area, they were able to make more effective and efficient solutions. However it was observed during the experiment that users did not totally understand what was required of them in terms of the individual task: They could successfully implement the rules they were given at the start of the scenario but would not always implement all of them. For example the graph and list users would actively think about the different rules (for instance keeping the number of platforms moved to a minimum) when formulating a solution whereas the electronic users would let the system do the work. By effectively removing this step, the users are not carrying out the preparatory strategies to the same level as the list and graphical users therefore potentially minimising the overall effectiveness (Xiao et al., 1997).

When developing the electronic tool a large part of the process involved the end users. This enabled the correct information to be displayed and the necessary information filtered out for the final tool. The electronic nature of the tool also meant that certain information could be hidden until required or be accessed from different functions. By fully understanding why the information is required this tool proved to be effective in handling disruption and managing station areas. The graphical Docker tool however was already functioning in the same manner as the electronic tool. By being able to observe the existing strategies used when interacting with it the tool could be designed effectively. The Train Graph however was a standard one size fits all tool that was slightly adapted to fulfil the needs of the project. It was not designed specifically for any particular area. Some signallers commented that the layout did not make sense, it was not intuitive and it did not contain the functionality that they were expecting. It often did things that they did not expect, and information was difficult to find. This may have affected the usage rate of the Train Graph and would be consistent with research carried out by Elm and Woods (1985).

8.2.4 Adoption of Technology and Trust

This section mainly addresses objective 3:

> *Explore the implications of introducing new tools into signalling environments to support proactive control.*

The main issue faced when introducing new or replacement technologies into established environments is whether it will be willingly accepted by users, (Venkatesh et al., 2003) especially when the current systems (in the case of Train Graph, TRUST and CCF) are well used.

The Train Graph study was an example of how design considerations and future usage considerations can impact upon the perceived usefulness of a system. The Train Graph was an interim solution to a larger project and development was therefore limited. For this reason the tool did not fulfil the expectations of the signallers. This instant disappointment affected the attitudes towards Train Graph from that point onwards. Generally the attitudes towards the Train Graph were more positive for the new users than for the existing users. This would indicate that much of the frustrations appeared through use. Using the second development of the Technology Acceptance Model (TAM2) and Innovation Diffusion Theory (IDT) as a basis to study the tool, key issues regarding Train Graph and its use were identified. A

Technology Acceptance Model was developed from the Train Graph case study. This can be seen in Figure 60.

Although trust is not part of the existing TAM or IDT models, it was apparent from this study that the quality of the data and the operator's trust in it significantly influences their attitude towards it and in turn the uptake.

Following its first stage of development, the main reason for lack of uptake, specifically with the SSMs was lack of trust in the information provided by the Train Graph. In this instance, the information is fed to the Train Graph directly from TRUST, a system all of the users are familiar with and use daily and which users still have access to in its original form. Prior experience of TRUST, in this case, was not seen to have much influence on the level of trust users have in the Train Graph. Even though the information is the same and the same wrong information is visible on the TRUST system, the Train Graph makes this wrong information more visible to the user, so the system is not trusted. Although unreliable data may be an external issue, the impact means that the acceptance and benefit of Train Graph was reduced.

Many SSMs found the display hard to read and cluttered. The colour codings on Train Graph however, are consistent with CCF and the layout (based on time along the horizontal axis) is the standard layout of other widely used planning tools, although these are not currently used by signallers. So it is likely that this issue is secondary to the issue of mistrust arising from incorrect information.

Overall, the TRSs and TRCs interviewed found the Train Graph useful, whereas the SSMs did not. This would indicate that job relevance is an important factor when considering usage on uptake. The TRS also had no issues with the ease of use of the tool, whereas the SSMs did. This is consistent with basic tenets of the TAM which suggests that the more a user perceives the technology to be useful, the more the user believes it is easy to use (Venkatesh et al. 2003). This was also echoed in the results of the factor analysis.

The SSMs in particular mentioned CCF frequently during the interviews and used this as a primary source of information. The TRS primarily used CCF in a list format and TRUST. This would indicate that both groups are using different experiences to base their learning of the new technology on and as the Train Graph uses TRUST as its primary source of information, the TRS are using TRUST to make sense of Train Graph (Orlikowski, 2008). By the SSMs using CCF to base their learning on, they may be also using the existing mental model of this system to learn the new technology. Consistent with Zhang's (2011) theory, the Train Graph is more consistent with the TRSs existing mental models of existing systems and layout of the railway they use, so less cognitive effort is required to adapt to the Train Graph. The SSMs however have a different view; a more compact detailed view of a small section of railway. This finding also agrees with Rogers' (1995) theory, specifically compatibility. Existing ideas and values when applied to a new technology can be seen to drive adoption rate. The existing ideas of the TRS in terms of their job goals can be seen as compatible with the view of the Train Graph. The SSMs however, working on a smaller area may not see it as compatible with their existing ideas.

When introducing new technologies, Zhang and Xu (2011) argue that the users existing mental models need to be modified or restructured in order to continue to guide the user's interaction with it. If the new technology does not fit the existing mental model, it can lead to frustration for the operator and will affect uptake and adoption (d Apollonia et al., 2004).

Existing familiarity, however, has been shown to lead to increased trust with a system and also lead to an increased belief that the technology is easy to use (Gefen et al., 2003). Due to the nature of the task that the Train Graph is attempting to aid, it is thought that this element of trust may be amplified due to the safety risks involved (Neumann, 1993). If the user perceives their decision to be important, or safety critical, then trusting the information you are basing your decision on becomes more important. Similarly, in the early stages of introduction to a new technology, trust between an operator and the system will develop through assessing the consistency of recurrent behaviours (Muir, 1987). Therefore the safety critical nature of the railway could be said to change the requirement on the artefact since behaviours are mainly rules and regulations driven.

8.2.5 Recommendations

This section addresses objective 4:

> *Develop recommendations for the development, integration and acceptance of decision support tools into existing and future rail signalling systems.*

By utilising the results from the two case studies, the experiment and the review of the existing literature, a decision support tool integration framework is proposed (figure 61). The overall output is performance. This considers the artefact (or decision support tool) as an input to performance. This is also influenced by the external environment and the individual task.

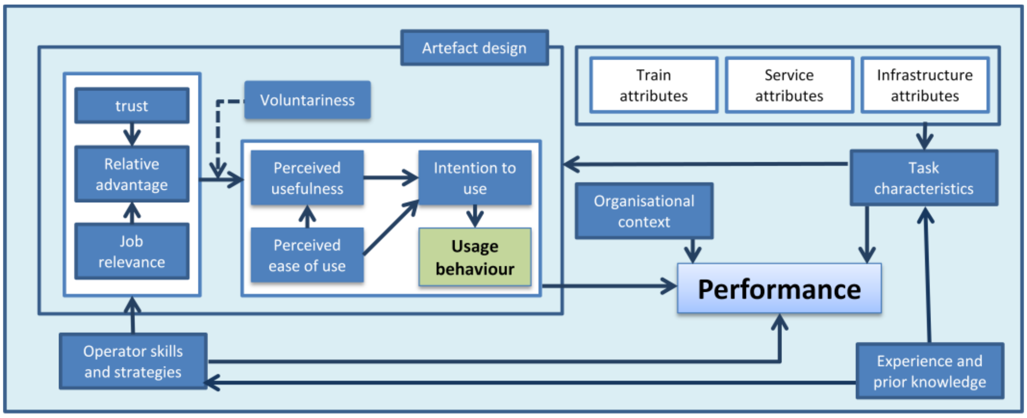


Figure 61 - proposed Decision Support Tool Integration Framework

This framework could be used by projects commencing the design of new decision support tools and use it as guidance to develop work streams. It is important to consider each of the characteristics within the framework when designing new decision support tools for rail environments and evaluate the impact they will have upon the system if they are not addressed. Utilising the Train Graph as a worked example, trust in the information that was being used to power Train Graph, plus the operator's subjective notion of whether it was relevant to their job influenced how beneficial they believed it would be to their job. In this instance the train running controllers believed it to be more advantageous to their job than the SSMs. This then influences how useful the tool is perceived to be which in turn influences usage behaviour. They also did not feel like they had to use it (voluntariness) and there was little motivation as they still had access to the existing tools. Operator skills and strategies along with task characteristics can influence this cycle. In this example, Train Graph is generally not perceived as being useful therefore it was not used. This meant that there was no impact on performance: the operators utilised the existing tools so performance was neither increased nor decreased. Task characteristics are in turn influenced by the external environment, which can influence performance. The organisational context also impacts performance, in this case the Train Graph could be used by more than one person at a time, which could have a positive or negative effect on performance.

8.3 Summary of recommendations

The recommendations for the development, integration and acceptance of decision support tools have been summarised below in terms of guidance for design, and guidance for implementation:

8.3.1 Design Guidance

This has been developed throughout the thesis by incorporating findings from literature with results from each of the studies.

- An artefact should be accurate, efficient, reliable, traceable and malleable.
- The level of automation in an artefact should not hinder the preparatory planning activities carried out by signallers: it should support them.
- When designing a new decision support tool or artefact it is important to identify how the information will be used. By using a participatory approach to design its chances of uptake and acceptance can be increased.

8.3.2 Implementation Guidance

The implementation guidance shown in table 45 should be used by design teams to help to identify the work streams that need to be carried out when designing a new decision support tool. This will ensure that the tool is used, and that the impact on performance is positive. This can be used in conjunction with the model in order to identify the impact each characteristic will have. Below is a summary of the key points.

Table 45 – Implementation Guidance

Model Characteristic	Ideal state in new tool / system
Trust	Operators will trust the information the tool provides and the information will be consistent.
Relative advantage	Users should see it as beneficial over existing tools / systems / processes
Job relevance	Users should see it as relevant to their job
Voluntariness	Users should not feel forced into using it
Operator skills and strategies	The new tool should complement and enhance existing skills and strategies
Organisational context	The tool should be usable within the environment(s) it is in and be compatible between teams if required and support the aims of each team effectively
Task Characteristics	The task characteristics should be identified and well defined
Train, service, and infrastructure attributes	These attributes should be identified and kept up to date within the system.

8.3.2.1 Trust

Trust in system can be increased by ensuring the input information is accurate. Prior knowledge and experience should also be considered at this point: operators will not trust a system that is not consistent with their existing thoughts and values.

8.3.2.2 Job relevance

It should be a key piece of work in any project to identify what information is needed when, and by whom. If the information the tool is providing is not deemed relevant to somebody's job, they will not use it, and may view it as a hindrance.

8.3.2.3 Task characteristics

Tasks should be supported by the artefact, and since tasks are influenced by many external and somewhat unpredictable characteristics the artefact should be adaptable and intuitive. It should assist the operator in task completion.

8.3.2.4 Organisational context

Organisational context should be considered when designing any decision support tool. How the information will be displayed and conveyed to third parties will need to be a key input to the design of any tool. Organisational pressures should also be considered at this point. The tool needs to support the overall aims and goals of the organisation.

8.4 Limitations of the Research

The main limitation was having to carry out data collection while operators were carrying out their jobs. This meant that extremely in depth methods such as cognitive dimensions or ethnography could not be used. However, having access to operators in their working environment meant that rich observational data could be gathered.

Another limitation of the research was not being able to repeat the experiment on trained signallers. This would have given more strength to the influence of signaller experience and knowledge when designing tools, however this was mitigated to some degree by the use of SMEs. SMEs were used throughout this research to provide input particularly about signalling operations.

An additional limitation was the involvement in the Train Graph project. Although fully immersed in this project, it was being carried out by another part of the business therefore opportunities to study and influence were more limited than one would have liked. This was mitigated by developing specific research questions that could be contributed to by a large number of signallers but also fulfilled the needs of the project.

8.5 Chapter Summary

This chapter has brought together the findings from this research focusing around the objectives set in chapter 1. Findings on cognitive artefacts in decision-making and planning were presented and an integration framework, along with key recommendations for the successful design and implementation of artefacts into railway environments, was developed. The final chapter describes the impact of the research and suggests future work.

9. CONCLUSIONS

This chapter summarises the research carried out in this thesis and the impact it has on the research area. The previous general discussion chapter brought together the research findings from case studies one and two to specifically address the thesis research aims in line with the existing literature. This chapter is intended to draw the significant themes together, make recommendations for design guidelines that result from the finding, and finally include suggestions for future work.

The research aim of this thesis was to study the skills and strategies signallers use when replanning. By carrying out a literature review it became apparent that the notion of planning specifically using artefacts in safety critical environments was not well covered. Consequently, the findings of this study have a strong impact on the field of cognitive artefacts and the influence artefacts have on decision-making, particularly in a rail environment. By studying the use of artefacts and their effect on signaller skills and strategies in a real-world environment, the potential impact of semi automated tools on decision making strategies was explored.

The focus of the research presented in this thesis was two specific case studies. The first part of case study one used observations and interviews to establish the existing planning strategies used by signallers and their interactions with different artefacts. The second part of case study one built on this to investigate the impact of semi-automated graphical tools on these strategies in comparison to existing style tools. The second case study explored the existing use and uptake of a graphical based electronic tool in order to establish what key factors affected the uptake and integration of tools into existing environments.

The study found that the artefacts available to signallers had a clear effect on the re-planning strategies used. It became clear that a key feature of any artefact used to aid decision-making should be that it is malleable and it has the ability to remember current cases, display constraints and simulate possible solutions. The graphical nature of any tool means it requires less interpretation and as a result enables operators to be more proactive rather than reactive. Being able to try out moves before committing to them was essential in creating future plans and predicting the future state of the railway.

The case study one experiment and case study two showed that by using automation to offload simple logic decisions, users were able to use their knowledge and experience to plan. It is clear that within Network Rail the future of signalling is moving towards larger regions of control and potentially less well defined specialist roles. In this scenario, it is essential that the next generation of automated and semi-automated artefacts available to the signaller are designed to take this into account.

When considering the integration of tools into existing environments, it became clear that the existing skills and strategies of the user, and their trust of the input information were key drivers in whether the operator would perceive the tool as being useful or easy to use. This in turn would drive usage behaviour. It was noticeable that the difference in usage between the graphical Docker seen in case study one and the Train Graph seen in case study two was in part due to the local development and ownership of the Docker tool and the lack of existing technology to provide the information in a similarly useful manner.

9.1 Design and Implementation Recommendations

This research examined existing signalling strategies and how they are currently supported by artefacts. By understanding the strategies and studying the existing support tools it was possible to identify the key considerations when designing and implementing decision support tools into rail environments.

A framework was developed that builds on the existing tenets of TAM that incorporates key drivers found from this research which include trust, job relevance, task characteristics and organisational context. This is summarised in Figure 61 and discussed in more detail in chapter 8. This is supplemented by specific design and implementation guidance (table 45). To help to ensure a decision support tool is accepted into an existing environment, the specified guidelines should be followed. By using these as guidance throughout a project, it will be easier for teams (often multidisciplinary and spread around the business) to identify and specify work packages to be carried out. They should be used as a basis for data collection and design. In addition, the framework can be used by members of a project team to identify the potential impact to the project if one of the constructs is not considered. For example, if when designing a new decision support tool, the question of how the tool will support prior knowledge and experience was not considered, this may impact on the individual tasks to be carried out (i.e. they will not be supported). It may also impact on the operator skills and strategies by not supporting these either. By being able to refer back to this framework throughout the project lifecycle, the potential for increased performance may be increased.

9.2 Impact of the Research

Within Network Rail, the work carried out in this thesis has been beneficial to the larger projects of the Train Graph and Traffic Management. The questionnaire data gathered for the train graph project was used to build a business case for additional research regarding traffic management systems and the impact this may have on future working arrangements. In addition, the evidence presented in this thesis regarding the benefits of electronic docking tools have been recognised by the wider business. The criteria for the electronic docking tool has been taking forward in Traffic Management and is being used to guide the design of dedicated platform docking tools within the Traffic Management system.

Furthermore, the findings from this research have implications beyond rail signalling. By suggesting the importance of preparatory planning activities when considering artefact design, this has an impact on how information is gathered and utilised when designing decision support tools. In contrast to work by O'Hara and Payne (1998) this research suggests that although increased mental effort can increase the knowledge and understanding of the task, when coupled with existing experience and knowledge while performing safety critical tasks this may become less important. The results of the docking experiment revealed that the list users understood the task more thoroughly than the electronic users, but by computationally offloading some of the simpler tasks (such as simple error identification), the operator is able to concentrate on utilising their skills, knowledge and experience to interpret the information they have access to and implement a plan.

The extensions made to TAM appropriate to the railway setting of the case studies used in this research can be applied to more general cases. The importance of experience and trust in the artefact was critical, particularly due to the safety critical nature of the signalling decisions, and the additions made to the framework shown in figure 61 is appropriate to other safety critical industries where user experience and expertise is high.

9.3 Future work

This research has demonstrated how decision support tools can be designed to be used in signalling environments. However, moving forward to traffic management the influence of different roles should be considered. Traffic management is being designed to be an adaptive system that can enable operators to manage large areas, split tasks and divide areas during disruption. The model proposed from this research suggests that job relevance and organisational context have a large influence on performance and usage behaviour. Operator skill and strategies also play a large part in this. Experimental work should be carried out to explore how decision support tools can be made adaptable enough to support different skills and strategies during disruption and what impact this will have upon artefact design and usage behaviour.

In addition to this, the impact of prior knowledge and experience in making decisions was explored in this thesis, but with regards to the docking experiment this was not explored fully due to not being tested on trained operators. Going forward into traffic management, operators will be expected to manage larger areas and may not have the level of local knowledge operators have today. This needs to be supported by the system somehow while not impacting on workload or task performance, and how this can be done effectively is not yet known.

Another direction for this research to be taken in would be to consider the impact decision support tools could have on signaller selection and training. It may be possible to utilise a tool such as the electronic Docker to explore the decision-making and problem-solving abilities of potential operators. The ability to think through problems effectively and develop efficient solutions will be an essential skill in the future, proactive way of running the railway. The experiment has already proven that the concepts can be learned very quickly, and that some participants were able to develop more efficient plans than others. By using the tool to look for individual differences in potential signallers, and by managing the learning effects through the selection process, a robust set of selection criteria could be built.

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APPENDIX A

Data gathering sheet used at the stations during case study one. The table below contains the data for stations A and B.

	a	b
Terminus Platforms	14	9 (3, 4, 12 - 18)
Through Platforms	0	9 (1, 2, 7 - 11, 19, 20)
Platform restrictions	Yes Different length platforms accommodating differing numbers of certain stock types	Yes Different length platforms accommodating differing numbers of certain stock types
Controlled by	VDU at WSCC	VDU at
ARS	No	Yes - often disabled in the station area due to number of stock changes
Docker Tool	Yes Graphical version detailing: - origin - time from origin - destination - arrival headcode - departure headcode - diagram number The graph itself shows arrival and departure time and whether the train is full or empty	Yes Graphical version detailing: - arrival headcode - departure headcode - diagram number The graph shows arrival and departure time, the direction of travel into and out of the platform and through platform restrictions (ie if a platform has to be kept clear so a train can arrive or depart another one). For any other information the SSM refers to the other "Docker" (list version detailing all trains and platform allocations).
Reactionary delays?	Not so many The SSM keeps an eye on the service (CCF). Any late running trains are identified and knock on effects dealt with where possible. However, if the SSM is dealing with other	Not so many The Docker tool allows the SSM to manage the station area and keep delays to a minimum. However, the complexity of the station and the wide variety of stock means that it is often difficult to re-dock trains with

	issues within his area of control then delays can occur. These are then managed when the SSM becomes available again.	little notice.
Signallers	1 managing actual station area and 1 handling throat. Plans to split station into top and bottom section	1
TOCs	5 East Coast Virgin Cross Country Trains First Transpennine First Scotrail	5 East Coast Virgin Cross Country Trains First Transpennine First Scotrail
Type of stock	Diesel and electric	Diesel and Electric
Platform Changes	50	40
Stock changes	Yes	Yes
How are stock changes handled?	Receive verbal request from TOC via telephone. SSM then lets TOC know whether change is possible. If the TOC does not give specific swap instructions (ie which train to use as a replacement) the SSM will make suggestions. If change incurrs knock on effects or incurrs delays, SSM will let TOC know and get agreement before making any changes. Sometimes 'stepping up' of sets may be required due to a failure or unexpected maintenance. In most cases the TOC will give instruction, but they may ask the SSMs advice. He would then advise accordingly. Ideally the SSM will keep the outward service to the booked	Receive planned changes daily in the form of a print out. The SSM plans these changes well in advance and tries to give the signaller at least an hours notice of these changes. More 'ad-hoc' changes via verbal request from TOC via telephone. SSM will log the request, then look at the chart to find a way to make it. The chart isn't as straight forward as the one at Glasgow as there are bi-di lines with through platforms, meaning trains entering and exiting certain platforms may block other ones. The stock changes are usually specified directly by the TOC, but the TOC will sometimes seek the advice of the SSM if they are unsure. The SSM then informs the signaller of any changes.

	platform, but this isn't always possible. The SSM's experience allows him to know instantly from looking at the diagram number, which trains are compatible. Trains will continue to be stepped up until the original train is declared fit for service or a replacement is brought in.	
How are knock on effects handled?	The Docker allows the SSM to spot most knock on effects resulting from any changes (such as cancellations, platform closures etc) and plan around them.	The SSM uses the Docker to assist in re-platforming trains due to knock on effects from incidents. Any changes take a fairly long time to work out due to the complexity of the station area. Sometimes it is easier to call the TOC and get them to accept a delay if it's as a result of their failure.
How are conflicts handled?	SSM looks for conflicts with any changes requested and informs the TOCs. SSM will then look for solutions and get agreement from the TOC	SSM will let the TOC know of any conflict visible. TOC will then call back with a solution
How are platform changes handled?	The SSM uses the Docker to identify any possible gaps. He uses his existing knowledge, CCF and maybe references the train length reckoner (a table stuck to the desk detailing platform lengths and differing stock lengths) to establish where a train can be moved to. If now option is immediately available - ie at peak time of if re-platforming a particularly long train, it may be possible to move some shorter trains, and even double dock certain ones, in order to re-dock a train.	The SSM uses the graphical Docker and the list Docker to identify and available gaps. These are then noted on a separate piece of paper. These are then filed for delay attribution purposes

Late running trains	SSM keeps an eye on CCF to identify any late running trains. He then checks the Docker for potential problems - ie if late train impacts on other services. In some cases the TOC may cancel a service, join 2 services or step up services to compenstae for the late running train. The TOC will consult with the SSM and they will usually come up with a plan together	If there is a late running train the SSM checks the graph to see how this will impact on other services. If the impact can be minimised by re-docking services then the SSM will do so. If it requires 'stepping up services' the SSM will contact the TOC who will instruct accordingly. Any possible conflicts are checked with the TOC prior to making the change.
Infrastructure failures - station area	If for instance a track circuit has failed in the platform area or a platform becomes unusable, The SSM is notified of any issues and then uses the Docker to plan around it. They will liase closely with the TOC and the station staff about any changes.	The SSM is informed of any station / platform failures by the station staff. Services are then altered accordingly. If only platform swaps are required, SSM will arrange and inform station staff of alterations. If more serious, for example a train is 'trapped' in a platform, the TOC will be notified, They will then make a decision on whether to cancel a service, replace a service or step up services.
Infrastructure failures - outside station area	A points or signal failure outside the station area could inpact on platform usability by limiting route in and out of the platforms. Again, the SSM would use TRUST and the Docker to plan around these issues	Depending on where the failure is, it could impact heaviliy on the usability of the platforms due to the layout, bi di lines and through platforms. Again, the SSM will use the graph to make any easy swaps and consult the TOC if the failure could impact more heavily on services.
How are station staff informed of changes?	SSM speaks directly to station staff	

Any existing issues?	Sets are often "left lying in" platforms in the morning, following overnight maintenance etc. This can cause problems fpr some of the first sets running into those platforms in the morning. VSTP trains are often instructed via control with no clear idea of when the train is going to arrive. NR control can often say how long the train is likely to be in the station so the SSM can start to plan accordingly. He will then keep an eye on the train using CCF and develop a firm plan to dock it. This may involve re-docking other trains.	Any extra trains or alterations are decided by the TOC and faxed through to the box. During special events such as Rugby at Murrayfield, a whole new list Docker is issued (so many changes that easier to do that than issue the changes alone). In these situations it is not possible to re-draw the graphical Docker so making any last minute changes to plan on these days "is not possible without the graph" so delays often occur. Mistakes are also often made - trains have in the past been signalled into platforms that are already occupied

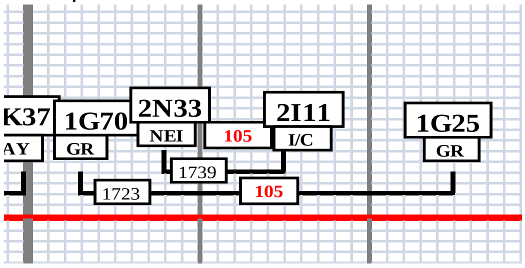
Appendix B

Basic function of re-docking a train using the graphical Docker.

Late running train

SSM will use TRUST to identify any late running trains. He will then establish whether or not this will impact on any other trains due to dock in that platform.

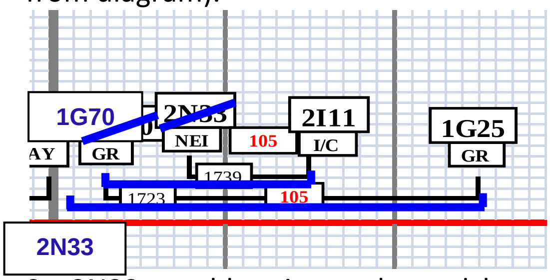
Example:



If 1G70 was running late the DSM would have to make a decision. As there are only 5 minutes between the planned arrival of 1G70 and the arrival of 2N33, the DSM would first establish how late it was running. This is done using TRUST. If a minute or two, DSM would most likely leave things as they were, especially if it was during peak running, due to lack of available platforms.

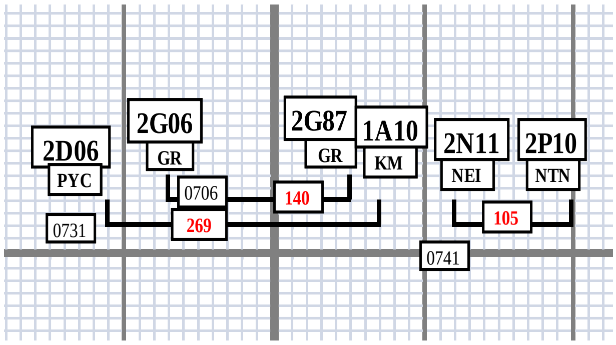
If it was running later, the DSM would try and move 2N33 in anticipation. This would be preferable to moving 1G70 as it is only in the platform for 7 minutes, compared to 22, so more likely to be able to find a platform. Also it arrives later, so there is more opportunity for the DSM to inform the signallers of any platform changes. In order to do this, the DSM would use the train diagram number to ascertain what type of train it was, how long it was etc and then use the ready checker (small piece of paper stuck to the desk that indicates the length of the platforms, and how many carriages of a certain train type can fit on each – most DSM's know this information) to establish if the train will fit.

Likewise if 2N33 was running early for some reason, (for instance if it was coming from the depot) and was going to arrive before 1G70, the DSM could decide (with consultation with the TOC) to perform a simple stock swap. This would only be done if there were no spare platforms, and would only be possible if the 2 trains were the same (both 105 in this instance – information from diagram).



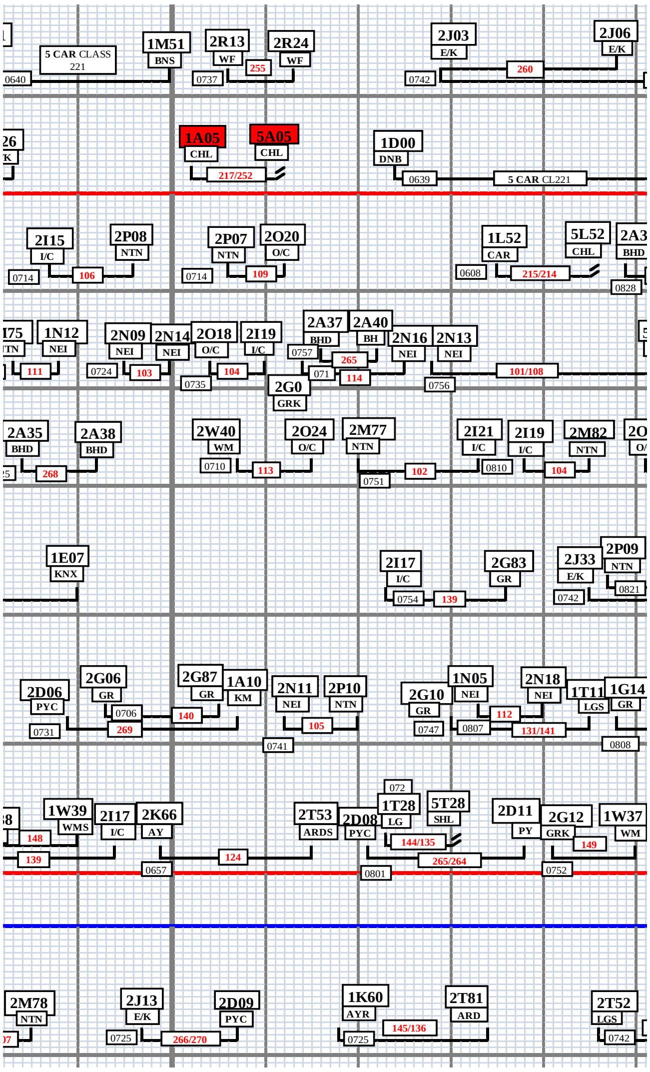
So 2N33 would arrive early, and leave as 1G25 instead of 2I11, and 1G70 would arrive in its timetabled slot, but leave earlier as 2I11 instead of 1G25. This is not an ideal solution, as it then involves all staff swapping trains. It could also interfere with any planned maintenance for either train.

Late running train – departing



For example, if 2G87 failed in the station or had a driver missing or some other issue that meant it couldn't depart, it would impact on the departure of 1A10. Depending on the fault, it could also impact on the arrival of 2N11. In this instance, the DSM would keep in very close contact with the TOC.

The Toc would either suggest a plan of action or ask for the DSM's advice. One of the first things the DSM would like to establish is how long the train is likely to be blocking the platform. This will then aid in planning and decision making. If no time estimate is available, the DSM assumes that the train will be



blocking the platform for a considerable period. The TOC may suggest certain set swaps or step ups, but may leave a reasonable amount of decision making to the DSM. One of the first things that would need to be done in the example above would be to re dock 2N11 in anticipation. This clears the platform and gives the DSM more time to play with. The next thing is to find a replacement for 2G87 and 1A10. This may involve using a train that was due to depart later to replace them.

For example;

2G87 would be replaced by 2D09

1A10 would be replaced by 2T53

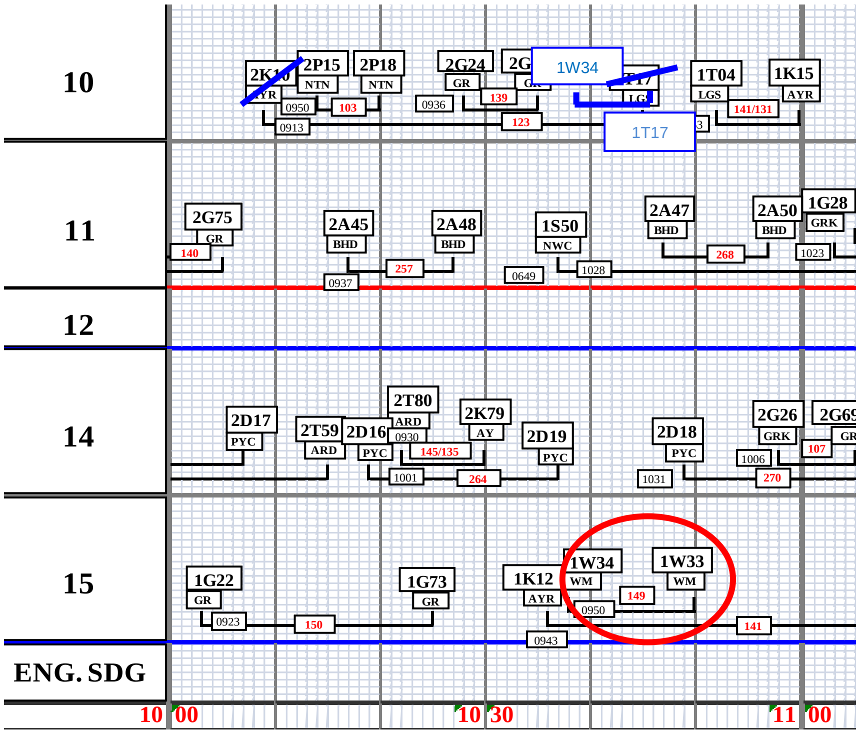
2D09 would be replaced by 2R24

2T53 would be replaced by 2P10

2R24 would be replaced by 2O24

This would continue until a replacement train was brought in, the trains became useable again or a train that was due to run out empty could be used. All of these moves involve heavy demands on train and station staff, so the fewer moves the better. The TOC would have to OK all step ups, and the comms centre would need to be kept informed of any changes, as would station staff. The DSM very rarely interacts directly with train drivers.

Cancelled train



1T17 was cancelled. Control instructed DSM to make 1T17 out of 1W34, and then empty stock would be bought in to make 1W33. The easiest thing in this instance was to put 1W34 where the cancelled train should have been – platform 10. The DSM lets the TOC know and also the comms centre, who informs the station. An issue then arises with the empty stock arriving to make 1W33. The DSM has to keep close contact with the TOC, as the original stock making 1W33 was due to dock on top of another service. The easiest option would be to put this train into the same platform, but it will depend a lot on when the empty stock will arrive. Often it is up to the DSM to keep an eye on this using TRUST, and acquired knowledge that trains take a certain amount of time to reach the station from certain points on the track to aid decision making. If the spare stock was going to arrive before 1K12, then it would be necessary to put this stock in a different platform. If this was not possible, the DSM could choose to hold the empty train at a signal if possible in order to allow 1K12 to arrive first as planned. This would involve close contact with the signallers.

APPENDIX C

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Managing Station Areas

Scenario 10:

- Train 1S39 due in platform 5 at 11:16 is now a 6 car train. Train 2R03 due in platform 4 at 11:35 cannot access platform 4 due to a signalling failure.

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Managing Station Areas

Scenario 9:

- Platform 15 needs to be closed for some planned maintenance. No trains will be able to use this platform between 10:39 and 10:47am. You are being given this information at 8am.

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Managing Station Areas

Scenario 8:

- Train 2K18, due to arrive in platform 10 at 12:07, will now be arriving at the station at 12pm

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Scenario 7:

- Train 1G28 due to arrive in platform 11 at 11:03 is running 6 minutes late

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Scenario 6:

- Platform 8 will be out of use from 11:50 until 12:50. All trains in platform 8 between these times must be moved. The station manager has indicated that he would like to put the trains in platform 7 instead.

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Scenario 5:

- Train 1K16 arriving in platform 10 at 11:36 will now not be departing until 12:33

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Scenario 4:

- Train 2O26, due to arrive in platform 8 at 10:20 can no longer use that platform as the train before it is running late. Due to this train being a diesel train, it can only use platforms 7 and 8.

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Scenario 3:

- Train 1A13, due to arrive in platform 9 at 10:05 is running late, and will not arrive until 10:16. As a result, it has missed its clear route into the platform and can no longer get into platform 9. It is currently 10:04 and all of the passengers are already on platform 9. As the train will only be in the station for 2 minutes you need to ensure that all of the passengers can board the train on the new platform in this short space of time.

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Managing Station Areas

Scenario 2:

- There has been a mix up with the catering contractor and all of the supplies for train 1Y77, due to arrive in platform 3 at 10:59 have been delivered to platform 6 instead and no-one is available to move them. These supplies must go on 1Y77

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Scenario 1:

- Train 2N25 due to arrive in platform 6 at 10:29 is now a 6 car instead of a 3 car train.

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Managing Station Areas

Examples:

- 1Y75 due to arrive in platform 3 at 10:09 can no longer enter due to points problems. Put this train in another platform.
- Answer:

  Put in platform 4
- Train 2Y67, due to arrive in platform 1 at 10:55 can no longer use that platform as the previous train has failed in the station. The passengers have already been instructed to go to platform 1 and are waiting there for their train. Put the train in another platform.
- Answer:

  Put in platform 2

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Managing Station Areas

The task:

- You will be given a series of scenarios. Each one is independent. You must solve the problems posed by the scenario as quickly as possible
- You may draw, scribble and doodle on your paper if you wish
- You will have a copy of the platform allocations, train types and rules for you to look at whenever you wish
- When you have solved the scenario, write down your solution in the answer box and fill in the short questionnaire
- Wait for the next scenario

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Managing Station Areas

List tool:

Platform	Train number on arrival	Arrival time	Train Type	Departure time	Train number on departure
15	1G22	10:03	L	10:25	1G73
~~8~~ 4	2R21	10:04	L	10:16	2R08
9	1A13	10:05	S	10:18	2J30
3	1Y75	10:09	S	10:14	2Y52
10	2K10	10:09	L	10:45	1T17
10	2P15	10:14	L	10:20	2P18
11	2A45	10:17	S	10:27	2A48
14	2D16	10:19	S	10:37	2D19
8	2O26	10:20	S	10:45	2M90
14	2T80	10:22	L	10:30	2K79
1	5M11	10:23	V	10:40	1M11

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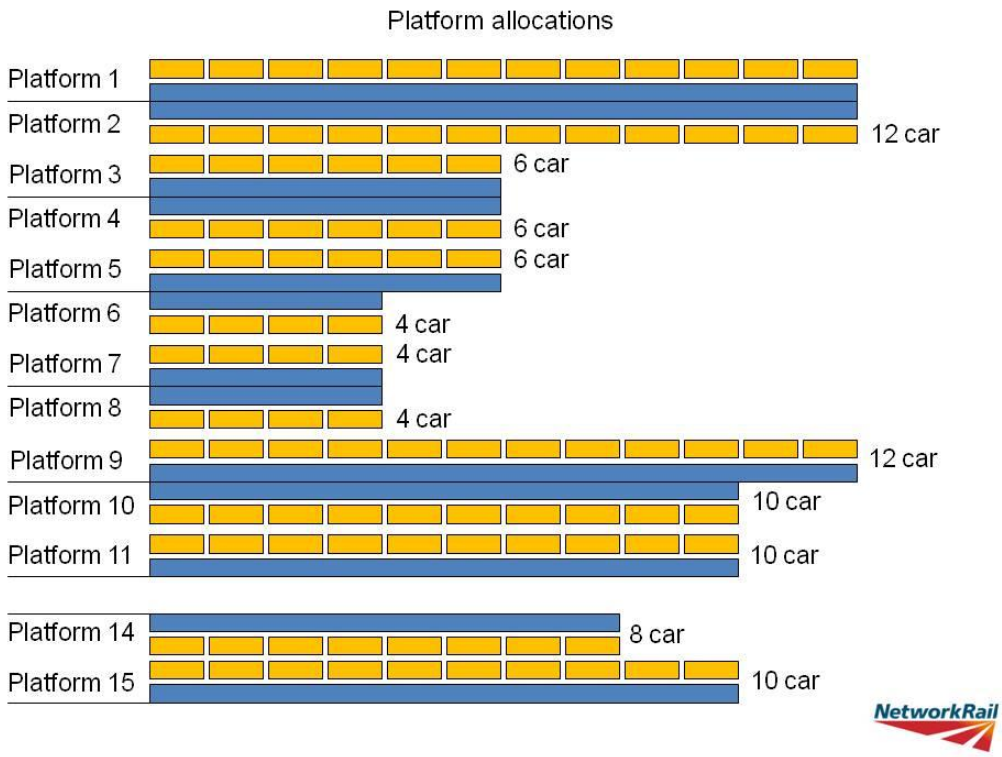
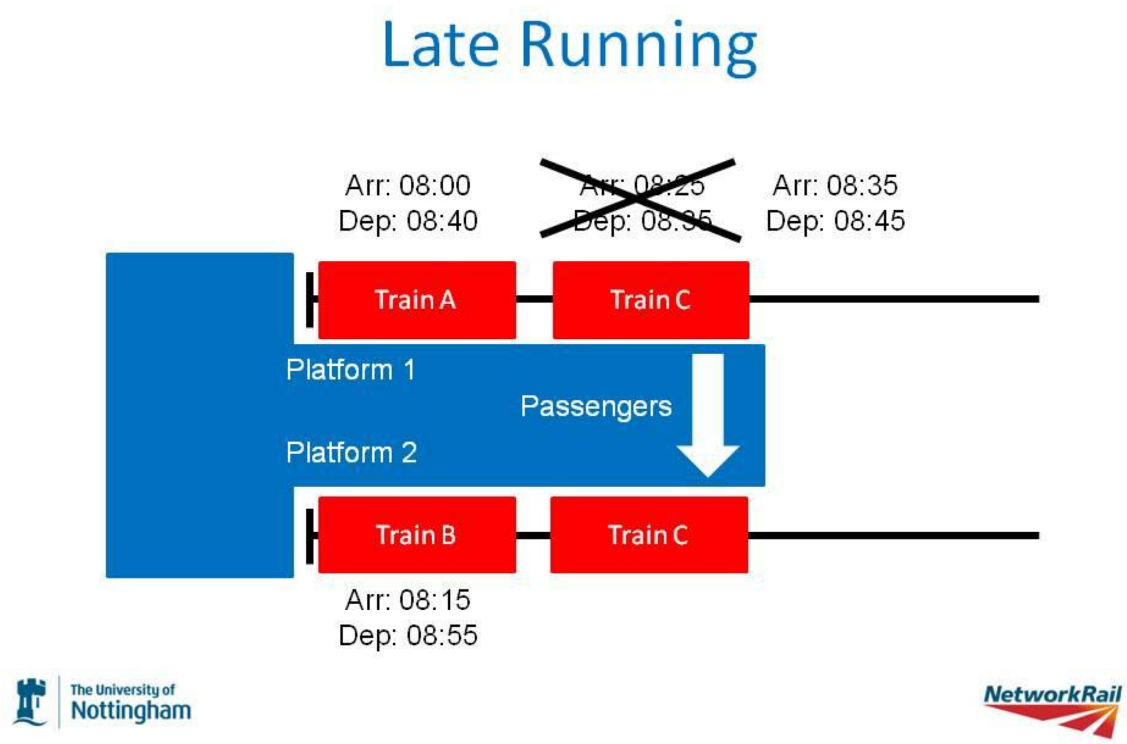


Managing Station Areas



Your Rules:

- Keep delays to a minimum
- All carriages must fit on the platform
- Try to keep the train as close to the original platform as possible
- You may stack trains up to 3 deep if they will fit and not block the exit for other trains
- You must leave at least 2 minutes clear either side of a train
- Platform 12 is currently out of use

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Managing Station Areas

Strategies

- If trains are running late, you may need to put the train into another platform to stop it from delaying others
- If there are no gaps, you can put the train behind another one – make sure it leaves first though and they will all fit
- You may need to move more than one train to accommodate it
- You may not always have to move the affected trains

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Disruption

- Staff shortages
- Infrastructure failures / repairs
  - Planned and unplanned
- Stock swaps
  - Maintenance
  - Shortages elsewhere
- Late running
  - Entering or exiting the station

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Managing Station Areas

Your Aim:

To keep the station running to plan – trains should arrive and depart, on time, from their booked platforms.

When disruption occurs, ensure that movements return to the planned timetable as quickly as possible, keeping delays and further disruption to a minimum.

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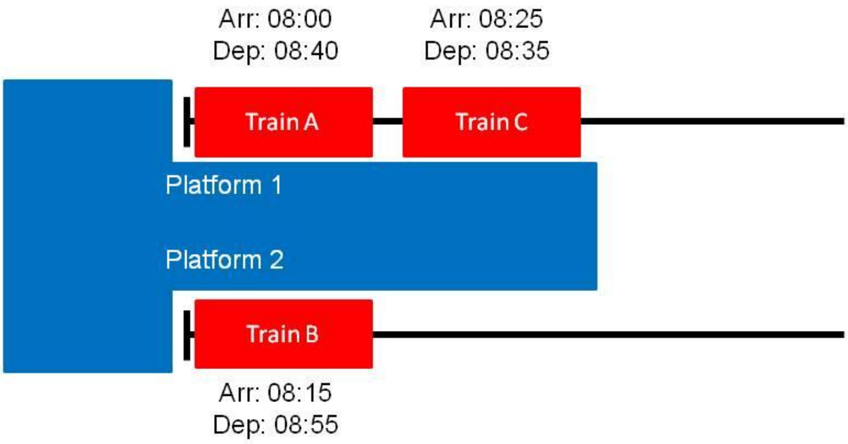
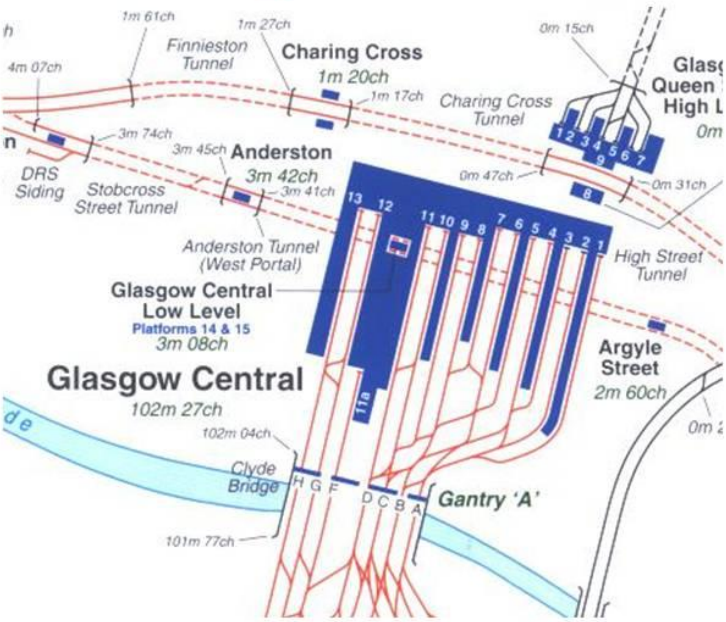
Managing Station Areas

Trains in platform



Current artefacts

Glasgow Station



Your Job:

For the next 45 minutes you will be managing Glasgow Central: the busiest mainline railway station outside London.

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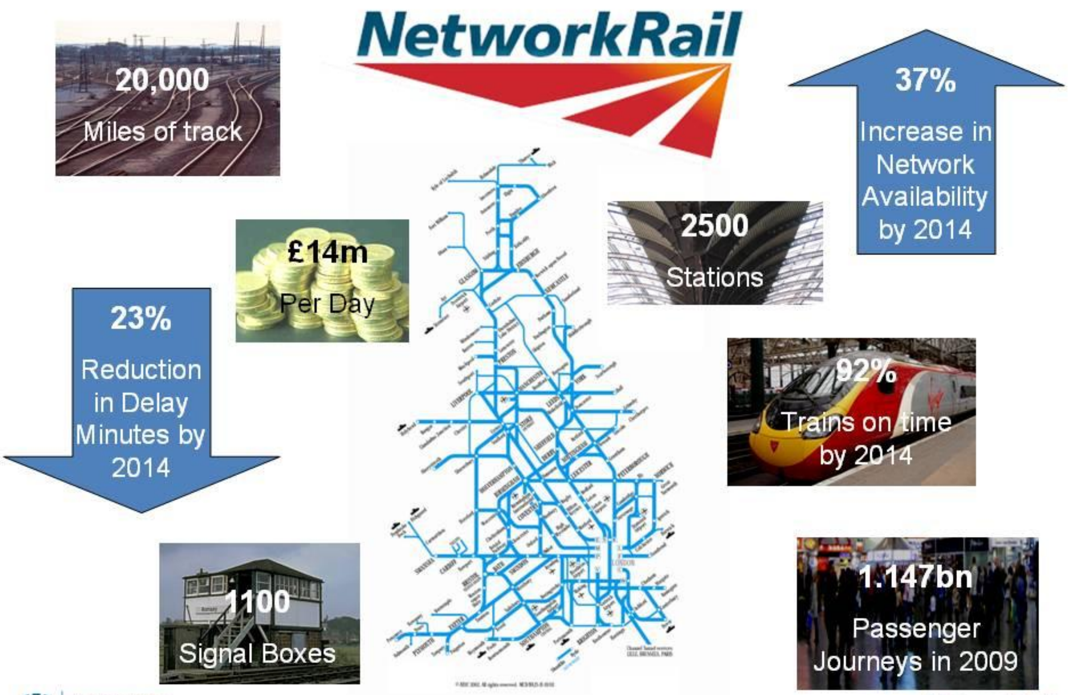
Introduction



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NetworkRail

Become a railway signaller

Rebecca Anderson-Palmer

The University of Nottingham

NetworkRail

APPENDIX D

Uptake

- How long has the Train Graph been live?
- Is it being used?
  - If not why not?

Use

- Who uses it?
- What is it being used for?
- How often?

Benefits

- Are there any benefits of using the Train Graph over other aids already in use?

Communication

- Have communication routes changed within the box?
- Has communication changed in / out of the box?

Information

- What information does Train Graph provide you with that you can't get from elsewhere?
- How is this information used?

Interface

- Is it easy to use / read?

Software

- Do you have any issues with the functionality of the graph?
- Any issues with the software?

APPENDIX E

The Following Questionnaire will take no longer than 10 minutes to complete.

1	How long have you worked in the railway industry? ....
2	What is your current job role? (SSM / TRS / TRC) ....
3	How long have you worked in your current role? (As SSM or TRS or TRC) ....

For the following questions a 7 point scale is used.
Please circle the number that most closely describes your opinion.

Q **Example: I enjoy watching television**

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

4 Using Train Graph will enable me to accomplish tasks more quickly

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

5 The information the Train Graph provides is of good quality

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

6 Train Graph will provide more information than existing systems

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

7 Using Train Graph will improve the quality of work I do

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree

	1	2	3	4	5	6	7
8	I trust the information the Train Graph provides						
	Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
	1	2	3	4	5	6	7
9	Using Train Graph will improve my job performance						
	Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
	1	2	3	4	5	6	7
10	Train Graph is clear and understandable						
	Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
	1	2	3	4	5	6	7
11	Train Graph will be useful in my job						
	Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
	1	2	3	4	5	6	7
12	The information Train Graph provides will be more useful than existing systems						
	Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
	1	2	3	4	5	6	7
13	Train Graph will be advantageous to my job						
	Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
	1	2	3	4	5	6	7
14	Interacting with the Train Graph will not require a lot of mental effort						
	Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree

1	2	3	4	5	6	7

15 I would have difficulty explaining why using Train Graph may be beneficial

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

16 Learning to operate Train Graph was easy for me

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

17 My use of Train Graph will be voluntary

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

18 I find it easy to get the Train Graph to do what I want it to do

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

19 I find Train Graph easy to use

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

20 In my job, using Train Graph will be relevant

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

21 I intend to use Train Graph for the next 6 months

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

22 In my job, using Train Graph is important

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

23 I trust the data that is used to produce the Train Graph

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

24 What do you think you will use the Train Graph for?

25 Do you have any concerns about the Train Graph? If so, what?

Thank you for taking the time to complete this questionnaire. Should you need further assistance, contact Rebecca Anderson-Palmer: epxra4@nottingham.ac.uk

The Following Questionnaire will take no longer than 10 minutes to complete.

1	How long have you worked in the railway industry? ....
2	What is your current job role? (SSM / TRS / TRC) ....
3	How long have you worked in your current role? (As SSM or TRS or TRC) ....
4	How long has Train Graph been installed on your workstation? ....

For the following questions a 7 point scale is used.
Please circle the number that most closely describes your opinion.

Q **Example: I enjoy watching television**

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

5 Using Train Graph enables me to accomplish tasks more quickly

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

6 The information the Train Graph provides is of good quality

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

7 Train Graph provides more information than existing systems

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

8 Using Train Graph improves the quality of work I do

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree

1	2	3	4	5	6	7

9 I trust the information the Train Graph provides

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

10 Using Train Graph improves my job performance

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

11 Train Graph is clear and understandable

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

12 I find Train Graph to be useful in my job

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

13 The information Train Graph provides is more useful than existing systems

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

14 Overall, I find Train Graph to be advantageous to my job

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

15 Interacting with the Train Graph does not require a lot of mental effort

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree

1	2	3	4	5	6	7

16 I would have difficulty explaining why using Train Graph may be beneficial

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

17 Learning to operate Train Graph is easy for me

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
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21 In my job, using Train Graph is relevant

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

22 I intend to continue using Train Graph for the next 6 months

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

23 In my job, using Train Graph is important

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

24 I trust the data that is used to produce the Train Graph

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly Agree
1	2	3	4	5	6	7

25 What do you use the Train Graph for?

26 Do you have any concerns about the Train Graph? If so, what?

Thank you for taking the time to complete this questionnaire. Should you need further assistance, contact Rebecca Anderson-Palmer: epxra4@nottingham.ac.uk