Resilience in the planning of rail engineering work

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Abstract

The railway industry is today broadly recognised as a complex sociotechnical system that operates under considerable pressures for increased capacity and reliability. These pressures impact across the industry, in particular on rail engineering because of its responsibility in providing and maintaining the rail infrastructure. Within rail engineering, there is a growing need to address safety and operational risks emerging from high complexity.

Planning has been identified as a fundamental organisational function for the safety and efficiency of engineering work. Within this scope, this thesis recognises in the planning of rail engineering work the characteristics of complex sociotechnical systems and investigates planning activities as a part of a wider rail engineering system.

Resilience engineering has been recently proposed as a safety management approach that focuses on the development of means for better coping with the variability and uncertainty inherent to large scale complex sociotechnical system. The research documented in this thesis proposes the use of a resilience engineering based approach as a way to improve the ability of the rail engineering planning system to successfully contribute to the safety and efficiency of engineering work.

Overall, the purpose of this research was to describe and understand human and organisational factors of rail engineering planning, understand planning performance in view of the support it provides to work delivery, and investigate improvement to the planning system based on resilience engineering concepts. A contribution to the development of resilience engineering as a discipline was also made, mainly through the investigation of possible methods for measuring and monitoring system resilience.

The thesis has taken a research approach with emphasis on extensive top-down and cross-organisational exploratory work of the engineering work planning process. This was achieved through the use of quantitative and qualitative methods, namely the analysis of archival data on operational and safety performance, interviews, observations, and a questionnaire. The integration of the researcher within Network Rail's Ergonomics National

Specialist Team (NST) was fundamental for the access to a wide range of data and for the employment of a participant observation approach.

The engineering work planning system is described as a complex decision making process, ranging from high level strategic business decisions down to the definition and scheduling of work delivery details. The main human and organisational factors that either hindered or facilitated planning decision making were identified and archival data were used to study planning performance. Results from these research steps were then used to support the understanding and measurement of resilience in planning. Data were interpreted in view of the resilience literature and used as basis for the investigation of potential measurement tools and system interactions with relevance for the understanding of resilience as an emergent system property.

The methods used permitted a detailed description of the planning process and the identification of planning performance features within the wider frame of the rail engineering system. Human, organisational and system level factors were identified, which contributed to the understanding of planning and the identification of constraints and facilitating factors on decision making processes. Throughout the duration of this project, contributions to the development of resilience engineering and its methods were made, whilst identifying sources of resilience in the planning system and contributing to the development of measurement tools by means of a questionnaire approach. The understanding of resilience in rail engineering planning was used as a support for recommendations towards the improvement of the planning function’s ability to cope with operational pressures and successfully support work delivery.

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Glossary of terms

Annual Integrated Work Plan (AIWP)	List of all the engineering work foreseen for delivery nationally and within a timetable year.
Annual tonnage	Estimate of the volume of train traffic operating over a given section of track.
Area Delivery Planning Unit (ADPU)	Unit responsible for managing the planning of engineering work within the geographical domain of a given area.
Confirmed Period Possession Plan (CPPP)	Document which contains all the engineering work which has been confirmed for delivery within a given period of the timetable year.
Continuous welded rail	Rail that is welded together end-to-end.
Controller of Site Safety (COSS)	Person responsible for setting up safe system of work and ensuring the safety of those working on or near the line.
Engineering access	Defines the presence of every equipment and persons on track or within its premises for the purpose of carrying out engineering work.
Engineering possession of the line	Designation of the protection arrangements that are put in place for engineering access, which include the transfer of control of the line from the signaller to the PICOP.
Engineering Supervisor (ES)	Person responsible for setting up and controlling all the work activities within an engineering worksite
Engineering worksite	Designation of the protection arrangements that maintain a safety distance between independent pieces of work within a given possession.
Equated Track Mile	Concept which supports the estimate of the work necessary to maintain a given section of track by factoring in a number of characteristics of the track equipments within that section.
Ergonomics National Specialist Team	Team within Network Rail which provides human factors and ergonomics support across all company functions and at national level.
Infrastructure Investments	Function within Network Rail responsible for the development of investment plans and for its submission to the planning process.

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Infrastructure Maintenance	Function within Network Rail responsible for the supervision and delivery of engineering work necessary to maintain rail equipments in operational conditions and in compliance with safety standards.
Jointed track	Track which instead of welded together, is mechanically jointed end-to-end.
Maintenance delivery Unit (MDU)	Units that are responsible for managing and delivering the required maintenance work within a given section of track.
National control logs	Daily records produced by Network Rail control centres, reporting all occurrences that affect the infrastructure or operations.
National delivery services (NDS)	Function within Network Rail responsible for managing all resources necessary for the delivery of engineering work, including the planning process.
Network Access Unit (NAU)	Oversees agreements between train operators (TOCs) and Network Rail regarding the rights to access the rail infrastructure, either for running trains in the case of operators, or for engineering work in the case of Network Rail.
Operations control	All operational aspects that relate to the monitoring and management of the railways. Network Rail controls railway operations by means of control centres distributed throughout the country.
Overhead Line Equipment (OLE)	Catenary and other related equipments for electric propulsion of trains.
Person in Charge of Possession (PICOP)	Person who receives control of the line from the signaller and takes possession of the line for the purpose of carrying out engineering work.
Railway infrastructure	Designation used to refer to all equipments which support train operations, such as tracks, points and crossovers, signals, stations, among others.
Railway points	Track equipment (asset) which allows trains to converge, diverge or cross over from one rail route to another. These are often designated under the generic term of Switches & Crossings.
Rules of the Route (RotR)	Documents issued by NAU on behalf of route directors, which formalise the agreements between Network Rail and TOCs in terms of access to the infrastructure.
Signaller	Person responsible for the management of rail traffic (signalling trains).
Territory Delivery Planning Unit (TDPU)	Unit responsible for managing the planning of engineering work within the geographical domain of a given territory.
Train Operating Companies (TOCs)	Term used to refer to companies responsible for running trains. The designation FOC (Freight Operating Company) may be used to refer to companies dedicated to freight traffic on the rail network.
Weekly Operating Notice (WON)	Document issued every week and for each route, containing all details of operating conditions for each section of track, including engineering access, speed restrictions, among others.

1. Introduction

The UK rail industry is experiencing an unprecedented level of growth and development. Demands for more and more reliable train services within the limited capacity of the rail infrastructure place the industry under considerable government and public pressure. As the owner of the rail infrastructure, Network Rail is challenged to carry out the engineering work necessary to achieve the envisaged capacity increments, whilst reducing disturbances to train services. Within this context, **rail engineering is considered a critical element for the efficiency, reliability and safety of the railway as a whole**.

1.1. Background

As pointed out by Wilson *et al* (2007a), there are many engineering problems at the core of the railway system, with various degrees of difficulty and complexity. Achieving the current targets of modernisation and capacity enhancement requires a high standard of engineering work. Beyond advanced technology-based rail engineering capacities, this also demands efficient and safe conditions to access the rail infrastructure, protect the infrastructure, people and equipment on it, and deliver the necessary work. Not only must the protection of people working on the railways be guaranteed, but also the allocation and utilisation of engineering resources must be efficient, which inevitably, requires some form of planning. It is thought that many of the risks, failures and general issues regarding the performance and safety of rail engineering work can be more or less directly traced back to planning problems (Wilson *et al* (2009), Schock 2010 and Schock *et al* 2010). **Understanding the planning process is therefore, an essential step in addressing the current demands for high efficiency, reliability and safety**.

Wilson *et al* (2009) identify the railway as a classical example of a complex system in which performance conditions are often underspecified and demand constant adjustments to unexpected events and varying operating environments. Within such conditions, Hale *et al* (1998) observe that most current safety analysis and investigation methods and processes may be unsuitable, as they are grounded in predominantly static and well known organisational environments. Investigations into recent accidents such as the Columbia shuttle (Woods, 2003) or within the railway domain, Clapham Junction (Hidden, 1989) and Ladbroke Grove (HSE, 2000), reveal at their origin complex combinations of organisational factors that are beyond the scope of purely technical or human failures. Within this frame, **research on safety and efficiency in the planning of rail engineering work needs to recognise the challenges of high complexity in sociotechnical systems**.

While identifying complexity in the context of rail engineering and its challenges, Wilson *et al* (2009) propose resilience engineering as a potentially relevant approach towards coping with new emerging risks and high production pressures. In line with the same viewpoint, **the research of this thesis hypothesises that the adoption of resilience principles constitutes a potentially valuable approach to ensure that planning successfully contributes to the safety and efficiency of engineering work**. As later discussed and for the purpose of this research, resilience is generally regarded as the ability to safely cope with high performance pressures, such as those emerging from the demands for a modern and enhanced railway (Woods & Hollnagel, 2006).

1.2. Aim and objectives

Railway research, particularly in the field of human factors and ergonomics, has known considerable development in recent years (Wilson & Norris, 2005). Wilson *et al* (2007a) illustrate the progress of human factors research and systems ergonomics approaches in the area of rail engineering. Research on planning and scheduling activities has known considerable growth in recent years. Within the domain of human factors, a considerable number of studies have been dedicated to control, planning and scheduling in various manufacturing industrial contexts (McCarthy & Wilson, 2001a). In terms of the planning of engineering activities, aircraft maintenance is likely to be the most extensively researched field (Kinnison, 2004). Within the rail industry, despite the work described by Wilson *et al* (2009) and Schock (2010), the domain of engineering planning remains relatively unexplored.

Within the field of resilience, Hale & Heijer (2006b) provide a broad discussion of concepts in the scope of the railway as whole, but so far, research in resilience engineering has mainly favoured other complex and high risk industries such as air transportation, nuclear power production and health care. McDonald (2006) refers to studies developed on aircraft maintenance in which several aspects related to high complexity and production pressures have been addressed. Despite the growing interest manifested by different scientific domains (i.e. engineering, ecology, sociology psychology and economics), robust methods of measurement and monitoring resilience are still in the early stages of development (see section 3.4).

The overall aim of this thesis is to **understand and recommend improvements in the rail engineering planning process**. To do this, the planning system was examined and analysed within both a systems ergonomics and a resilience engineering perspective, aiming to extend methods and use of resilience as a field of study. The consequent research objectives were to:

1) Develop a description of the rail engineering planning system as a complex sociotechnical system.
2) Identify the critical human and organisational factors of the rail engineering planning system.
3) Investigate relations between planning and engineering work delivery and identify the impacts of planning on work delivery.
4) Describe resilience within the planning system and identify means to improve it.
5) Contribute to the development of a framework, methods and measures for assessing resilience in planning.
6) Produce recommendations to promote safety and efficiency in rail engineering through improved planning.

As stated above, planning remains a relatively unexplored domain of rail engineering, which justifies the focus of objectives on the development of descriptive and exploratory work. A wide range of quantitative and qualitative methods, as well as data sources, were used. These are summarised in Table 1.1. Objective 6 is not shown in this table as recommendations were produced based on the overall set of data and analysis developed.

Table 1.1: Summary of methods used

Objective 1	• Analysis of planning documentation and business process • Planning familiarisation interview • Semi-structured interviews • Planning archival data analysis
Objective 2	• Planning familiarisation interview • Familiarisation interviews with planning stakeholders • Semi-structured interviews
Objective 3	• Familiarisation interviews with planning stakeholders • Planning archival data analysis • Safety data analysis • Infrastructure archival data analysis • Archival data from a system perspective
Objective 4	• Analysis of interview data from a resilience perspective • Archival data from a system perspective • Questionnaire • Functional analysis (Functional Resonance Analysis Method – International resilience workgroups)
Objective 5	• Archival data from a system perspective • Questionnaire • Cooperation with international resilience workgroups

The research methods and their framework within this thesis are further detailed in Chapter 4.

1.3. Structure of the thesis

The research conducted initially focused on understanding and describing planning and its processes. Planning was then analysed in view of its interactions and impacts on engineering work, aiming to build a system perspective on rail engineering. Lastly, these system interactions were interpreted in light of resilience engineering literature, aiming to produce recommendations for enhanced system resilience.

Chapter 2 provides an overview of the railway context in which the research was conducted. The descriptions presented regarding engineering access and delivery (section 2.2) and the engineering planning system (section 2.3), were derived from initial familiarisation work by the author. Given the complexity of this research context, it was considered useful to provide a basic understanding of railway engineering beforehand. This helps to frame both the literature investigated (Chapter 3) and the research methods used

(Chapter 4).

Research data are then presented for three different topics:

- Understanding the planning system (Chapter 5)
- Understanding asset management and work delivery (Chapter 6)
- Understanding and measuring resilience in planning (Chapter 7)

In order to facilitate the reading of this thesis, each of these chapters starts with a table that traces the data discussed back to the main objectives stated in the previous section.

Chapter 8 discusses the overall contribution of this project to the field of resilience engineering and the relevant recommendations for improving safety and efficiency in railway engineering.

2. Research context

This research was conducted under a grant from the centre for Rail Research (RRUK) and Network Rail, where the author was based for the duration of the project. The focus was set on the sociotechnical system of planning rail engineering work, with particular interest in the interactions occurring between its components and with its operating environment.

The growing number of services operating throughout the network reduces opportunities to work on the infrastructure for repairs or renewals, which generates growing pressures over the rail engineering work system. When scheduling and planning for the required engineering work, Network Rail needs to consider access to the infrastructure as a scarce resource and explore ways of utilising it in the most efficient way within the industry’s safety standards. Thus, to ensure the safety of track workers and the reliability of the work undertaken, research into more flexible ways of planning is needed, so that renewals, enhancement and maintenance needs can be efficiently integrated within the shorter time windows available for engineering access.

Throughout the duration of this project, various transformation programmes were set in motion within various areas of the Network Rail organisation, some of which had implications to the wider rail industry. In particular, the reorganisation of planning imposed considerable challenges for the development and implementation of sound research methods. Although all stages of data collection were carried out prior to the implementation of the new planning structure, some transformations came into action during the distribution of the questionnaire (section 4.10). Mainly, at that point planning staff was being transferred to different organisational functions, whilst maintaining the same planning process and methods. The main features of the former and current planning process are explored in this chapter to provide a clearer understanding of the depth of the ongoing transformations. These transformations will then be recalled at different stages of this thesis, whenever necessary to clarify the work in question.

Although planning constitutes the focus of analysis, a basic understanding of the overall engineering organisation was considered necessary to interpret the investigation results. The following sections of this chapter provide a broad description of planning and an overview of the main organisational areas and functions that participate in it.

2.1. The rail industry in the UK

The UK rail industry is characterised by a wide diversity of rail infrastructure, with a variety in track and equipment types, requirements, complexity and ages, as well as varying profiles in traffic types and frequency. Such diversity presents an equally diverse range of engineering challenges in terms of planning and delivery requirements. For instance, planning of work will differ considerably depending on constraints such as having less time to access the infrastructure or fewer options for diverting traffic whilst working on other lines, or the frequency of maintenance required by aging equipment. The following factors can be put forward as causes:

- The different volumes and type of train traffic (passenger or freight trains, type of rolling stock, among others), which impose different degrees of wear down on track assets.
- The coexistence of modern rail infrastructure with equipment that has been in operation for nearly a century.
- The great technological diversity in many areas such as electrification (overhead line or third rail) and signalling systems, among others.
- The operation of rural lines in close proximity to complex and heavy traffic areas, such as those on the approach to a major terminal like London Euston or Paddington stations.

After a considerable decay between the 1950s and 1870s, the UK railways register at present time, one of the fastest growths in Europe. According to Eurostat (European Statistical Services), in the five year period going from 2004 to 2008, the number of passenger-kilometres has increased 22%, against 13% in Germany and 16% in France.

The European Directive 91/440 required member states to separate the management of rail operations and infrastructure from the provision of rail services, thus creating the necessary conditions for the “open access” to service providers. The Railways Act 1993 set out the privatisation process of British Rail, under which, Railtrack became the owner of the rail infrastructure in 1994. A series of major accidents such as Southall in 1997 (Hull, 2000) and Ladbroke Grove in 1999 (HSE, 2000), revealed evidence of poor management, and in 2002, Railtrack was replaced by Network Rail, the current owner and manager of the infrastructure. This represented an important change in the rail industry, as while Railtrack was a private shareholder company, Network Rail was constituted as a (not for dividend) company limited by guarantee. Instead of shareholders, Network Rail is constituted by members such as representatives of the public, the industry and the Department for Transport (member with special membership rights). On a wider base, entities participating and cooperating with Network Rail in the management and development of the network are normally designated as stakeholders. This includes representatives of passengers, engineering contractors, train operating companies (TOCs) and governance, among others.

The activities and performance of Network Rail are bounded by the Network License granted by the Secretary of State for Transport (as per Railways Act 1993) and monitored by the Office of Rail Regulation (ORR). This license sets the standards and terms for the service that Network Rail is required to provide to train operators. On a strategic level, Network Rail negotiates with governance the scope and targets for the development of the railways. From these negotiations emerges an investment contract for the up-coming five year period. Each of these five year intervals is designated as a Control Period (CP) and it sets the investment that the government will place on the infrastructure against targeted capacity improvements to be delivered by Network Rail. In 2009, the government has approved an investment of approximately 24 billion pounds for CP4 (from 2009 to 2014). In order to achieve the efficiency targets for this control period and deliver the desired enhanced capacity, as previously mentioned, Network Rail has engaged in significant organisational transformations.

2.2. Engineering access and delivery

Managing access to the infrastructure is one of Network Rail's key responsibilities. Access is the term used to refer to activities carried out in the rail infrastructure. The network is accessed either by operators to run trains or by Network Rail and its contractors to carry out (deliver) engineering work. The levels of service desired by train operators and envisaged by governance have to be balanced against the volume of engineering work required to maintain and develop the network. Train operating companies acquire from Network Rail access to the infrastructure, under the terms of either a franchise, or an “open access” contract, depending on the stature attributed to the route in cause. Under these contracts, train operators are granted a given number of timetable hours for train services and Network Rail is required to manage the remaining available access to deliver its annual engineering work plan. If any additional time is necessary for renewals or enhancement engineering work or for emergency maintenance, then Network Rail must negotiate with train operators, as this access becomes disruptive to train services. Within this context, the planning of engineering work faces a considerable exposure to business and operational pressures as it deals directly with critical decisions regarding the delivery of Network Rail’s service to its customers (train operators). As explained by McCarthy & Wilson (2001a) in regards to planning, scheduling and control, these tend to be critical organisational processes, as “they link customers with the primary manufacturing resources, balance the conflicting constraints on, and competition for these resources, and shoulder overall responsibility for meeting demand. These aspects are further explored in section 3.5.

Network Rail develops a national annual work plan for engineering access that aims at allocating resources as efficiently as possible at a local and national level. This plan is formed by the renewals and enhancement projects, together with the foreseeable maintenance work. Projects depend on the investment programme agreed with the government and stakeholders, while the maintenance programme is initially defined on the base of the cyclic work required by compliance with the engineering standards. These standards establish the volume of work, such as patrolling and inspection, which is periodically required to ensure the safety and reliability of rail assets (equipments). In addition to the cyclic requirements, other types of work fall within maintenance scope, namely, small renewals works such as the replacement of assets that have reached the end of their life cycle. Above all, maintenance must maintain capacity to respond to emergency work requirements. Whenever engineering interventions emerge from incidents on the infrastructure, maintenance is often forced to review its planned work and redefine priorities accordingly. Within this scope, the development of the annual work plan requires the interaction between numerous stakeholders and organisational functions within Network Rail, and needs to cover all geographical areas of the rail infrastructure.

The focus of investigation in this thesis was set on Network Rail's organisational structure and the cross-functional interactions that take place for the coordination of planning needs at local and national levels. This includes functions responsible for the core of planning, those that provide input to planning and functions that deliver the output of planning. The relevant organisational functions can be described as follows:

Infrastructure Maintenance is responsible for overseeing the safety of the line to run trains and for carrying out the maintenance work needed to guarantee this safety of the line. The rail network is divided into sections, which are then managed by Maintenance Delivery Unit (MDU). Each MDU is responsible for scheduling and resourcing the maintenance work required and submitting it to the planning process as independent work packs. These work packs are broadly an objective or type of work to be carried out in a specific asset or section of line.

Infrastructure Investments are responsible for developing enhancement and renewals projects, as well as overseeing their deployment. Starting from the scope of development set for each route, project teams in each of the five territories (see later in Table 2.1) are responsible for carrying out a given enhancement or renewals programme through the different stages of the Guide to Railway Investment Projects (GRIP). GRIP sets out eight development stages that have to be followed in order to see any project through from its planning to its completion. The stages are as follows: output definition; pre-feasibility; option selection; single option development; detailed design; construction, test and commission; scheme hand back; and project close out. Each stage delivers an agreed set of outputs according to defined quality criteria. Project teams are responsible for carrying out GRIP stages in such a way that they are able to meet the deadlines imposed by the planning process for the submission of each work pack necessary to complete the given investment project. These responsibilities also include any necessary work to plan the independent work packs. This includes identifying necessary resources and requesting them, and carrying out site walks, which are meant to provide a detailed local knowledge of the area on which work will be delivered.

Operations and Customer Services is the Network Rail function in charge of managing the relations with train operators (customers) and every aspect related to running trains on the network, including traffic control and signalling. Signallers manage train traffic and every transfer of control over sections of track that are scheduled for engineering work access. Within this function are also integrated **route control centres**. These are not directly related to planning but are responsible for overseeing all aspects of operations and managing any occurrence that may affect them. Throughout the planning process, integrated in this area of the organisation, the **Network Access Unit** (NAU) is responsible for formalising any agreement between train operators and Network Rail regarding the rights to access the infrastructure, either for running trains in the case of operators, or for engineering work in the case of Network Rail. This function also issues the Weekly Operating Notice (WON), which contains details of every engineering access planned for each week of the year. WONs are distributed to each signal box in order to inform signallers of the time, date, location and other relevant details, for every engineering access scheduled. The contents of WONs in terms of engineering work are illustrated in Appendix 1.

The **National Delivery Service** (NDS) constitutes the core of planning. This organisational function is responsible for gathering all work requests (work packs) and for managing and allocating resources, in particular, the fleet of wagons and track machinery. NDS integrates work packs submitted by maintenance and investments as best as possible within the limitations of access and remaining resources, such as machinery and staff, among others. Once resource utilisation is optimised and as many work packs as possible are accepted, an Annual Integrated Work Plan (AIWP) is issued.

The functions previously described operate according to different geographical structures, in order to cover the entire network. Table 2.1 summarises the different geographical structures across which planning operates.

Table 2.1: Geographical structures relevant for planning

<table>
<tr><th rowspan="2">Territory</th><th rowspan="2">Route (groups)</th><th rowspan="2">Maintenance Delivery Unit</th><th colspan="2">Area</th></tr>
<tr><th>Engineering</th><th>WON</th></tr>
<tr><td rowspan="9">London North East (LNE)</td><td rowspan="2">Midlands & Continental (M&C)</td><td>Bedford</td><td rowspan="2">Midlands & Continental</td><td rowspan="2">East Midlands</td></tr>
<tr><td>Derby</td></tr>
<tr><td rowspan="7">London North East</td><td>Hitchin</td><td rowspan="4">Great Northern</td><td rowspan="2">LNE (S)</td></tr>
<tr><td>Lincoln</td></tr>
<tr><td>Doncaster</td><td rowspan="2">LNE (Central)</td></tr>
<tr><td>Sheffield</td></tr>
<tr><td>Leeds</td><td rowspan="3">North Eastern</td><td rowspan="3">LNE (N)</td></tr>
<tr><td>Newcastle</td></tr>
<tr><td>York</td></tr>
<tr><td rowspan="10">London North West (LNW)</td><td rowspan="10">London North West</td><td>Chester</td><td rowspan="3">Central</td><td rowspan="5">LNW (N)</td></tr>
<tr><td>Crewe</td></tr>
<tr><td>Manchester</td></tr>
<tr><td>Carlisle</td><td rowspan="2">Lancashire & Cumbria</td></tr>
<tr><td>Preston</td></tr>
<tr><td>Bletchley</td><td rowspan="3">West Coast South</td><td rowspan="5">LNW (S)</td></tr>
<tr><td>Stafford</td></tr>
<tr><td>Stonebridge Park</td></tr>
<tr><td>Saltley</td><td rowspan="2">West Midlands</td></tr>
<tr><td>Sandwell-Dudley</td></tr>
<tr><td rowspan="11">South East</td><td rowspan="3">Anglia</td><td>Colchester</td><td rowspan="3">Anglia</td><td rowspan="3">Anglia</td></tr>
<tr><td>Romford</td></tr>
<tr><td>Tottenham</td></tr>
<tr><td rowspan="3">Kent</td><td>Ashford</td><td rowspan="3">Kent</td><td rowspan="5">Kent & Sussex</td></tr>
<tr><td>London Bridge</td></tr>
<tr><td>Orpington</td></tr>
<tr><td rowspan="2">Sussex</td><td>Brighton</td><td rowspan="2">Sussex</td></tr>
<tr><td>Croydon</td></tr>
<tr><td rowspan="3">Wessex</td><td>Clapham</td><td rowspan="3">Wessex</td><td rowspan="3">Wessex</td></tr>
<tr><td>Eastleigh</td></tr>
<tr><td>Woking</td></tr>
<tr><td rowspan="4">Scotland</td><td rowspan="4">Scotland</td><td>Edinburgh</td><td rowspan="2">Scotland East</td><td rowspan="4">Scotland</td></tr>
<tr><td>Perth</td></tr>
<tr><td>Glasgow</td><td rowspan="2">Scotland West</td></tr>
<tr><td>Motherwell</td></tr>
</table>

Western	Western	Reading	Thames Valley	Western
		Swindon		
		Bristol	West Country	
		Plymouth		
		Cardiff	Wales & Marches	
		Shrewsbury		

Territories are part of the geographical structure of Infrastructure Investments. Prior to the transformation of the planning organisation in 2008 and 2009, territory level structures were responsible for the initial stages of planning. The five Territory Delivery Planning Units (TDPUs) would develop an outline of the required access and fundamental resources according to the work submitted by projects and the foreseeable volume of maintenance. Currently, the new planning process is mostly based on area level structures and TDPUs no longer exist.

Routes are the main geographical structure for the Operations and Customer Services function of Network Rail. In general terms, a route defines a given rail path that connects to strategic network locations. Routes are grouped under nine different management structures. Each route (group) director is responsible for defining the scope of work needed to respond to the targets set for the running Control Period. Since June 2005 under a revision of the Network Licence, Network Rail is obligated to develop and maintain Route Utilisation Strategies (RUSs). As Network Rail defines it, RUSs are developed in conjunction with rail industry partners and they seek to balance capacity, passenger & freight demand, as well as operational performance and cost, in order to address the requirements of funders and stakeholders. Hence, engineering work scopes are defined according to the requirements set by each RUS.

Maintenance Delivery Units, as previously mentioned, are the local structures responsible for overseeing a given section of the network. This means managing and maintaining all assets, namely tracks, track equipments such as points, and signalling and electrification equipments. For each of these assets, MDUs must schedule and deliver the patrolling, inspection and other repair work, and submit it for formal acceptance to the planning process as independent work packs. As shown in Table 2.1, there are 40 MDUs distributed throughout the country.

Areas are the main geographic structure for planning. Prior to the transformation programme, area planning units were part of Infrastructure Maintenance as Area Delivery Planning Units (ADPUs). The 16 ADPUs across the country would receive the planned work for each quarter from TDPUs and further detail it and verify all the requirements for its delivery. The transformation has placed the area planning units under NDS and these are now responsible for developing all stages of the planning process. These units correspond to the 16 engineering areas in Table 2.1. Area units provide the details of the engineering work to be delivered each week to Operations and Costumer Services, which then publishes them according to the structure of the WON areas, as shown in Table 2.1.

Table 2.2 summarises the correspondence between the geographical structures and organisational functions, as previously discussed.

Table 2.2: Correspondence between geographical structures and organisational functions

Geographical structures	Territory	Route	WON Area	Maintenance Delivery Unit	Engineering Area
Organisational functions	Infrastructure Investments	Operations and Customer Services (NAU)		Infrastructure Maintenance	National Delivery Service

2.3. Engineering planning system

The system for the planning of engineering work, in a simplistic way, aims to schedule all work packs within the access opportunities available for each year, whilst optimising the utilisation of resources (machinery, haulage, staff and access, among others). This system consists of the functions and geographical structures previously described. NDS and NAU constitute the core of the planning system, while the participation of maintenance and investments has considerably changed during the course of this research, as a consequence of the planning transformation programme. The reorganisation has integrated under NDS most of the planning responsibilities that were formally disseminated under maintenance and investments. Both maintenance and investments remain responsible for producing the work packs necessary to respond to the infrastructure needs but no longer have planning teams (TDPUs and ADPUs) under their organisational structure.

In order to achieve the desired optimal application of resources, detailed information is progressively developed to support the delivery of work, whist ensuring its reliability and safety. The development of this information follows a planning process that is formally designed by Network Rail and agreed by all stakeholders. The aim of the planning process is to ensure the integrity and robustness of the annual plan by establishing what information every stakeholder is required to provide at each stage, as well as impose common deadlines for the completion of those stages. Overall, the planning process aims to impose deadlines for decisions to be reached at national level, regarding the work going forward to delivery and the deployment of resources. Despite the standards imposed by the process, work requests (work packs submitted to the planning process) are brought in at various stages in a response to unpredicted infrastructural and business demands, often generating more or less profound changes to work until the hours before its delivery.

Diagrams in Figure 2.1, Figure 2.2 and Figure 2.3 illustrate the transformations to which the organisational structure of planning was submitted during the implementation of a new planning process. These diagrams were developed based on the overall understanding of the planning organisation, mostly acquired throughout the interview processes carried out in this research (Sections 4.4 and 4.5), and through the consultation of Network Rail planning documentation. Figure 2.1 describes the structure that existed when this research was initiated. This diagram was developed based on the planning process described in the Network Rail Business Process Document referenced as NR/SP/MTC/0056 (commonly designated as PL0056 - *Work & possession planning for the railway infrastructure*). Using the initial contacts with planners, namely those used for the semi-structured interview process (section 4.5), the accuracy of this diagram was then confirmed.

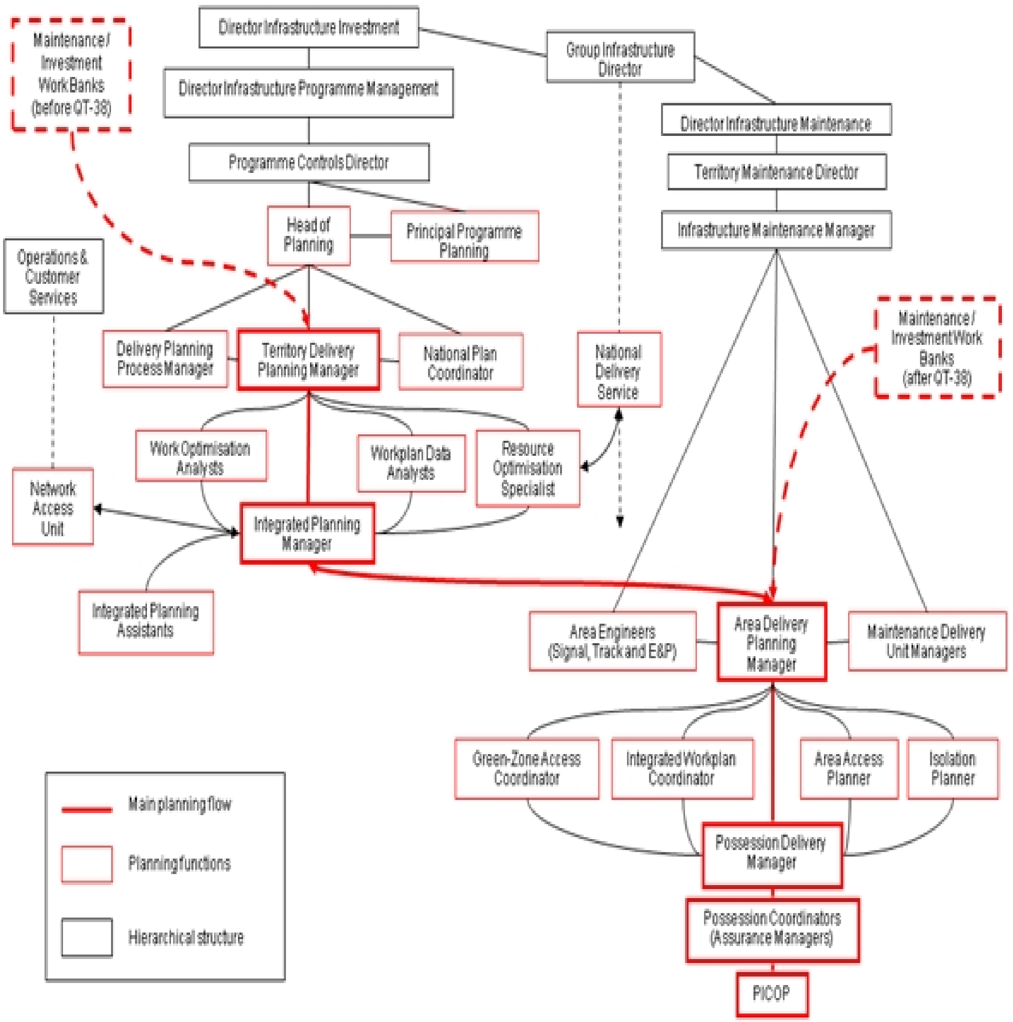


Figure 2.1: Planning process at start of research

As the transformation was set in motion, the structure shown in Figure 2.2 was created as an intermediary stage for reallocation of staff and resources. The new planning process is described in two main documents (NR/L2/NDS/202 - *Engineering access & NDS-supplied resource planning* and NR/L3/NDS/302 - *Planning of engineering access & NDS-supplied resource for work deliverers*) and the organisational structure that was developed to support it is shown in Figure 2.3. Figure 2.2 and Figure 2.3 were developed from Figure 2.1 and its accuracy was later verified through discussions with people leading the transformation programme for planning.

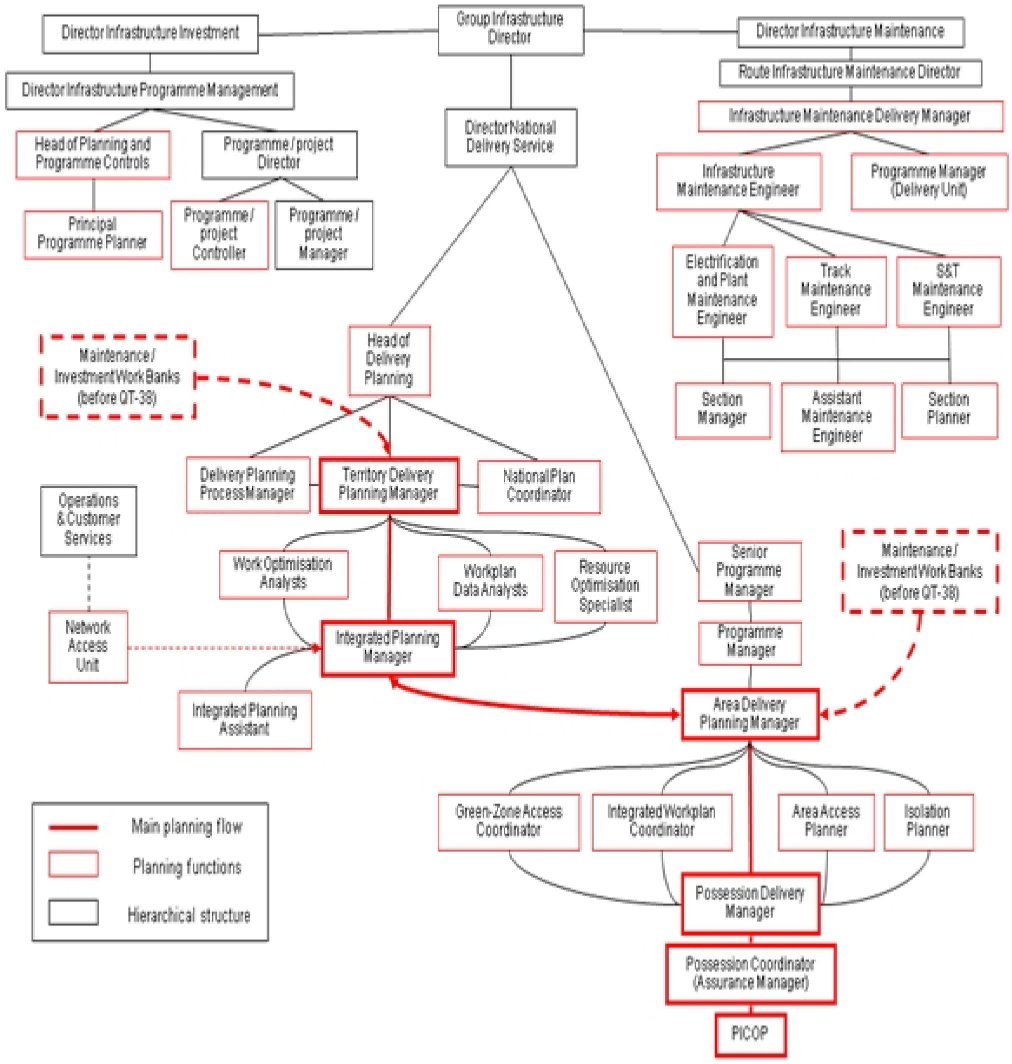


Figure 2.2: Planning process during reorganisation (reallocation of staff to NDS)

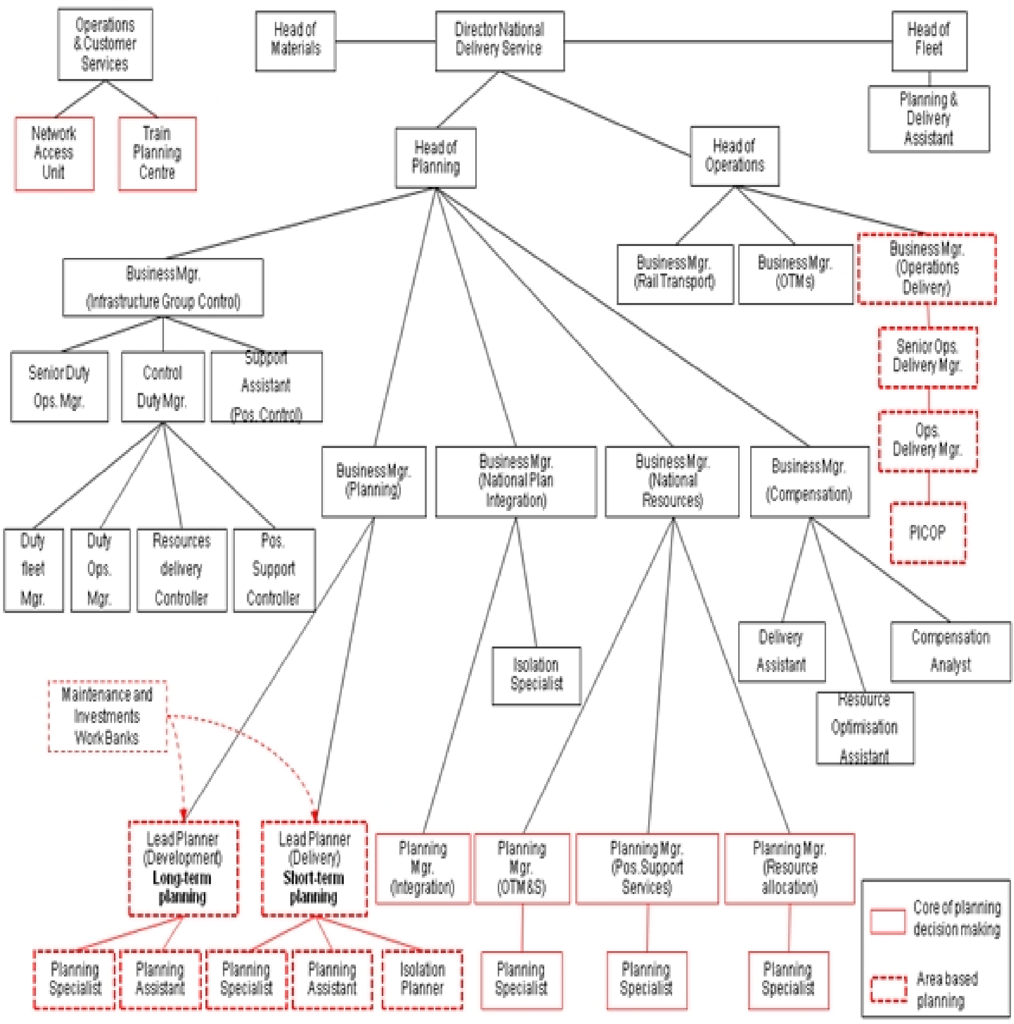


Figure 2.3: Planning process after reorganisation

A detailed description of these processes and their respective organisational structures was considered too extensive and of little use for the purpose of this thesis. At this point, a broad understanding of the planning system is provided based on three levels that although not corresponding to formal planning stages, represent levels of granularity that progressively respond to the planning and delivery requirements: Access, possession and worksite planning.

2.3.1. Access planning

This is the initial step and consists on agreeing with train operators the access to which each of the parties involved will be entitle to for the upcoming year. This stage starts approximately 90 weeks before the start of the timetable (TT) year foreseen for the delivery of work and is concluded with the publication of the Rules of the Route (RotR). The RotR represent a contract between Network Rail and TOCs regarding the timetable hours for train services and those available for engineering access. Network Rail develops these negotiations on the base of the foreseeable work needed, for both maintenance and projects. The overview of this work is given by the Annual Integrated Work Plan (AIWP), which is developed prior to the publication of the RotR. As mentioned above, NAU has the lead responsibility in formalising the negotiations but most of the information is exchanged between TOCs and TDPUs. In some cases where late changes are made to the access conditions ADPUs are likely to directly contact TOCs and later formalise agreements through NAU.

2.3.2. Possession planning

This stage is developed quarterly and starts approximately 45 weeks before the start of each quarter (QT). It corresponds to the integration of work packs within each of the times and locations available for engineering access. This process is primarily driven by TDPUs, although ADPUs will intervene, as profound changes to the contents of possessions are made throughout later stages. The term possession represents the actual transfer of control over the line from the signaller to a Person in Charge of Possession (PICOP) and designates the protection arrangements that need to be established prior to and during engineering access. According to the Rule Book, possessions are referred to as “T3” arrangements. The PICOP is responsible for overseeing any movements within the limits of possessions or those going in or out to lines open to normal traffic. During this stage, the AIWP is progressively detailed and work packs are derived in independent work items. Planning then analyses the possibilities of slotting items into possessions, which will lead to the issuing of a confirmed possession plan for each of the four periods of the year. This is referred to as the Confirmed Period Possession Plan (CPPP) and it concludes this stage of planning.

2.3.3. Worksite planning

This is progressively developed alongside possession planning, as it produces the necessary details for the integration and coordination of work items within possessions. However, the core of this process is developed at ADPU level and it is held from 26 weeks before the time of delivery (T).

Possession Coordinators or Possession Assurance Managers (depending on the area of the country) are the planners responsible for preparing all information that PICOPs will be requiring on the night of delivery. At this point, planners hold a set of meetings until the week before delivery (T-1), which progressively detail the contents of possessions and worksites, as stakeholders bring in new information regarding work and how they intend to deliver it.

This stage focuses on verifying all the requirements to carry out work, such as the timings and locations for each of the steps, resources and electrical isolations, among others. Particular attention is given to potential sources of conflict between work items which could compromise the safety or the deliverability of work. The term worksite designates the safety arrangements that separate a particular sequence of work from the remaining area under possession. Thus, a worksite is always within the limits of the area of track under possession and a possession may have one or more worksites.

Worksite arrangements, together with possession arrangements, create two overlapping safety barriers, which aim at not only protecting ongoing work from open line traffic, but also preventing any movements within possessions that could result in hazardous situations for both track crews and equipment. Each worksite is placed under the control of an Engineering Supervisor (ES). The ES is responsible for overseeing and authorising movements and work within the worksite, as well as coordinating these activities with the PICOP. A worksite can either integrate several work items or be composed of a single item, depending on the complexity and risks implicated in its delivery. For instance, while some patrolling or minor maintenance work may be delivered within the same worksite, work that involves movements of on-track machinery is unlikely to be deliverable together with work that affects the ability to use that same track.

2.3.4. The planning process

The three stages described above and the organisational structures that develop them (NAU, TDPU and ADPU) form the core of planning as a system. Figure 2.4 was developed based on the formal planning documents previously mentioned in order to represent the three levels of granularity previously described. The timings indicated correspond to formal references given by the planning process, at which each of the levels of planning is initiated. The square boxes show the documents that formalise the output of each of the levels of planning.

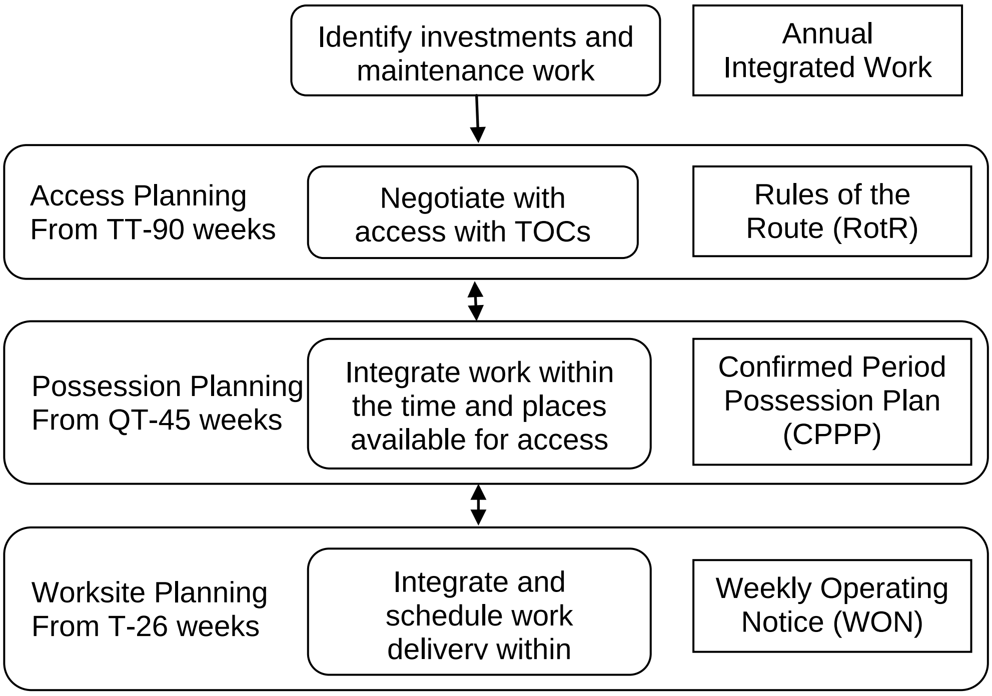


Figure 2.4: Basic steps of the planning system

The process is designed in such a way that a down flow of information occurs, which progressively details work towards its delivery. However, two-way arrows were used to show that exchange of information between levels takes place, as for instance, while worksites are being planned, changes to possessions and even access may still occur. These three stages could be interpreted as high level planning functions, which despite being designed to relate in a linear manner from start to finish of the process, they in fact develop complex and iterative exchanges of information.

Although a precise figure was never obtained regarding people dedicated to engineering work planning tasks, anecdotal information obtained from various colleagues at Network Rail placed this number at around 2000 people. The iterative flow of information and the range of people, organisational functions and geographical structures across which the planning system operates justify its characterisation as a complex distributed sociotechnical system. As stated by Wilson et al (2007a) in regards to the railway as whole, “events, operations, people and technical systems are widely distributed in time and space: they are often mobile, people must collaborate using refined social as well as technical skills, and the distributed system is spread across regional, national, and cultural boundaries".

A significant volume of less complex maintenance work (in general, those that do not affect the safe running of trains) is often delivered under less demanding and less complex protection arrangements. These arrangements are designated as "T2" in the Rule Book. One of the factors that justify the delivery of this work under fewer protection arrangements is the absence of machinery on track, which could affect the safety of the line. Hence, the planning of T2s does not require going through the complex planning stages that allocate track machinery and other critical resources. Network Rail documentation indicated that T2 arrangements do not follow the standards imposed by the planning system here described. Informal consultations with people involved in engineering planning and delivery revealed that the scheduling and planning of T2s is developed almost exclusively at MDU level. Because the planning of this type of access clearly falls outside the process of T3 arrangements, they were not considered within the scope of this research. Hence, this study can be described as the planning of work that involves possession of the line.

2.4. Safety and engineering data sources

This research refers to several data sources that support the planning and delivery of engineering work, as well as other functions within Network Rail and in some cases, the wider rail industry. This section clarifies, the systems and data sources used, in order to make the contents of this thesis more comprehensive. The descriptions here provided were mostly produced from work carried out during the initial stages of this research, aiming to build an overall knowledge and understanding of the rail industry.

2.4.1. Possession Planning System

The Possession Planning System (PPS) is the main support tool of planning. It generates a database of all engineering work that has been formally submitted to planning and provides details of engineering access for the publishing of the WON. Possessions and worksites are created and given a unique reference by the system. Although the system refers to worksites, the items inputted under this designation and to which a reference is attributed will not necessarily correspond to an actual worksite on the night of its delivery. In fact, these are work items and are treated as such during the entire planning process, down to the publication of the WON. A worksite can be composed of several work items. This is frequently the case for track patrolling work, as most work items can be carried out simultaneously whilst other types of work are delivered in the same area.

The planner responsible for inputting items in PPS is required to provide a minimum of details, such as time and dates, routes that will be affected by possession (and therefore unavailable for train services), the mileage to be blocked (actual location given in track miles), details of electrical isolations if needed, and other general details of work. Every item created in PPS remains under a status of “proposed” until all the necessary details are provided and inputted, at which point the item can be attributed a status of “approved”. Because no worksite can be delivered unless integrated within a possession, one of the requirements for worksites is its linkage to a possession. Once a reference number is given, PPS keeps a record of any changes made to the item with that reference, even if the item is given a status of “cancelled”.

PPS contains free text fields for the input of remarks regarding traffic and any other general details of work. Beyond this, the required information, mainly concerning the time and location of work and electric isolations, must be inputted according to a specific format. Although other parameters are available in PPS, only the ones described in Table 2.3 were considered relevant for the scope of this research.

Table 2.3: Description of information contents in PPS

Details	Additional remarks regarding traffic (time and head codes of engineering trains scheduled for a given possession) or any specific work details (key staff contact numbers, critical safety or deliverability issues)
Blocked line	Line which will be blocked to train services during possession (up or down line, fast or slow line, among other designations)
Route	Section of route on which work will be taking place and therefore, will be blocked to train services

Isolation	Input only required for worksite entries, providing details for electric isolations whenever these are required to carry out the work in question
On-track requirement	Input only required for worksite entries, providing details of any on-track machinery that will be operating within the given worksite

PPS records every change made to these parameters according to three basic inputs:

- Created: This operation indicates that information was inputted on a given field for the first time. This is also registered in the system when the referenced item itself is initially inputted into PP.
- Amended: The content of a field, which has been previously created, is submitted to modifications.
- Deleted: Information within a field is removed and details are eliminated from PPS.

2.4.2. Planning meeting minutes

Meeting minutes consist of a record produced during every planning meeting, in which any changes proposed and discussed are noted. Prior to each meeting, the planner overseeing the given stage of the process produces from PPS a printout of every work item proposed. This printout resembles the format of the WON (Appendix 1) and shows updated details for each item. This is referred to as a “data freeze”. During planning meetings, as items are discussed, the meeting chair checks whether the printed details are correct and records any changes agreed, in order to subsequently update details into PPS. Hence, despite the more or less common practices and notations used by the majority of planners, these records are mostly made of hand written free text.

2.4.3. PossMan

PossMan is a system developed by the planning teams in Maintenance using a Microsoft Access programming. This software assists planners during the last stages of the process, mainly in managing the grouping of work items into actual worksites and linking all the respective resources. This represents more or less what was previously described as the lower level of planning (worksite planning). Hence, this system manages a part of the planning process for which PPS offered no support. While PPS is oriented towards feeding details of engineering work for operations, PossMan aims at providing information more suitable for those responsible for delivery. The output of PossMan is normally referred to as the Weekly Engineering Notice (WEN).

2.4.4. Safety Management Information System

Safety Management Information System (SMIS) is an internet based software application for safety related incidents. It is managed by the Rail Safety and Standards Board (RSSB) and it gathers and codes information on relevant incidents from all areas of the industry and nationally. Fundamentally, it links events to the assets on which they took place and the people affected. This database is then available to all those involved in safety activities in all industry stakeholders.

2.4.5. National control logs

Control logs are daily records produced by Network Rail control centres, reporting all occurrences that affect the infrastructure or operations. Controllers at these centres receive information from all parts of the organisation regarding accidents and incidents, and non-compliances or irregularities taking place within the premises for which Network Rail is responsible. The logs are built under the format of free text documents, in which controllers progressively add any relevant information. Information reaches controllers, usually by phone, or they obtain it by contacting any potential source, whenever they feel further clarification is needed. Control logs constitute one of the main sources for the production of safety data, including the building of SMIS.

2.4.6. Asset Incident Trends

Asset Incident Trends is a database generated by engineering statistics, using an Excel spreadsheet format. It produces an overall picture of major types of infrastructure related events and their incidence in each engineering area, and for each of the 13 periods of the year (each period has four weeks). The database classifies 51 types of incidents that range from possession of the line incidents, track related events, signalling, electrification and even weather related occurrences.

2.4.7. Ellipse

Ellipse is an overarching system that manages asset information. All the equipments of the national infrastructure are recorded in this system, together with their status in terms of operational conditions. Thus, Ellipse provides information about any assets in need of work, which then feeds the work scope submitted by maintenance to planning.

2.4.8. Asset data

Engineering statistics provided two main sources of asset data: Asset counts and Equated Track Miles (ETM).

Asset counts are produced by the Engineering Information National Specialist Team for each Maintenance Delivery Unit and updated for every period of the year. The intention is to provide a guide for several engineering activities rather than a definitive set of asset counts. Assets are grouped according to the following categories:

- Stations
- Bridges
- Tunnels
- Signal boxes
- Track circuits
- Signals
- Train Protection and Warning System (TPWS)
- Insulated Block Joint (insulation of track circuits)
- Points operating equipment

The concept of **Equated Track Miles** (ETM) provides an estimate of the volume of work that each Maintenance Delivery Unit is required to carry out. ETM tables are used to inform a number of different areas of the business, such as investments and cost predictions, among others. This is calculated by the Engineering Information Team based on the asset counts and the actual mileage under the control of each MDU. Each section of track is multiplied by coefficients that distinguish between different levels of maintenance complexity, depending on the type of asset to be maintained.

The following track features are used as calculating coefficients:

- Continuous Welded Rail (CWR)
- Jointed Track (JTD)
- Switches & Crossings (S&C)

As CWR is easiest to maintain, it is given a lower factor than JTD. In the same way, S&C is the most difficult to maintain and therefore has a higher factor than the previous ones. In addition, a coefficient designated as Track Category accounts for the age of track and the Annual Tonnage for the estimated volume of traffic passing through a given section. This means that an area with less miles of track, straight sections of track with no S&C and low annual tonnage will have a lower ETM. Appendix 2 provides the conversion table with the coefficients to be applied to each track section and calculate the corresponding ETM.

3. Literature

This chapter explores the key fields of knowledge that support the research carried out. As put forward in the introduction, **sociotechnical systems** were considered the background for the investigation of **growing complexity** and its impacts on safety. As a starting point, system theories are discussed, as well as the characteristics of complexity (section 3.1). This has supported the study of the planning system and the understanding of its main human and organisational factors.

The planning of rail engineering work, as the focus of research, was described in relation to critical business decision making (section 2.2). An introduction of basic concepts on **decision making** is given in section 3.2, which supported the understanding of planning as a complex process ranging from the definition of high level business targets, down to work delivery. This also helped the identification of planning boundaries and its framing within the broader engineering system. The understanding of **decision making as a complex and distributed process** also supported the presentation of literature on **planning and scheduling activities** (section 3.5), and thus further contributed for the investigation of planning within the context of rail engineering and the identification of human and organisational factors.

Resilience engineering is proposed in section 3.4 as an approach to **safety management in complex sociotechnical systems**, which aims to develop mechanisms that can better **cope with variability and uncertainty** that are inherent to complex environments. While section 3.1 introduces literature on the sources of this variability and uncertainty, section 3.3 provides a background on **safety related issues and the challenges of safety within complex systems** which may require new approaches such as resilience engineering.

3.1. Complex sociotechnical systems

The planning of engineering work was early on described as a complex sociotechnical system. This section provides a definition and main characteristics for this concept, and clarifies the arguments which justify its use within the scope of this research.

3.1.1. Systems

Mansfield (2010) defines a system as a “hierarchic or networked group of interdependent components that when regarded as a whole, exhibit a certain behaviour that is not present in any one part, but arises from the interaction of the parts”. In systems, not only the whole is “greater” than the sum of the parts, but also the functioning of parts is conditioned by the relations between them (Jackson, 2010). Jackson (2010) further considers that the interactions and interdependencies are what define the nature of the system. Relations between components may be structured by links of physical, social or organisational, or even formal or informal nature, among others. The behaviour exhibited by the system and produced by the existing relations within it, is referred to by the author as an emergent property of the system in question. Such properties are the characteristics of the whole and not of its parts (Jackson, 2010). This is also what defines the boundaries of the system. The limits of a given system are the consequence of the relations considered and the behaviours originated. As noted by Hollnagel (2009a), this renders the definition of system boundaries dependent on the purpose and scope of its description. Any elements beyond, outside or not involved in the relations and behaviours considered are designated as the environment of the system.

The World Wide Web has been a frequent subject of research on system theories (Barabási & Albert, 1999). In this context, numerous systems can be described, depending on the purposes and functions under consideration. For instance, online purchases can be considered a system, ranging from decision making about buying, to the flow of information that produces the purchase, and finally, to the delivery of the bought products. This system has few physical structures and boundaries and yet it can be defined through the steps necessary to achieve the intended goal of acquiring something. This system interacts and/or overlaps with other systems such as the sales website company, the banking system (for purposes of payment), and supply and delivery services among others. From this perspective, the operational environment of one system is in itself, a system, and a given environment may be shared by several “separate” systems.

3.1.2. Sociotechnical system

The notion of sociotechnical system is likely to be one most frequently used in recent studies of organisational contexts. Mansfield (2010) points out that the term was first used in the context of work studies and it was aimed at emphasising the interaction between people and technology. This presupposes interactions between people and between people and technology. From this perspective, sociotechnical systems are distinct from purely technical systems, and from natural systems (Vugrin *et al*, 2010). While technical systems are those created by humans but under normal conditions, operate independently (certain types of software for instance), natural systems includes all those which were not created by humans and where no human intervention exists (natural ecosystems).

Jackson (2010) distinguishes a socioecological system from a human intensive system. Jackson (2010) defines the later as any system where the human element is the dominant one. This would include every organisation, from governmental institutions to companies and communities, as illustrated by the system responsible for the response to the hurricane Katrina (Jackson, 2010). A socioecological system is defined by Jackson (2010) as the result of human intervention in a natural system, such as the building of dams on rivers or any conservation action in forest or other natural habitats. In human-intensive as well as in socioecological systems, there is bound to be some form of interaction between humans and technology, and therefore, both could also be considered sociotechnical systems.

From a human factors perspective, any such systems could be considered “human intensive”, since at any instance, the control of a dam or the management, planning and implementation of conservation measures rely on human decisions and actions. To some extent, different degrees of “intensity” could be considered. As pointed out by Jackson (2010) and mentioned in the previous section, the key principle of any systems approach is the definition of its boundaries. The limits of the system in analysis in this thesis are discussed in the framework chapter (Section 4.1)

3.1.3. Systems approach

Jackson (2010) considers this a designation for methods dedicated to the design, analysis and management of complex systems. Jackson (2010) synthesises this approach with the following steps:

- The **identification of system elements** provides grounds for the selection of appropriate methods and disciplines for the study of each element.
- The **subdivision of elements** into smaller elements enables proper focus on relevant system parts.
- The **grouping of elements** provides means for better understanding the relations between elements with common goals and of overall system structure.
- The **identification of system boundaries** supports the definition of the system and its goals, as well as the identification of the elements that most contribute to these overall goals.
- The **identification of functions** for each system element further develops the understanding of system operations and how system functions are performed.
- The **analysis of interactions** between system elements complements knowledge of system functions by looking into how elements perform together to achieve system goals.
- Understanding the **system environment** is crucial for the analysis of constraints on system operations and performance of system elements. Whenever relevant for system design or analysis, this may include looking at elements independently and their environment within the system, as each system element may have different environments and therefore, also be subjected to different performance constraints.
- The **identification of the emergent properties** of the system, as previously stated by Mansfield (2010), constitutes a crucial step for understanding system functions and goals, as well as boundaries.
- The development of a **synthesis** of functions and structures supports interpretation and understanding of system performance.
- Like in any robust scientific approach, **verification and validation** are fundamental steps to be considered.

The work developed in the course of this research took into consideration these steps, aiming to build a consistent approach to the investigation of the engineering work planning system. The section on scope and objectives will further explore these steps in view of the stated specific objectives.

3.1.4. Complexity

Keeping in mind the scale and complexity that characterise the rail engineering planning system, complexity is clearly one of the most important aspects of systems within the scope of this research. Although intuitively the meaning of this concept may be more or less understood, this section clarifies the aspects of system complexity considered relevant within the context of the planning of rail engineering work. Carayon (2006) explores complexity in sociotechnical systems and points out as its sources, the interactions among people who work across organisational, geographical, cultural and temporal boundaries.

Mansfield (2010) establishes a distinction between complicated and complex systems, based on how each of these two types of systems changes and evolves in time. The behaviour of complicated systems follows specific rules and, despite its numerous components, the relations between them remain fairly stable. Mechanical clocks are an example of complicated systems given by Mansfield (2010). The change of state in the clock's components will be likely to change the time it displays on the dials for instance, but will not alter the clock itself and how it works (unless the system malfunctions). Hence, the behaviour of a complicated system is said to be linear, as it could be described through a representation of the sequence of its relations and how they alter the state of the system in time (Mansfield, 2010).

Complex systems on the other hand, are characterised by numerous interactions occurring between many of its parts at each given time. Axelrod & Cohen (1999) define complexity as the outcome of interactions, which lead to current events within the system, critically influencing the probability of future ones. Mansfield (2010) considers that complexity is only perceivable through the behaviour of the system, as opposed to considering its components separately. In this sense, the author considers that complexity is an emergent property. Axelrod & Cohen (1999) add that complexity emerges from the multiple ways in which events in complex systems tend to combine their effects, rather than simply adding, as in a mechanical clock. Consequences of events tend to diffuse unevenly via the multiple interactions occurring in the system. As mentioned by Axelrod & Cohen (1999), Mansfield (2010) and Marais *et al* (2007), complex systems can change in multiple dimensions. Components in complex systems may alter their state, form or even position within the system's structure, and these changes produce effects across the system through the interactions with other system components. Hence, order in complex systems is emergent, rather than predetermined (Jackson, 2010).

Leveson (2004) states that many systems have today reached a level of complexity with a potential for interactions that cannot be fully understood. The author points out the contribution of software for this increasing complexity, as it gave way to "more integrated, multi-loop control in systems with dynamically interacting components" (Leveson, 2004). Bertalanffy (2003) develops a similar distinction when referring to closed and open systems. Closed systems have no communication with their environment and therefore, components tend to settle into a state of equilibrium. Once more, the example of the mechanical clock applies, as no interactions with its environment exist and it operates in more or less accurate constancy. Open systems are subject to information exchanges with their environments. Their behaviour is characterised by the constant search for a dynamic equilibrium, as a response to the information exchanged with their environment. Open systems tend to acquire the traits of complexity, as they develop adapting mechanisms to their environment.

Within this context, the main distinction between a complicated and a complex system resides in the fact that while the behaviour of the first remains compatible with principles of linearity and constancy, understanding the latter requires a nonlinear perspective. Nonlinearity is here considered the multiple dimensions that must be perceived concurrently, in order to understand the behaviour of a complex system. In this frame of mind and for the purpose of this research, a complex system is defined as a network of components that interact nonlinearly and give rise to emergent behaviours (and properties), which cannot be perceived from the properties and behaviours of components. Mansfield (2010) proposes the change from caterpillar to butterfly as an example of a complex system. This is clearly a system where a change in one component can initiate interactions difficult to predict, which, as the author states, can either die away or grow to modify the system and its behaviour.

Cook (2001) refers to a system of systems to discuss the high scale and complexity that today can be found in a great variety of contexts. When studying complex systems, often its components should themselves be viewed as sub-systems of a larger system, which leads to a more adequate perspective of complexity and its sources of variability and unpredictability (Cook, 2001). Jackson (2010) notes that this perspective should be applied when discussing systems that, despite their ability to operate independently, are often faced with the need to coordinate their efforts towards a common goal, and therefore, interact as a broader system. Examples of this can be found in fire departments, which may operate separately, but also coordinate themselves locally, nationally or even internationally when faced with major accidents, or in the multitude of airplanes flying across the globe and coordinating with different air traffic control systems.

3.1.5. Variability and uncertainty

Fujita (2006a) states that no system can avoid changes. They occur continuously throughout the lifetime of the system and are driven both by internal (e.g. through people's actions) and external (e.g. economic pressures) factors. Mansfield (2010) considers the influences that components exert on each other through their relations as the source of change in the system. The interactions amongst components generate pressures for change in the state of the system and of components themselves. Mansfield (2010) adds that because of its dynamics, complex systems are rarely in equilibrium. They change over time and their behaviour may emerge in many unexpected ways. Because of their propensity for change, Jackson (2010) refers to "complex adaptive systems". Jackson (2010) considers that complexity in systems is also related to the need to constantly adapt to disruptions emanating from system pressures. Hence, complex systems are normally characterised by variability in time.

Pressures amongst system components are themselves the result of pressures from the system's environment. Svedung & Rasmussen (1998) refer to pressures generated by changes in public opinion and awareness, political climate, market conditions, and the increasing pace of technological changes, and state that, in order to survive, systems must adapt to such changes in their environment. Changes in the environment initiate change (adaptation) processes within systems and, in return, the changes in the system will eventually produce changes in the environment.

The shifting pressures between the system and its environment are the source of high dynamics and unpredictability. Axelrod & Cohen (1999) consider that because of the forces (pressures) within the system, which shape future events, cannot be added in a simple and linear manner, prediction in complex systems becomes very difficult. Jackson (2010) points out that in complex (adaptive) systems, history is irreversible and the future is often unpredictable. Once actions are taken within the system, chain reactions can be produced that cannot be undone. The unpredictability of complex systems increases as decisions and actions become difficult to trace back. As stated in the previous section, complex systems can develop changes across many different dimensions and therefore, they exhibit a non-linear behaviour. Leveson (2004) adds that some systems have developed such degrees of interactive complexity that even experts may have incomplete information about its behaviours. This generates uncertainty in operations of complex systems. As later approached in section 3.4, one of the aims of resilience engineering often discussed by Hollnagel *et al* (2006) regard the ability to cope with variability of system operations and uncertainty about possible outcomes.

3.1.6. Intractability

On the basis of complexity and its resulting patterns of change, Hollnagel (2009a) discusses tractable and intractable systems. The low complexity that characterises tractability provides the opportunity for a sufficiently thorough description of the system and its operation. Not only are there fewer components and details to be described, but also the relatively low dynamics of the system allows for the analysis process to be concluded and actions to be taken without compromising the validity of its outcome in view of the system's state and condition. On the contrary, intractable systems incorporate the traits of complexity and therefore, operations tend to be underspecified (Hollnagel, 2009a). Table 3.1 summarises the main characteristics of tractable and intractable systems.

Table 3.1: Tractable and intractable systems (from Hollnagel, 2009a)

	Tractable systems	Intractable systems
Number of details	Descriptions are simple with few details	Descriptions are elaborate with many details
Comprehensibility	Principles of functioning are known	Principles of functioning are partly unknown
Stability	System does not change while being described	System changes before description is completed
Relation to other systems	Independence	Interdependence
Controllability	Easy to control	Difficult to control

The intractability of complex systems presents a major challenge for safety management. Within underspecified conditions, decisions must be made based on incomplete knowledge of operating principles and solutions must be reached within a timeframe compatible with the fast pace change of the system (Hollnagel, 2009a).

3.2. Decision making

The planning of engineering work is related to critical business decisions (the delivery of Network Rail’s service to its customers). This section explores basic concepts and perspectives on decision making, and places them within the context of complexity and unpredictability previously debated.

3.2.1. Concepts

Technology, in particular computerisation, has given information a growing importance in every work environment. Along with this transformation, making decisions has progressively become a necessary response to new demands, such as having to regulate, monitor or control parameters of industrial equipment. The prominence that human cognitive aspects have gained in the last few decades generated an interest from a wide range of scientific fields, even beyond those related to human factors, such as economics and business management. Crozier & Ranyard (1997) attribute this phenomenon to a combination of economic, social and technological developments that produced a situation where people have to make important decisions about every aspect of their lives, ranging from health issues, family, career and education, among others.

Wicklund & Brehm (1976) define **cognition or cognitive elements** as any knowledge one has about their environment or oneself. From this perspective, decision making can be broadly defined as the mental processes resulting in the selection of a course of action among several alternatives. In practice, Svenson (1996) defines decision making as the response to pressures generated by conflicting circumstances or differing goals that have to be negotiated and reconciled. The notion of conflict as the source of the need to decide has lead to the development of two important concepts:

- Festinger (1985) describes this conflict as the source of **cognitive dissonance**. Festinger (1985) refers to dissonance as the existence of non-fitting knowledge (cognition) or opinion about the environment or about oneself. For instance, within the rail engineering work environment, a dissonance could be described as having to allocate resources to a given work item when such resources are unavailable or simply having more work items to schedule than the available access necessary to deliver it. Dissonance pressures the individual to search for a more suitable circumstance, which implies making choices.
- In opposition to dissonance, Wicklund & Brehm (1976) refer to **cognitive consonance** when one element psychologically implies another, within one's cultural or behavioural patterns, or experience. The authors mention psychological implication in regards to cognitions which are logically connected. For instance, allocating resources to one particular work item is consonant with knowing that such item is approved for delivery.

In general terms, voting for a candidate is consonant with believing that this person has the necessary qualities to hold the office in question, whilst dissonance would be voting for a candidate knowing that such a person is unfit for the duties.

Svenson (1996) presents two different approaches to the study of decisions making:

- The **structural research approach** relates choices and their ratings to the input variables. This involves analysing aspects of decisions such as the possible maximum gains across different options and probabilities of decision outcome. The author points out that under this perspective, no attempts are made to infer the psychological processes that occur at different stages between problem presentation and reaching a decision.

- The **process research approach** focuses on these particular psychological aspects of decision making. The recognition and description of different stages from the conflicting circumstance to reaching a decision are envisaged by means of methods such as information search patterns and think aloud protocols.

In contrast with a structure approach, Crozier & Ranyard (1997) consider three attributes of decisions when viewed as a process:

- Reaching a decision acquires a dimension in time. Decisions are assumed to take a period of time to be reached, which could be minutes, hours or days.
- Decision makers explore a range of possible strategies to reach decisions and adapt their decision rules to changing circumstances.
- The representation of the problem at hand initially built by the decision maker evolves as the decision process develops.

Svenson (1996) argues that a process perspective is essential for the exploration of regularities (invariant elements) in decision making. Svenson (1992) had previously advocated that beyond the analysis of pre-decision information gathering and processing stages, research on decision making should also focus on post-decision processes, which further emphasises the importance of a process approach. Within this context, Svenson (1996) introduces the four types of decision problems described in Table 3.2, which embed different levels of complexity.

Table 3.2: The four types of decision problems (from Svenson, 1996)

	Description
Level 1	Quick decisions that tend to recur to automatic and unconscious decisions. Decisions made based on previous experience (recognition-primed decisions - Kleine 1989 in Svenson 1996).
Level 2	The decision involves one or a few attributes but these are not generating any kind of conflict. The solution remains relatively obvious.
Level 3	Decisions involving alternatives with conflicting goals.
Level 4	The alternatives are not known, nor the attributes that define them. Problem solving constitutes an important sub-process at this level.

Svenson (1996) points out that these levels should not be interpreted as being isolated and that decision makers may refer to several levels within a broader decision process. “Lower level processes are also nested within higher level decision processes as sub-processes of the latter”.

3.2.2. Distributed decision making

Institutions are today required to make decisions regarding investments, research and development or the deployment of resources in complex and uncertain environments (Crozier & Ranyard, 1997). This means that beyond individual people, the way organisations reach solutions to their problems should also be considered.

The concept of distributed decision making has been particularly relevant for research in organisational contexts and management. Schneeweiss (2003) describes this as the design and coordination of decisions connected within a broader decision process. Schneeweiss (2003) considers that the growing complexity of society can no longer be understood and governed by the paradigm of centralised decision making and that distributed decision making has become a predominant methodology of handling complex systems. Zeleny (1981) cites Stafford Beer in “Platform for change” (1975), where he considers that “the real decision making process involves a lot of people and the whole structure is redolent with feedback. At every decisive moment, of which there will be great many within the total decision, we range ahead and back and sideways”. Schneeweiss (2003) further considers that complex decision problems are solved by splitting them up into their components, either by a single individual through intellectual segregations and subsequent coordination, or by multiple individuals participating in some problem of mutual interest.

Zeleny (1981) considers that it is only when people are faced with multiple objectives, criteria, functions and attributes that a decision making process emerges. Zeleny (1981) describes decision making as dynamic processes of information searching in many different directions. The information gathered is then assessed, reconsidered or discarded. This generates numerous sources of feedback, which in return, renews the information search. “Man is a reluctant decision maker, not a swiftly calculating machine” (Zeleny, 1981). Zeleny (1981) proposes four generic stages for decision making processes:

- The **pre-decision stage** regards the initial sense of conflict, tension or dissatisfaction that provides the motivation for a decision process to be initiated. This conflict emerges from the lack of satisfying or feasible alternatives in view of the existing circumstances or perceived scenarios. Zeleny (1981) points out that if a feasible and satisfying alternative is found then the conflict no longer exists and the decision process ceases. The author considers such circumstances quite rare and therefore, the effort towards resolving the conflict shifts to an attempt to minimise the conflicting aspects. This amounts to containing the conflict within an acceptable level.
- As the process develops, **partial decisions** are made, which constitute a directional adjustment of the decision problem. Alternatives are discarded, new ones may be admitted and the remaining ones redefined. Overall, this generates a review of the conflicting elements, and thus, a redefinition of the problem at hand. Zeleny (1981) considers that two elements contribute to the development of partial decision processes: the prevalence of the pre-decision conflict and the post-decision dissonance which emerges as confidence in the choice made is questioned. Svenson (1996) refers to this process as **differentiation**. Svenson (1996) advocates that the purpose of a decision process is not to simply fulfil the decision rules in question but rather to generate an alternative course of action sufficiently distinct from the remaining alternatives. This is achieved by restructuring the decision process according to the context and persons involved.
- Through partial decision processes, the alternatives deemed feasible and the ideal scenario are progressively brought closer together, which eventually leads to an acceptable level of satisfaction and a **final decision** is reached. A partial decision differs from a final decision in the sense that in the latter case, the decision makers were able to reduce the post-decision dissonance to an acceptable level. At this point, Zeleny (1981) argues that there are few alternatives being pondered and these tend to be very similar.

- The **post-decision stage** consists of managing the dissonance emerging from making a choice. The decision makers review and reassess the process, as well as the decision rules applied. The process through which decision makers reinforce the attractiveness of the choice made and reduce the relevance of the remaining alternatives is referred to by Svenson (1996) as **consolidation**. The consolidation process that follows what becomes a final decision differs from the preceding ones in the sense that it achieves a satisfying level of confirmation of the choice made.

Zeleny (1981) points out that every post-decision stage can be considered a pre-decision stage for a next step within a wider decision process. From this perspective, these four stages illustrate the process of decision making. The notion of partial decision introduces an iterative characteristic to the process that becomes increasingly relevant as problems become more complex.

Svedung & Rasmussen (1998) apply this process perspective to decision making in risk management. A hierarchical system is described as one single decision making process, ranging from governance, down to the operational level where a given hazardous process must be carried out and controlled. The authors argue that such an approach is necessary to understand what initiates and drives decisions (partial decisions) at each hierarchical level of the system. From one level to the next, decisions are affected and shaped by different types of pressures, such as public opinions, political trends, company and market shifts and availability of resources. These pressures affect the way people at each level develop their decisions and decisions at each level affect decisions on the next one. As stated earlier in regards to complex systems (section 3.1.5), pressures are the source of changes in systems. This places decision making in the context of change in systems, as decision making processes are themselves triggered by conflicting and pressuring circumstances (Zeleny, 1981 and Svenson, 1996). The relevancy of the model proposed by Svedung & Rasmussen (1998) will be further discussed in the context of safety in complex systems.

For several research fields related to organisational issues, this remains an important subject, with relevant questions to be answered. As an example, the term “decision engineering” is today frequently used to describe scientific efforts on the development of tools and techniques for informed operational and business decision making (Miller *et al*, 2009).

3.3. Safety in complex systems

As stated in the introduction, one of the focuses of this research is safety, in particular, resilience engineering as a safety management approach in complex systems. The aspects of system complexity previously discussed are of crucial importance for the field of safety management. As illustrated by the investigation into the NASA shuttle accidents (Marais *et al*, 2007), the uncertainty associated with complexity renders safety management equally complex. This section refers in more detail to the challenges that system complexity creates for the management of safety.

3.3.1. Background on safety issues

Safety is commonly defined as the absence of unacceptable risks (Hurst, 1998). This implies that a system is able to achieve its goals without loss of life or material damage (Jackson, 2010). Owens & Leveson (2006) consider safety to be a control problem. The purpose of safety oriented activities is to eliminate risk and therefore, to control events or courses of action that could lead to unsafe circumstances and potential accidents. From this perspective, accidents are the consequence of “component failures, external disturbances, and/or dysfunctional interactions among system components” (Owens & Leveson, 2006 pp 8). According to Kirwan (1998), managing safety relates to decisions on all practices, roles and functions involved in preventing such failures and disturbances. It involves all aspects of how safety is achieved or how other activities are performed in a safe way.

As already mentioned in the introduction (section 1.1), Hale *et al* (1998) argue that most of the current safety management practices and tools are rooted in the experience of earlier large scale organisations, in which changes would tend to be less frequent and of little magnitude. Strict regulations and standards applicable across all industrial activities were the core of safety management in organisations characterised by stable and well known operations. Hale *et al* (1998) further argue that “traditional” safety principles may be inadequate in the face of today’s complex and fast pace changing organisations. Hale *et al* (1998) question whether safety can be managed through a careful analysis of past occurrences and prediction methods for what may be the consequences of each possible course of action. By the time such an approach produces a decision, the organisation may have shifted and the solution found may no longer be applicable or even safe.

Because the pathways that convey people and goods also enable risks to travel, as the degree of economical, political and social interchange between states increases, disasters rapidly acquire the potential to cross boundaries (Boin *et al*, 2010). Leveson (2004) explains fast pace changes with the introduction of new technologies into systems. While in the early twentieth century, new technologies would take about 30 years to reach the market, this can today take three years and products may become obsolete in five years Leveson (2004). Dekker (2004) adds that although computational speed has drastically improved access to information and the ability to generate data, humans are unable to keep up with such evolutions. People cannot process and make sense of the volumes of information that currently flow across complex systems. This is the context in which high complexity can lead to an increased risk exposure, and as initially mentioned, it can create additional challenges for the management of safety. Within complex environments, safety cannot be merely chosen, rather it must be searched (Widalvsky, 2004). As later discussed (section 3.4), this is also the context in which Hollnagel (2011a) places resilience engineering's view on safety: The ability to succeed under varying conditions.

3.3.2. The changing nature of accidents

There is a common understanding of the term accident as being an unforeseen and unplanned event or circumstance, which leads to an undesired outcome, normally of loss or injury (Hollnagel, 2004). It is today widely recognised that dependence on technology has produced new and important sources of risk, and as a direct consequence, the nature of accidents has also shifted (Leveson, 2004). The scale that systems have attained creates the power to impact future generations through environmental pollution and genetic damage. As an example, Perrow (1999) mentions that activities such as the production of nuclear power, chemical and biological derivates, or the transportation of hazardous materials, are today a common presence, even in the vicinity of populated areas. The catastrophic potential of these industries has become evident in past disasters like the Three Mile Island, Bhopal or Chernobyl.

Leveson (2004) considers that complex systems cannot be managed under the assumption that accidents are produced by an uncontrolled and undesired release or transfer of energy between technical components. Technology is evolving faster than the methods to control and manage it, and consequently, unknown elements are introduced into system operations. Therefore, partially unknown operations must be taken into account as a contribution for the production of accidents in complex systems. Leveson (2004) further discusses the widespread use of computers and observes how this has created a potential for information loss, imprecision or incompleteness, which can lead to severe physical and financial losses.

Within complex scenarios, risk does not emerge solely from the presence of toxic or explosive materials Perrow (1999). Examples of this can be found in railway accidents like Clapham Junction (Hidden, 1989) or Ladbroke Grove (HSE, 2000), among others. Perrow (1999) considers that high risk systems are characterised by an interacting tendency that can lead to unexpected combinations of events. This is described as a system characteristic, as opposed to one of components or operators. In accordance to what was previously defined as a complex system, Perrow (1999) also refers to interactive complexity in high risk systems. Due to the numerous possible combinations of events and even greater number of potential outcomes, the author considers this interactivity the source of “normal accidents”, in the sense that occurrences in complex environments must be considered inevitable. Accidents in complex environments tend to be the result of unpredicted interactions and thus, as supported by Owens & Leveson (2006), the spread of potentially harmful interactions throughout the system have to be controlled.

As Leveson (2004) points out, accidents within complex environments tend to produce unpredicted chain reaction effects, which could rapidly reach intolerable proportions. Prevention of accidents requires a more proactive approach, in order to develop the ability to anticipate threats. Hindsight has become a benefit that complex systems may no longer afford. Weick &

Sutcliffe (2007) add that high risk technologies must be controlled by means other than trial and error learning, as in many cases, the first error may also be the last trial. The challenge at hand within complex scenarios, is linking events that are further away in time and space than what would normally be the case when managing risks purely derived from technical or operator failures (Hale *et al*, 1998). Within this context, there is clearly a need to innovate safety practices in order to contemplate new types of accident aetiology.

3.3.3. High reliability

High reliability gained relevancy in the field of safety, as certain types of organisations exhibited a progressive intolerance to failure, which made high standards performance an imperative (Weick & Sutcliffe, 2007). As stated earlier, there are today organisations in which the cost of failure can be so great that it must be prevented and contained “at all cost” (Leveson, 2004). Weick & Sutcliffe (2007) refer to high reliability organisations (HRO) when the potential for error and disaster has become overwhelming and mention as examples, nuclear power stations, air traffic control systems and medical emergency teams, among others. This is also consistent with the notion of high risk systems and the concept of normal accidents, as discussed by Perrow (1999). Because these are aspects in which resilience engineering is also founded, a brief discussion on what constitutes a HRO was considered relevant.

Reliability can be defined according to different concepts, depending on the domain to which it applies (O’Connor, 2002). Intuitively, we regard something as reliable when it meets certain expectations. These expectations can be defined in terms of durability, absence of failures, or generally, an expected level of performance (safety or otherwise). O’Connor (2002) defines reliability as the ability of an item to perform a required function under stated conditions and for a stated period of time. High reliability therefore, corresponds to a condition in which the desired level of performance is achieved and maintained under the specified conditions and within (or beyond) the given period of time.

Several structural, cultural or technological features are mentioned by different authors as sources of high reliability. Weick & Sutcliffe (2007) consider that the uniqueness of these systems resides in their ability to continually learn from successful and flawed endeavours, and adjust performance accordingly. The authors identify five principles at the origin of this behaviour and leading to high reliability:

- HROs have a distinct **preoccupation with failure**. Any lapse is treated as a symptom that something in the system may be performing to less than perfect standards. HROs encourage error reporting, as they are aware that, no matter how small, failures can coincide and accumulate towards disastrous outcome.
- HROs are **reluctant to oversimplify** operating scenarios. Although some degree of simplification is required so that people can maintain focus on key issues towards success, simplifying the context reduces perception. HROs learn to appreciate diversity of experience and scepticism.
- HROs remain **sensitive to operations**. This means that the organisation is continuously aware of its front line and the events that affect it. This creates a situational awareness, which enables people to make the continuous adjustments that can prevent error accumulation.
- HROs are **committed to resilience** in the sense that they recognise the importance of learning through experience and build on it. Reason (1997) uses the expression "learning culture" to define this commitment.
- Finally, Weick & Sutcliffe (2007) consider that HROs are **deferent to expertise**. Such organisations aim to cultivate diversity as a way to increase ability to cope with complexity. This enables decisions to be made where the specific knowledge of events and expertise exists, regardless of their hierarchical position.

Similarly, Hurst (1998) states that complex systems and hazardous technology can be safely controlled if appropriate design and management techniques are followed. The author considers the following four conditions as necessary to create and maintain safety within the standards of high reliability:

- Leadership attributes a **high priority** status to safety and reliability
- Levels of **redundancy** are sufficient to compensate for failures
- **Decentralised authority**, strong organisational culture and continuous training successfully reduces error rates

- Effective **organisational learning** is achieved through trial and error processes and complemented by anticipation and simulation mechanisms for potential failures

Hurst (1998) recognises that such conditions clearly overlap with the characteristics of organisations with strong safety cultures. O'Connor (2002) not only relates high reliability with safety culture issues, but also considers its implications for the management of quality in industry. As later discussed, many of the organisational aspects here described are also relevant for resilience engineering.

3.3.4. Safety culture

The increasing awareness of factors that shape the behaviour of people and their decisions, as well as their resulting impact on the safety of organisations, has lead to a growing interest in organisational culture and in particular, safety culture (Hale & Hovden, 1998). Hurst (1998) generally describes safety culture as a set of ideas and beliefs that all members of the organisation share about risk, accidents and health. These shared values, attitudes and patterns of behaviour give the organisation its particular character ("the way we do things around here").

Safety culture issues are today widely reported in the outcome of investigations into several major disasters such as the one of the Columbia space shuttle (Woods, 2003). However, as could be observed by the author of this thesis in the course of the work developed at Network Rail, a great deal of misunderstanding remains around the concept of safety culture. Although people often refer to the need to improve safety culture as if this constituted a concrete feature of the organisation, as pointed out by Hurst (1998), most aspects of safety culture are intangible even though they lead to tangible and observable manifestations.

Similarly to high reliability issues, safety culture is also closely related to aspects of resilience engineering. Because of this overlap and the evident need to clarify the domain of this concept, some discussion on the subject was considered important.

Both Kirwan (1998) and Hurst (1998) cite the Advisory Committee for the Safety of Nuclear Installations (ACSNI) in its formal definition of safety culture:

> *The safety culture of an organisation is the product of the individual and group values, attitudes, perceptions, competencies and patterns of behaviour that determine commitment to, and the style and proficiency of, an organisation's health and safety management (ACSNI, 1993)*.

Hurst (1998) further points out that this definition leads to consideration of two important elements as constituents of safety culture: The underlying beliefs and attitudes towards safety, which are expressed both at an individual and group level, and the tangible safety manifestations through which these beliefs and attitudes are expressed. The relevancy for the management of safety resides in the strong relations between these tangible manifestations and the underlying elements of the culture. In order to shape behaviours and decisions, safety management practices must focus on the underlying elements of safety culture, rather than their manifestations (Hurst, 1998). Turner & Pidgeon (1997) add that safety culture encompasses the gaps between what is formally determined by the safety management system and the non-formalised aspects of operations. These are the informal strategies put in place to manage "grey areas" (the gaps). These strategies constitute the tangible manifestations of safety culture and they are developed based on experience according to the beliefs in terms of what is safe and unsafe of those applying them (Turner & Pidgeon, 1997).

The challenge becomes then the development of strategies and methods to identify and act upon the existing beliefs and attitudes. The purpose of an organisation would be to incorporate into its safety management, features that work towards what Kirwan (1998) considers a positive safety culture. According to Kirwan (1998), organisations with a positive safety culture are characterised by communications founded on mutual trust, by shared perceptions of the importance of safety and by confidence in the efficacy of the existing preventive measures. Hurst (1998) considers that a good (positive) safety culture results from adequate resources, good communications and a cooperation that ensures a balance between safety imperatives and production needs. The focus on communications and cooperation derives from the importance of group attitudes and processes to the management of safety (Kirwan, 1998). As noted above, factors shaping decision making are crucial for safety culture and most decisions will involve at least two people and often more. Communications and group factors become dominant, as the set of values and attitudes (safety culture) greatly influences the quality of the information flows developed within the organisation (Kirwan, 1998).

As observed by Jackson (2010), there are many different approaches to safety culture and the only certainty is that there are no right ones and no wrong ones. At each place in time and for each organisation, some methods to approach safety culture may be more adequate and efficient than others.

3.3.5. Drift into failure

The “drift into failure” is the process through which system operations are progressively brought closer to the limits of safety, in a constant adaptation to the changing pressures of their environment. Dekker (2004) considers this the “greatest residual risk” in today’s sociotechnical systems and defines it as an incremental movement towards the boundaries of a safety envelope. Rasmussen (1997) discusses a “natural migration of activities towards the boundary of acceptable performance”, which usually precedes major accidents. In analogous terms, Jackson (2010) discusses drift toward brittleness, while considering brittleness the opposite of resilience (section 3.4.1). Above all, this concept places emphasis on the dynamic nature of system operations, as Cook & Rasmussen (2005) discuss within the context of patient safety in health care.

Rasmussen (1997) places the routes of this migration in the degrees of freedom that individuals are left with for the management of their normal activities and for the decisions they are confronted with. Despite the constraints and objectives put in place by laws, rules and procedures, actors at all levels of the system are left with a “work space” within which they are required to make decisions and manage pressures. Dekker (2004) considers the scarcity of resources and competition the most relevant types of system pressures, which can drive an organisation and people within it, to push the limits of safe operations. Because commercial gains at boundaries (limits of system capacities) tend to be greater, systems are driven closer and closer to limits in order to achieve and maintain success within dynamic environments. An every-day example of this can be found in the context of car driving: people tend to drive faster and often exceed speed limits to get to their destination faster and save time, but by doing so they increase the risk of causing or having an accident. Leveson *et al* (2004) discuss the NASA "faster, better, cheaper" approach, which clearly illustrates the severe impacts of system pressures. While facing pressures to cut costs and better justify their expenditures and missions, NASA accelerated its launching schedules, which reduced time necessary to perform required maintenance and shuttle testing. The fear for the survival of the space programme has eroded safety procedures. Woods (2003) comments in regards to the Columbia accident that NASA failed to balance safety with intense production pressure, which resulted in a pattern of drift towards failure.

The key problem in dealing with the drift into failure of complex systems is the difficulty in perceiving the actual shift, as well as the proximity of safety boundaries during everyday operations (normal work). As Dekker (2006) points out, from one hand, safety boundaries are themselves dynamic, which increases the difficulty in maintaining perception of safety margins in relation to operations. On the other hand, there is a more or less implicit consensus amongst the members of the organisation, in regards to what is "normal work". Any changes in common practices (the norm) are usually imperceptible, as they slowly and progressively accumulate towards a new adjustment to pressures. Previously, Dekker (2004) stated that uncertain technology and incomplete knowledge of the boundaries render people incapable of stopping the drift or even perceiving it.

Dekker (2004) discusses the crash of Alaska Airlines 261 flight in 2000, as an illustration of drift into failure. Initial reports pointed to a mechanical failure (snap of the tail trim system), as a result of poor maintenance. However, thorough investigations revealed that for more than a decade, decisions made at all levels of the safety system contributed for this outcome. Decisions involving all hierarchical levels of safety, such as aviation regulators, airliner and manufacturer safety and maintenance committees, and maintenance crews, had progressively eroded safety barriers and brought the system closer to safety boundaries (and beyond). Dekker (2004) points out that only in hindsight, decisions such as extending the trim maintenance intervals appear to have jeopardised safety. The organisational complexity that surrounded such decision processes made it virtually impossible to detect the way in which the equally complex structure of safety barriers was being weakened at different levels of the system.

The concept of drift into failure illustrates the challenges of managing safety in complex systems. The drift of systems is clearly associated with complexity and the ability to make informed decisions in view of the behaviours exhibit by the system. Complexity “blurs” visibility over system performance and what may seem an adequate decision or course of action, could be leading the system towards safety boundaries (Dekker, 2004). As earlier described, safety is about controlling the performance of systems (Leveson, 2006). The fact that systems may drift beyond the mechanisms and procedures intended to control their performance, suggests the need for safety approaches more appropriate to the demands of complex environments.

3.3.6. A system approach to safety

Hale & Hovden (1998) point out the importance of major accidents (e.g. Three Mile Island, Bhopal or Chernobyl) in the shift of safety management perspectives. Investigations into major occurrences of the 19070’s and 1980’s concluded that the bureaucratic and strict safety structures in place could not account for causal factors that were found to be beyond human and technical failures (Turner & Pidgeon, 1997). The perception of the widening gap between systems complexity and existing safety practices lead to the adoption of more flexible approaches, aiming to better respond to the fast pace changes and heterogeneity of modern organisations. To this end, Hale *et al* (1998) discuss the self-regulation and certification approaches initiated in the 1970’s. The principle at stake was that responsibility and accountability had to fall on those creating the risks, rather than governments and their agents issuing regulations and standards to control such risks. In line with this shift in safety practices, aviation and nuclear power are among the first industries to develop safety management systems. These systems constitute an organised approach to managing safety (Dijkstra, 2006), and beyond supporting specific safety needs, they facilitate the oversight role of national authorities.

The development of self-regulating management systems incentivised organisations to investment in research directed at their specific safety endeavours. Hale *et al* (1998) mention the growing interest of companies in developmental studies focusing on organisational design learning and management. Through such studies, safety research has gained interest in system theories, as a way to better understand complex synergies and combinations of events. Hale & Hovden (1998) refer to this as the “third age of safety”. After a first age, during which safety focused on purely technical issues (initial industrial contexts), a second age with strong emphasis on human factors (human error and information technology), this third age of safety focuses on risks emerging from interactions between system components.

In terms of accident analysis, an approach to safety based on system theories allows more complex relationships between events to be considered and provides a way to look more deeply at why the events occurred (Leveson *et al,* 2003). Traditional models such as event trees, aim at building chains of events, either by placing those at the origin as route causes, or at the “sharp end” as immediate causes of accidents. System based models consider all events at the “sharp end” of the undesired outcome (Hollnagel, 2004). Although a timeline remains essential to understand occurrences, the focus is set on the relations between events, rather than their sequence in time. Events are considered as parts of the whole rather than distinct elements. Instead of looking at accidents as an end result, they are considered “emergent phenomena”, as they arise from the combination of the concurrent events (Hollnagel, 2004).

The work of Rasmussen (1997) explains the relevancy of system views to understand safety in complex environments. Rasmussen (1997) refers to safety sociotechnical systems, which span across legislators, managers, work planners and operator levels. This model was earlier mentioned when discussing organisational decision making perspectives (Svedung & Rasmussen, 1998 in section 3.2.2) and is here represented in Figure 3.1.

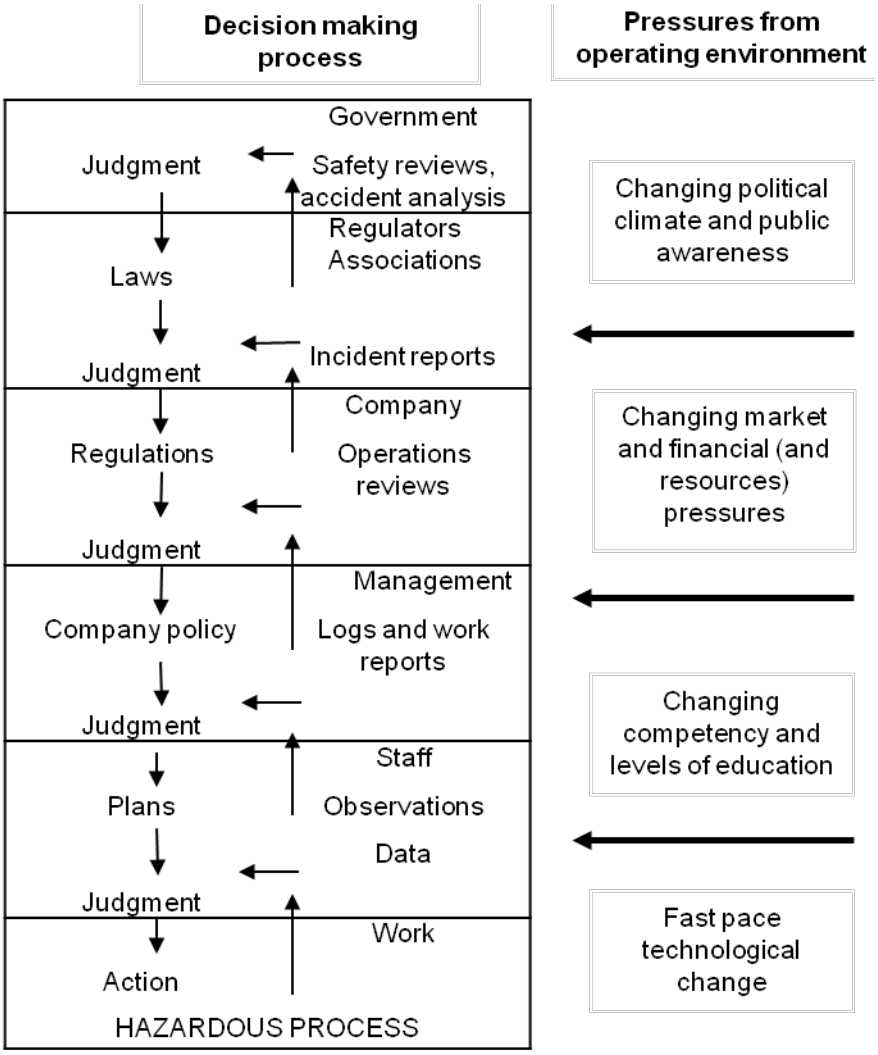


Figure 3.1: Sociotechnical system involved in risk management (from Rasmussen, 1997)

The control of hazardous processes relies on a series of laws, rules, instructions and procedures that are produced and applied throughout this system. Rasmussen (1997) argues that in order to address risks emerging from dynamic social contexts, the decisions made by politicians, safety officers, work planners and operators, as well as the pressures that constrain them, must be considered within a functional approach, as opposed to a structural decomposition into static elements. As earlier discussed, decisions are triggered by conflicting circumstances that pressure people towards making some kind of choice. Therefore, Rasmussen (1997) and later Svedung & Rasmussen (1998) maintain that risk management in complex systems requires understanding how pressures at each level affect decision making, and how decisions at one level affect decisions of the next one. An example of this can be found in the response to the devastation caused by the hurricane Katrina in 2005. As Westrum (2006b) discusses, despite the availability of supplies and resources to relieve the victims, these were not used because of authority disputes or breakdowns in communication. The failure of the hierarchical structure and its communications led to a complete stall in the system. Whatever possible ways there might have been to minimise the damage to the system and enable it to recover its operation more quickly had failed.

Leveson *et al* (2003) address the same hierarchical system perspective. They argue that the downstream decisions such as the ones represented in Figure 3.1, introduce the boundaries deemed necessary to carry out the hazardous process within acceptable safety limits. On the upstream flow, information on system performance is provided to the higher hierarchical levels, which will then support future decisions, as necessary. Leveson *et al* (2003), define this flow of information as a safety control loop. From this perspective, lack of control over the system may arise whenever the information flow is interrupted, inaccurate or is taking too much time, among other information related issues. The authors point out the relevancy of this concept, as systems become increasing dependent on information technologies.

In light of a systems approach to safety, Leveson (2004) considers that many accidents attributed in a recent past to human error, would be more accurately described as the result of inadequate system and interface design. Models based on system theories consider accidents as arising from the interactions among system components and lead to the investigation of multiple causal factors and concurrent events (Leveson *et al*, 2003). Woods (2003) discusses the findings of the Columbia Accident Investigation Board and points out the identification of “holes in the organisational decision making”. The organisational factors identified as causes for such holes were not considered unique to NASA and its programmes, but rather “generic vulnerabilities that have contributed to other failures and tragedies across other complex industrial settings”.

The integration of system theories into safety management has led to the recognition of concurrent risk factors and system level interactions which would escape “traditional” safety methods that tend to decompose events into linear chains of events. Because the nature of accidents has shifted, safety measures such as the use of “redundancy”, are becoming ineffective and in many cases, adding complexity to the system (Leveson, 2004). In this context, research on new ways of managing safety can be considered a crucial endeavour for the survival of today's complex systems. A systemic approach to safety appears to be more adequate to the challenges of high complexity, as it focuses on the dynamic nature of system interactions and the non-linearity of its effects (Hollnagel, 2004).

3.4. Resilience engineering

Resilience engineering is considered a new approach to safety management that focuses on how to deal with complexity (Woods & Hollnagel, 2006). This approach is proposed as a framework for the improvement of rail engineering planning, in terms of its ability to cope with the challenges emerging from high complexity.

Beyond the aspects of system complexity previously discussed, the global scenario of resource scarcity, environmental pollution and climate change is also put forward as a cause for many of the serious safety and security threats currently faced by societies. Boin *et al* (2010) distinguish such threats from "routine emergencies" such as fires and traffic accidents, and characterise them as "low-chance", "high-impact" events that can compromise life sustaining systems and require governmental intervention under high uncertainty conditions. These are the circumstances in which resilience is highlighted as a possible solution for the sustainability, reliability and safety of systems (Boin *et al*, 2010 and Jackson, 2010).

The concept of resilience covers many different matters (Westrum, 2006a) is used across many different scientific domains. Resilience is firmly based in the fields of engineering, biology and psychiatry (Gunderson *et al* 2002, Jackson 2010, Vugrin *et al* 2010, Boin *et al* 2010 and Holling 2010). While engineering applies this concept to materials and technical systems, biology focuses on living organisms and systems, and psychiatry aims at understanding resilience from an individual perspective (Boin *et al*, 2010). This section explores resilience engineering concepts and provides the theoretical background that justifies its use as a framework in the context of rail engineering work.

3.4.1. Definitions

Resilience is generally interpreted as the ability to recover from or to resist being affected by some shock, insult or disturbance (Vugrin *et al*, 2010). Foremost, given that it regards the recovery after events, this concept must encompass a given timeline and therefore, should be regarded as a process rather than a given quality. Sutcliffe & Vogus (2003) refer to resilience as an emerging process in organisations, which develops through continually dealing with risks, stresses and strains. Within the same dynamic perspective, Westrum (2006a) considers three conditions as the fundamentals of resilient situations, which Jackson (2010) later paraphrases as follows:

- **Avoidance** relates to the ability to foresee potential threats and prevent something bad from happening.
- **Survival** implies that the system, while experiencing disturbance, maintains operations, even if partially incapacitated. This means that the system is able to cope with ongoing trouble and therefore, prevent something bad from becoming worse.
- **Recovery** refers to the ability of the system to repair itself and regain desired performance after something bad has happened.

Jackson (2010) regards resilience as the opposite of brittleness. In this sense, while the purpose of resilience in systems is achieving safety, brittleness leads to an unsafe condition of the system. Avoidance is clearly the ideal system condition but as earlier observed, total absence of error is unrealistic within indeterminate and complex scenarios (Weick & Sutcliffe, 2007 and Leveson, 2004). Hence, an organisation needs to develop additional capabilities as, whenever avoidance mechanisms become insufficient to face conditions, survival abilities should be put into action and recovery the envisaged goal. Jackson (2010) considers that at least two of these three conditions must be met in order for resilience to be considered.

The concept of resilience, as previously described, contemplates a wide range of possible applications. It is clearly a trans-disciplinary aspect in organisations (Jackson, 2010). This becomes evident not only in the range of professionals that participate in groups such as the Resilience Engineering Network but also in the diversity of definitions found in the literature. In order to explore the actual diversity of applications and build an appropriate understanding of the concept for this research, a literature survey of definitions was conducted. Keeping in mind the context of sociotechnical systems as the focus of this research, this survey was limited to the frame of systems approaches to resilience. Table 3.3 summarises the most relevant definitions found in the literature. For reasons of practicality, only more explicit definitions found in relevant systems literature were considered. The keywords also shown in this table are used as indication for resilience properties in systems. These will be further explained in the next sections and explored throughout this thesis in the context of rail engineering work.

Table 3.3: Definitions of resilience

Authors	Definition	Keywords
Adger (2000) in Vugrin *et al* (2010)	Ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change	External stresses
Allenby (2005) in Vugrin *et al* (2010)	Capability of a system to maintain its functions and structure in the face of internal and external change and to degrade gracefully when it must	Internal and external change Degrade gracefully
Boin *et al* (2010)	Ability to negotiate the flux (of events) without succumbing to it	Negotiate
Comfort (1999) in Vugrin *et al* (2010)	Capacity to adapt existing resources and skills to new situations and operating conditions	Adapt Resources and skills
Fiksel (2003) in Vugrin *et al* (2010)	The essence of sustainability. The ability to resist disorder	Sustainability Disorder
Fujita (2006b)	Utilisation of system's potential abilities (engineered features or acquired adaptive abilities) to the utmost extent and in a controlled manner, both in expected and unexpected situations	Potential abilities Utmost extent Controlled manner
Gunderson *et al* (2002)	Strength of mutual reinforcement between processes, incorporating both the ability of a system to persist despite disruptions and the ability to regenerate and maintain existing organisation	Mutual reinforcement Persist Regenerate
Hale & Heijer (2006a)	Ability to steer the activities of the organisation so that it may sail close to the area where accidents will happen but always staying out of the dangerous area	Steer activities Dangerous area

Holling (1973) in Vugrin *et al* (2010)	A measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables	Persistence Absorb change and disturbance Maintain relationships
Hollnagel (2006)	Ability of an organisation to efficiently adjust to harmful influences rather than to shun or resist them Intrinsic ability of a system to react to and recover from disturbances at an early stage, with minimal effect on its dynamic stability	Efficiently adjust Harmful influences React and recover Dynamic stability
Hollnagel (2011a)	The intrinsic ability of a system to adjust its functioning prior to, during or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions	Adjust functioning Sustain required operations Expected and unexpected conditions
Jackson (2010)	Processes, disciplines and infrastructures that need to be in place to make sure that undesired events do not happen or that systems may survive such events and maintain operation	Processes, disciplines and infrastructure s Survive Maintain operation
Leveson *et al* (2006)	Ability of systems to prevent or adapt to changing conditions in order to maintain (control over) a system property	Prevent or adapt Changing conditions
Starbuck & Farjoun (2005)	Continued willingness to drop one's tools in the interest of greater agility	Continued willingness Greater agility
Sutcliffe & Vogus (2003)	Maintenance of positive adjustment under challenging conditions Ability to absorb strain and preserve or improve functioning despite the presence of adversity Continuing ability to use internal and external resources successfully to resolve issues Capacity to rebound from adversity strengthened and more resourceful	Positive adjustment Internal and external resources Strengthened
Tierney & Bruneau (2007) in Vugrin *et al* (2010)	Inherent strength and ability to be flexible and adaptable after environmental shocks and disruptive events	Strength Flexible and adaptable

U.S. Department of Homeland Security Risk Steering Committee (2008) in Vugrin *et al* (2010)	Ability to resist, absorb, recover from or successfully adapt to adversity or a change in conditions Capacity of an organisation to recognise threats and hazards and make adjustments that will improve future protection efforts and risk reduction measures	Resist, absorb, recover Recognise threats and hazards
Vugrin *et al* (2010)	Ability to efficiently reduce both the magnitude and duration of the deviation from targeted system performance levels	Magnitude and duration Deviation from targeted performance
Walker & Salt (2006)	Ability of a system to absorb disturbance and still retain its basic function and structure	Absorb Function and structure
Weick & Sutcliffe (2007)	Intrinsic ability of an organisation (system) to maintain or regain a dynamically stable state, which allows it to continue operations after a major mishap or in the presence of continuous significant stresses	Maintain or regain Dynamically stable state Continuous significant stresses
Westrum (2006a)	Ability to prevent something bad from happening, from becoming worse, or to recover from it once it has happened	Prevent Becoming worse Recover from
Widalvsky (2004)	Capacity to cope with unanticipated dangers after they have become manifest, learning to bounce back	Unanticipated dangers Bounce back
Woods & Hollnagel (2006)	A paradigm for safety management that focuses on how to help people cope with complexity under pressure to achieve success	Safety management Complexity Pressure
Wreathall (2006)	Ability of an organisation (system) to keep, or recover quickly to, a stable state, allowing it to continue operations during and after a major mishap or in the presence of continuous significant stresses Ability to have appropriate levels of resources (particularly reserves) that can react to sudden increasing challenges or onset of a major hazard	Keep or recover quickly Stable state Continuous significant stresses Appropriate level of resources React

Several of the authors mentioned in Table 3.3 (Vugrin *et al* 2010, Gunderson *et al* 2002, Walker & Salt 2006, among others) distinguish two types of resilience, which reflect different views on how humans interact with and manage the world around them (Walker & Salt, 2006):

- **Engineering resilience** is considered a more “classical” view, emanating from physics models. It assumes a system exists around an equilibrium state and its resilience is defined in terms of the ability to resist departure from, or rapidly return to that equilibrium after significant disturbances (Holling, 2010). From this perspective, efforts aim at maintaining a degree of constancy in the system by containing its variability.
- **Ecological resilience** assumes that systems can reorganise themselves and therefore, contemplates the possibility of systems shifting from one domain of stability to an entirely different one. In this sense, resilience is defined by the magnitude of disturbance that a system can absorb (avoid) before it shifts from one set of mutually reinforcing processes and structures to a new one (Gunderson *et al*, 2002). The focus is set on the persistency of relations among parts of the system. Like many plants that bend with the wind instead of stiffly attempting to resist it, ecological resilience assumes the possibility of the system shifting to new equilibrium states in order to ensure its basic structure and function (Walker & salt, 2006).

Following the conditions of Westrum (2006a), both perspectives contemplate some form of avoidance, survival and recovery and therefore, could be considered within the domain of resilience. On the one hand, engineering resilience aims primarily for avoidance capacities (anticipation of threats) and would resort to recovery (and perhaps survival) capabilities to ensure fast return to its known stability condition. On the other hand, ecological resilience maintains more tolerance in the face of threats and endeavours mostly for survival and recovery capacities as a way to deal with the resulting constant change. This constitutes a fundamental distinction between these perspectives: While the engineering perspective aims to achieve and maintain a condition of stability, the ecological perspective aims at creating capacity to cope with variability.

Widalvsky (2004) considers that both perspectives constitute valid and useful safety approaches, depending on the type of organisation and its activities. In line with this view point, this research adopts as a working definition of resilience the one given by Hollnagel (2011a), which contemplates both the engineering and ecological perspectives:

> *The intrinsic ability of a system to adjust its functioning prior to, during or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions* (pp xxxvi)

In line with the principles enumerated by Westrum (2006a), Wreathall (2006) considers that the expression "resilience engineering" refers to the development and implementation of the tools necessary to achieve and maintain resilience in the system. As discussed by Jackson (2010), engineering is here used in a broad sense and contemplates all aspects and features used to generate (engineer) resilience in the system. Rather than referring to resilience engineering, Jackson (2010) talks about architecting resilient systems.

The relevancy of the engineering and ecological approaches for the safety of organisations will be explored in the next section, in order to clarify the potential benefits of resilience engineering as a safety management approach.

3.4.2. Stability versus flexibility

Widalvsky (2004) suggests that the search for constancy that characterises the engineering perspective defines more appropriately a condition of stability, rather than resilience. Widalvsky (2004) further argues that, under stable conditions, the future is less uncertain. In such conditions, risks can be known, predicted and therefore, anticipated more easily. Hence, the ability to anticipate threats is closely related to the existence of some form of operational stability in the system. If there is a well known condition of equilibrium in which the organisation aims to remain, then safety management can be built around anticipation capabilities. This is the scope of safety measures such as fire drills, which aim to prepare people for a known threat. Safety management in HROs, such as nuclear power plants, is an example of this evolution: Safety regulations and measures were added cumulatively in the attempt to anticipate new dangers (Widalvsky, 2004). Woods & Hollnagel (2006) consider that safety practices have always been dominated by hindsight in the sense that their focus was set on preventing undesired events from happening again. This path of development was based on the experience of well known and stable system operations, as earlier pointed out by Hale *et al* (1998) in section 3.3.1.

System complexity has lead organisations to consider other safety requirements, beyond the anticipation of known events. As discussed in section 3.3.2, organisations face today constant pressure and must be capable of adapting to rapidly changing environments (Marais *et al*, 2007). Safety management must accept and recognise variability in operations and can no longer solely rely on the predictability and anticipation of known threats (Leveson, 2004). The rapidly changing environment inherent to high complexity requires systems to be flexible in order to adjust to new environmental conditions (McDonald, 2006). Dealing with variability is clearly in line with the principles of the ecological perspective of resilience, rather than the engineering one (stability), as this perspective focuses on the development of means to manage change and its unpredictability (Widalvsky, 2004). The rationale for accepting variability, as opposed to enforcing stability, lies with life's inherent uncertainty and complexity (Widalvsky, 2004). Management under complex conditions is necessarily based upon incomplete understanding, and in face of uncertainty, we are unlikely to attain a sufficient degree of anticipation (Gunderson *et al*, 2002). Widalvsky (2004) proposes the human body as an example of ecological resilience and its ability to cope with change. Rather than resisting aggressions from the environment, the human body takes on contaminations and builds on them to improve its immunity.

As argued by Gunderson *et al* (2002), aiming for stability requires less effort than considering the potential unknown threats and the need for flexibility. Nevertheless, an absolute stable condition could only be achieved through perfect anticipation (Widalvsky, 2004). As discussed in section 3.2.2, in order to make decisions, no matter how complex or simple they might be, people are forced to simplify scenarios and make assumptions on a number of factors. Like people, organisations must assume that certain aspects of their operation and their environment remain stable, in order to reduce uncertainty and define possible courses of action and make a decision (Widalvsky, 2004 and Hollnagel, 2009a). Within this context, even when faced with high complexity and the uncertainty of constant change, organisations must find some form of stability on which to ground their (safety) management decisions. It is only based on stability that the need for change and adjustment can be perceived (Widalvsky, 2004). McDonald (2006) further explores this by discussing the relation of sociotechnical systems with their environment in terms of a balance between stability and flexibility. Achieving stability with the physical, social and economic elements of the operating environment is characterised as an otherwise positive or successful outcome. However, rather than a static condition, this stability constitutes a dynamic (therefore, flexible) equilibrium with the system's environment. It is only by achieving such equilibrium and maintaining it (therefore, having stability) that undesired variability and its potential for failure can be detected. Maintaining stability requires the capacity to adjust (McDonald, 2006). Hence, both stability and flexibility must be considered for the safety of complex systems.

The arguments presented in this section towards the ability to maintain stability and the ability to cope with variability, suggest that the engineering and the ecological perspective on resilience should be seen as complementary. As stated by the Resilience Engineering Network, resilience engineering looks for ways to enhance the ability of organisations to create processes that are robust yet flexible (retrieved from www.resilience-engineering.org on 13 April, 2009). Walker & salt (2006), suggest that while robustness is often associated with the image of a tree that resists firmly, flexibility is pictured as the plant that bends with the wind. Stability, as the ability to primarily avoid undesired events, provides the means for robustness. Accepting variability means maintaining a degree of flexibility necessary to deal with constant change. Hutter (2010) discusses resilience in the German public sector and refers to the need for strategies for dealing with natural hazards, which are both robust enough to deal with partly known and unknown contexts and simultaneously, flexible enough to manage "radical surprise". Resilience engineering relates to achieving and maintaining a balance between the need for stability, in order to achieve avoidance, and flexibility as a way to develop survival and recovery capacities. McDonald (2006) places resilience in the successful management of a balance between aspects that reinforce stability and others that work towards flexibility. Table 3.4 summarises the main aspects considered by McDonald (2006).

Table 3.4: Aspects of stability versus flexibility (from McDonald, 2006)

Stability	Flexibility
Formal procedures as a way to develop stronger routines and improve coordination	**Informal work** practices are developed on the base of local autonomy and consolidate it
Centralisation can increase reliability by reducing the variance induced by individual skills and experience	**Decentralisation** is at the core of distributed decision making
Standardisation facilitates and contributes to increased product quality	**Adjustability** of product standards in response to market or operational feedback and acquired expertise
Automation of routine or complex functions enforces standardisation (normally through the use of well tested technology)	Technologies that enable **appropriate human control**, rather than constraining it (normally requires innovative technology)

The challenge resides in the fact that although both stability and flexibility are needed to achieve and maintain resilience, at some point these might be contradictory objectives. For instance, organisations must realise when and how procedures should be made robust and what informal practices should be allowed to enrich local autonomy and response to operating variability (McDonald, 2006). The opposing nature of these organisational aspects will require trade-offs to be made. Where decisions are made to formalise, centralise or standardise, opportunities for informal practices, decentralisation and adjustability will have to be sacrificed. Grote *et al* (2009) discuss a demand for concurrent standardisation and flexibility. This is approached in detail in the next sections.

3.4.3. Managing uncertainty

The ability to cope with the variability and uncertainty that are inherent to complex operations is at the core of achieving and maintaining resilience (Hollnagel, 2011a). As shown in Table 3.3, definitions of resilience make frequent references to these abilities. Grote (2004) proposes two different approaches for the management of uncertainty in organisations, as summarised in Table 3.5.

Table 3.5: Two approaches to managing uncertainty in organisations (from Grote, 2004)

Minimising uncertainty	**Coping with uncertainty**
Complex central planning system	Planning as resource for local action
Reducing operative degrees of freedom through procedures and automation	Maximising operative degrees of freedom through local (lateral) coordination and cooperation
Disturbances are symptoms of inefficient system design and are to be avoided at all cost through heighten and cumulative control measures (regulations and procedures)	Disturbances are opportunities for the use and enhancement of competencies and for system change
Local dependence from centralised feed-forward control	Local autonomy coordinated through feedback control

Under well known operation scenarios and the stability conditions described in the previous section, safety management maintained reliance on the ability to prevent known threats and efforts were focused on thorough planning and monitoring of operations, as a way to **minimise uncertainty**. Rules and procedures aimed at minimising degrees of freedom to people at the front end of operations and any deviations from planned and prescribed processes were seen by management as the need for further planning and monitoring as the reinforcement of rules (Grote, 2004). Hence, as shown in Table 3.5, this is regarded as a feed-forward approach. From this perspective, local actors are entirely dependent on feed-forward control through centralised decision making (Grote, 2004).

The realisation of new accident aetiologies such as the ones emanating from high complexity and system interactions, as described in section 3.3.2, is at the origin of new approaches to the production of rules and procedures. As pointed out by Grote *et al* (2009), although rules may be generally regarded as useful guides for safe behaviour, there is a growing awareness that over-specification of procedures and incremental development of rules based on past experience goes against the need for flexible operating conditions that become necessary to deal with uncertainty. Within this context, the second approach in Table 3.5 aims at **coping with uncertainty** by enabling local control. From this perspective, control relies on local autonomy, as actors are given as many degrees of freedom as possible. Local actors become responsible for necessary adjustments to variability conditions. As Grote (2004) points out, within this operational context disturbances (momentary absence of stability) become opportunities for use and expansion of individual competencies and for organisational innovation and change.

Similar to the conclusions made in the previous section regarding the necessary balance between stability and flexibility, while some measure of centralised control is needed to ensure an efficient organisational and operational coordination, a certain degree of local autonomy is necessary to adjust tasks to ever changing operating conditions. Perrow (1999) discussed this based on the concept of couplings, which describes the strength or degree of interdependence between system components, subsystems or functions. Tight system couplings are typically found in continuous processing plants and other systems with a strong dependence on sequential operations. This reflects strong central control and very responsive relations between system components with little or no room for deviations from norms and procedures. Operational processes are intolerant to delays and to changes in sequence (Perrow, 1999). Conversely, loose couplings allow to a certain extent, parts of the system to perform according to their own logic and needs. Perrow (1999) illustrates this with aircraft manufacturing, where parts of the plane are manufactured separately and according to their own paces and processes but everything must be coordinated to achieve an efficient final assembly of the aircraft's fuselage. As observed earlier in section 3.3.1, the majority of current safety practices remain strongly reliant on strict regulations and centralised control. The relatively high numbers of safety norms produced by regulators of sectors such as the air and rail industries illustrate this. Within this context, most complex systems are characterised by tight couplings (Perrow, 1999).

Grote (2004) proposes the development of loose couplings as a way to balance the need for centralised coordination and reduced uncertainty, against the need for local autonomy to cope with the uncertainty of complex systems. Grote *et al* (2009) discuss the balance between standardisation and flexibility within the railway context through a more effective management of organisational routines and rules. Routines are described by the authors as the functional means through which organisations attempt to reduce uncertainty and manage complexity, by increasing stability, managerial control and legitimacy. Routines can provide simple "labels" for complex action patterns (Grote *et al*, 2009). In this sense, routines constitute a form of planning and structuring of complex tasks. As illustrated in Table 3.5, planning is an important element in managing uncertainty, either by attempting to minimise it or to cope with it.

3.4.4. Trade-offs

One of the most common realisations is that we cannot have everything in life. The immediate consequence is that people are frequently confronted with the need to make choices that involve giving up on one thing in order to have the other. This is generally described as a trade-off. Hollnagel (2009a) gives this concept a different level of consideration and considers it as a constant presence in every aspect of decision making, both individually and collectively within the scope of sociotechnical systems. From this perspective, every decision reached by a person or an organisation gives shape to a trade-off of some kind. Within this frame of mind, this section clarifies the roots of trade-offs and its relevance for resilience engineering.

As observed in section 3.2.2, organisations are today confronted with complex choices regarding the application of their resources (Crozier & Ranyard, 1997). For instance, if investments are to be made in technology, then other necessities will have to wait for new opportunities. In a simplistic way, Hollnagel (2009a) describes a decision according to three fundamental steps that are necessary to go from the external event that triggers the decision process, to its resulting course of action:

- An **evaluation** of the current situation and the problem at hand
- The **selection** of a given course of action from a range of options
- The **execution** of the chosen course of action, which amounts to planning the response to the initial problem

From this view point, trading-off is fundamentally generated during selection, as this step shapes the kind of choices made. It should be kept in mind that, as discussed by Zeleny (1981), a decision process is developed through an iteration of multiple partial decisions before a final decision is reached (section 3.2.2). As a consequence, even within this simple representation of a decision making process, within each evaluation, selection or execution step, several partial decisions must be considered, which themselves originate trade-offs. For instance, when evaluating, decisions have to be made on what information is needed or when that information is sufficient to build a good enough understanding of the situation. This substantiates the importance of trade-offs. They occur not just as the outcome of a decision making process, but also as a shaping factor throughout this same process by means of partial decisions. Hollnagel (2009a) describes this as the process (with trade-offs at their core) through which people adjust their performance, aiming to match the perceived conditions.

The scarcity of resources is at the origin of every trade-off (Woods, 2006a). Despite any other resource limitation, as pointed out by Hollnagel (2009a), everything takes a certain amount of time to be accomplished and everything takes place in time. Hence, for the large majority of situations, time can be considered the most crucial resource of all. When confronted with a task and the need to decide, capacity limitations most often refer to the inability to be fast enough within the time available (Hollnagel, 2009a). According to Hollnagel (2009a), this places two opposed concepts at the core of trade-offs:

- The need for **Efficiency**, in the sense that something is achieved with minimum expenditure of resources (in particular time), results from the insurmountable scarcity of resources (Hollnagel, 2009a). Because of this scarcity, tasks and decision making experiences pressure to keep resource utilisation to a minimum at all times. As noted by Woods (2003) in regards to the Columbia accident, under production pressure people develop shortcuts in reasoning, which leads to decisions being made based on assumptions. Although higher efficiency may be achieved, such shortcuts increase uncertainty and unpredictability (Hollnagel, 2009a).
- Conversely, **Thoroughness** stands for the ability to accomplish a given objective with disregard to any limitation. This implies that before an activity is carried out, there is sufficient confidence that all the resources and conditions necessary to achieve the intended outcome are in place (Hollnagel, 2009a). Hypothetically, this represents the possibility of carrying decision making processes through as much iteration (partial decisions) as desired. In practice, when carrying out rail engineering work, setting up site safety barriers and signs constitutes a precondition that aims to guaranty (or improve probability) that

work will be delivered safely.

Hollnagel (2009a) refers to this as the Efficiency-Thoroughness Trade-Off (ETTO) principle. Other authors, such as Dekker (2004), refer to a trade-off between safety and performance. While thoroughness, in principle, works towards safety by improving on preconditions necessary to avoid undesired results (achieve success), efficiency is devoted to performance improvement. From this, it follows that the ETTO principle is concerned with balancing conflicting goals, belonging to the domain of either thoroughness/safety or of efficiency/performance. The use of checklists constitutes a good example of this balancing act: By going through the checklist before taxiing to the runway, the pilot is reinforcing thoroughness (Hollnagel, 2009a). The checklist aims to improve certainty that the desired outcome (safety of take off and flight) will be achieved. Because a certain amount of time is needed to go through the checklists, efficiency is sacrificed.

As pointed out by Hollnagel (2009a) it rarely (if ever) is possible to be both thorough and efficient at the same time. Woods (2006a) illustrates this fact by the “faster, better, cheaper” policy adopted by NASA and its contribution to the Columbia accident. As observed in section 3.3.5, the Columbia accident can be broadly attributed to NASA’s failure in balancing safety against intense production pressure, which resulted in a pattern of drift towards failure. While complexity and a fragmented problem solving process hindered the ability to develop sufficient awareness of local and global conditions, pressures for performance led people to trade-off in favour of efficiency (Woods, 2003). Based on this same observation, Dekker (2004) intrinsically relates trade-offs with the drift into failure of complex systems. As illustrated by the Columbia accident, when trading-off favours efficiency beyond the capacities of the system, a drift into failure may occur.

From a resilience engineering perspective, the essence of a trade-off resides in the balance between as much efficiency as possible, so as to maintain operations close to safety boundaries, and the thoroughness necessary to ensure that such boundaries are not crossed (Woods, 2006a). In this regard, two capabilities are fundamental for trade-offs to contribute to resilience:

- People require information to support their decisions. Progress on safety ultimately depends on providing workers and managers with information about changing vulnerabilities (Woods & Hollnagel, 2006). Only then people can develop awareness of how much pressure for efficiency the system can sustain and when it is time to ponder with more thoroughness on the information available, or even to search for additional information (sacrifice decisions).
- Organisations need to develop ways of monitoring safety boundaries. As pointed out by Woods (2006a), systems need to maintain awareness and responsiveness to evidence of any potential shifting of decision criteria, which might lead the system across safety limits.

Woods (2006a) further points out that from a resilience perspective, the difficulty in balancing trade-offs ("ETTOing") is that thoroughness and therefore, attention to safety limits, is most necessary when performance pressures are higher. This means that precisely when they are most needed to respond to such heighten pressures, resources must be "sacrificed" to monitor and control the dynamics between system performance and safety boundaries. This is where resilience engineering should be placed.

3.4.5. Functional resonance

The theoretical foundations of functional resonance were firstly introduced by Hollnagel (2004). This concept was developed within the scope of a non-linear and dynamic approach to the safety of complex sociotechnical systems. Rather than the static analysis of processes or components and their sequences in time, the concept of function used conveys aspects of system performance. For the purpose of this discussion a function is regarded as a set of actions that a system performs towards the achievement of a given aim (Woltjer, 2009). From discussions at FRAM workshops (Functional Resonance Analysis Method – section 4.11.2), a function was generally described as something that transforms the state of the system.

The phenomenon of resonance in system operations is related to the fact that performance in complex environments is inherently variable in time. Variability can either be the result of short-term fluctuations on resources, demands or working conditions, among others, or slower and longer-term changes such as those depending on economical and commercial relations. Hollnagel (2004) places the slow drifts of systems towards "new norms and emerging tacit standards" within this context and considers as an example, the NASA processes of drift into failure (Woods, 2003).

As discussed in section 3.1.6, operations in complex systems are normally underspecified. Thus, carrying out tasks requires tools and formal procedures to be adapted to meet unforeseen (or unforeseeable) operating conditions. Approximate adjustments that are made by people at all levels of organisations (aiming to match operating conditions) must also be considered as sources of variability. As observed by Hollnagel (2009a), in the large majority of cases, these adjustments lead to successful outcomes and only rarely result in undesired events such as incidents and failures. This is clearly demonstrated by most accident rates in complex sociotechnical systems, which are typically beyond 10^{-6} occurrences per number of events (Amalberti *et al*, 2005). Hence, performance variability must be regarded as a useful resource, as it normally leads to success and only rarely, to failure. The processes that lead to success and failure are essentially the same, only their outcome is different, as "failure is the flip side of success" (Hollnagel, 2006).

Failure emerges when local variability produces insufficient or inappropriate adjustments to the variability of the environment (Hollnagel, 2006). It should be kept in mind that in view of the definitions given in section 3.1.1, for each system function, the remaining ones constitute its operating environment. This is systematised in Figure 3.2.

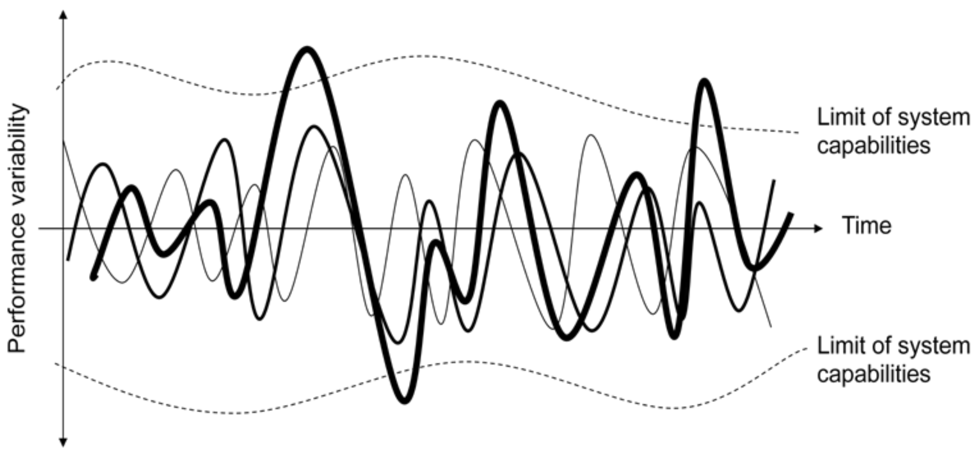


Figure 3.2: Performance variability and resonance (adapted from Hollnagel, 2008)

The variability of a number of functions (represented by thinner lines) may reinforce each other (resonate – represented by the thicker line) and exceed limits of system capacities (represented by dashed), which are also subject to variability. Thus, the thicker line in Figure 3.2 should be seen as the sum of the thinner lines. Functional resonance results from unforeseen interactions between the normal variability of functions. Normal variability of functions are weak signals and the resonance effect they may produce is the detectable signal, which may or may not exceed system capacities (Hollnagel, 2004).

Functional resonance emphasises the dynamic nature and non-linearity of performance in complex systems (Hollnagel, 2008). Based on this concept, accident analysis derives from an understanding of both “normal” and unusual functional relations in the system. Rather than aiming to eliminate variability, safety is built around the control of its sources and preventing it from assuming harmful proportions (Hollnagel, 2004). A system is in control if it is able to minimise to a manageable degree or eliminate undesired variability, or at least, that which is expected to exceed system capabilities (Hollnagel & Woods, 2006). The challenge then resides in providing people and organisations with tools to monitor not only sources of variability from within the system and its environment, but also changes of performance conditions that can lead to variations of system capabilities.

3.4.6. Measuring resilience

If the purpose of resilience engineering is to develop mechanisms and processes that can enhance system resilience (section 3.4.1), than adequate measurement becomes fundamental, as a way to monitor the success of such mechanisms and processes.

As pointed out by Hollnagel & Woods (2006), resilience, like safety, is something that a system “does” rather than something that it “has”. This observation highlights the emergence as well as the process nature of resilience. It is a characteristic of how a system performs through time, as opposed to a quality that, once acquired, remains (Hollnagel & Woods, 2006). This means that any means of measuring resilience must also be able to capture this dynamic nature of the concept through some integration over time. The concept of “drift into failure” (section 3.3.5) clearly contemplates the dynamic nature of systems. However, as pointed out by

Hollnagel & Woods (2006), the notion of safety boundaries is only metaphorical and thus, gaining perception of proximity or measuring a “distance” between operations and such limits becomes unrealistic.

Resilience cannot be measured by means of verifications such as the adherence to standards and rules. A measure of resilience must be in direct relation with how a system performs, and how capable it is in monitoring and controlling performance throughout a given period. In this sense, Hollnagel & Woods (2006) consider that only the potential for resilience can be measured and not resilience itself. Only the processes the system develops towards resilience can be assessed in time. If a system experiences failure, it can still exhibit resilience in the form of survival and recovery from that failure. Conversely, if a system experiences success, it does not mean it will keep on doing so. This is why Hollnagel & Woods (2006) consider that a “constant sense of unease" is necessary for a system to maintain resilience, as this prevents complacency.

The broadness of the resilience concept is implicit in its various definitions and can be perceived from the keywords mentioned in Table 3.3 (section 3.4.1). Hence, resilience parameters or inferable criteria must be able to capture a great diversity of system features (Hollnagel, 2011a). Hollnagel *et al* (2006) and Jackson (2010) provide ample descriptions for resilience characteristics based on recognisable system aspects of system performance. In particular, Wreathall (2006) summarises characteristics for what could be considered a resilient system, and Hale & Heijer, (2006b) and Hale *et al* (2006) discuss possible topics for measuring and auditing resilience. These are shown in Table 3.6 as characteristics for resilient and non resilient systems.

Table 3.6: Characteristics of resilient and non resilient systems (from Wreathall 2006, Hale & Heijer 2006b and Hale *et al* 2006)

Resilient system	Non resilient system
Top level commitment: Management recognises human performance concerns and tries to continuously and extensively address them	Defences erode under **production pressures**
Just culture: support on reporting of issues upwards through the organisation yet not adopting culpability attribution behaviours	Safety is not **built as inherently as possible into the system** and the way it operates by default

Learning culture: willingness to respond to events not with denial but through repair and reform	There is not a **high enough devotion to safety** above or alongside other system goals
Awareness: Data gathering that provides management with insights about various aspects of performance	There is a failure to revise risk assessments appropriately as **new evidence accumulates**
Preparedness: The organisation actively anticipates problems and prepares for them (constant sense of unease, Hollnagel & Woods 2006)	Past good performance is taken as a reason for future confidence about risk control (**complacency**)
Opacity: The organisation is aware of the boundaries and knows how close it is to the edge in terms of degraded defences and barriers	**Fragmented problem solving** clouds the big picture
Buffering capacity: Ability to adapt to new or complex problems without disrupting overall functionality. It requires that people are able to make decisions without having to wait on management instructions	The organisation responds **stiffly and slowly** to changing demands and is not able to cope with unexpected situations
Flexibility: Ability of the system to restructure itself in response to external changes or pressures	
Tolerance: how the system behaves near a boundary – slowly degrades or quickly collapses when pressure exceeds adaptive capacity	**Breakdown at boundaries** impedes communication and coordination, which do not have sufficient richness and redundancy

From the characteristics in Table 3.6, Hollnagel & Woods (2006) highlight three characteristics as fundamental abilities of a resilient system. These characteristics are aligned with the three conditions of resilient situations approached by Westrum (2006a):

- Being **prepared** provides the ability to **avoid** something bad from happening.
- Being **flexible** becomes fundamental to ensure **survival** under varying conditions and degraded modes.
- Being **adaptive** supports quick **recovery** from disruptions and regain of desired performance.

Although this constitutes useful guidance towards measuring and monitoring resilience, as discussed by Westrum (2006a), it still raises a number of questions regarding how these capabilities should be embedded in the system in order for it to be considered a resilient one. For instance, the type of events that a system must be capable of avoiding, under what circumstances should it be flexible and how fast should it be capable of recovering, among others.

Within the literature sources consulted on the subject of resilience, several other proposals are put forward as potential sources of measurement. Sutcliffe & Vogus (2003) consider that resilience requires the presence of latent resources that can be activated or recombined as new situations and challenges arise. Therefore, measuring the amount of latent resources, whether this is time, financial, or technical resource, may be one approach to measuring resilience. This still raises questions regarding the amount of latent resources necessary to face each new different challenge. Widalvsky (2004) argues that resilience is the ability to be vitally prepared for adversity and that this requires improving overall capability in a wide range of areas such as investigation, learning and acting, even when not knowing what will be called to act upon. Vugrin *et al* (2010) consider that the measurement of system resilience involves two components. The first is a systemic impact which is defined as the difference between a targeted and an actual system performance, following a disruptive event. The second component is the total recovery effort, which stands for the amount of resources expended during recovery processes, following the given disruption.

More recently, Hollnagel (2011a) proposes four main capabilities ("four cornerstones of resilience"), which derive from the definition given in Table 3.3 (section 3.4.1):

- **Knowing what to do** corresponds to the ability to address the "**actual**" and respond to regular or irregular disruptions by adjusting function to existing conditions.
- **Knowing what to look for** corresponds to the ability to address the "**critical**" by monitoring both the system and the environment for what could become a threat in the immediate time frame.
- **Knowing what to expect** corresponds to the ability to address the "**potential**" longer term threats, anticipate opportunities for changes in the system and identify sources of disruption and pressure and their consequences for system operations.
- **Knowing what has happened** corresponds to the ability to address the "**factual**" by learning from experiences of both successes and failures.

If by definition these four cornerstones characterise a resilient system then the scope of resilience engineering is to develop and manage the corresponding capabilities in the system. Based on these four capabilities, Hollnagel (2011b) proposes a Resilience Analysis Grid (RAG) as a way to manage resilience in system. An example of a RAG is shown in Figure 3.3.

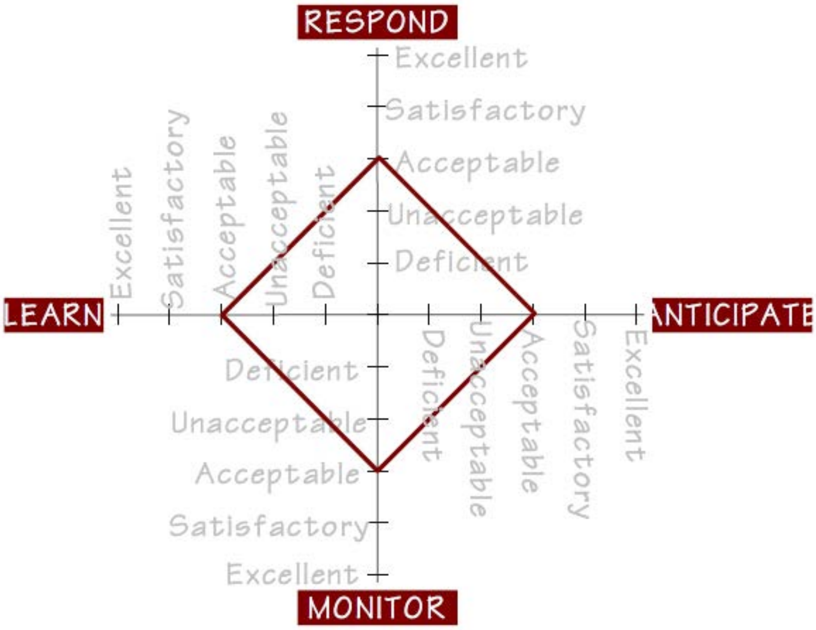


Figure 3.3: Example of a Resilience Analysis Grid - RAG (from Hollnagel, 2009b)

The management of resilience should be based on a balance between the four capabilities, as shown in Figure 3.3. This does not imply that all four capabilities should exist in the same proportion. As mentioned by Hollnagel (2011b), while for systems like a fire brigade, the ability to respond to the actual may be more important than to consider the potential, for others such as sales organisation, the ability to anticipate may be just as important as responding.

The development of this grid is based on the production of four sets of questions that can adequately represent each of the four capabilities according to the specifics of the operational and organisational context under analysis. Generic sets of questions are proposed by Hollnagel (2011b). These sets of questions can then be answered with the support of other methods such as interviews or group discussions with subject matter experts, in order to produce a quantified or semi-quantified assessment of issues raised in the questions asked. This requires context dependent approaches that can relate the consideration of these capabilities at a system high level with operational level and concrete aspects of system performance. Each domain or organisation may require its own specific set of tools and methods, whether these might be existing ones such as performance monitoring data, or new ones that need to be brought about to consider the requisites of a dynamic and non linear system perspective (Hollnagel, 2011a).

3.5. Planning and scheduling

As earlier described in section 2.2, the planning system is responsible for critical business decisions that directly affect Network Rail's relations with its customers. The impact of planning on the safety and reliability of the engineering work delivered on the infrastructure was also mentioned in the introduction. Dietrich & Jochum (2004) present a number of high risk contexts in which several references are made to aspects of planning and their importance for the safety of operations. In particular, Rooij (2004) discusses the investigation, negotiation and planning stages in the salvage process of the Russian submarine Kursk, and Remmer (2004) discusses an accident during the construction of a highway bridge in which insufficient and deficient planning of work were identified as direct causes. In relation to organisational resilience, McDonald (2006) discusses several aspects of planning within the field of aircraft maintenance. This section explores the importance of planning and scheduling from the perspective of both business and organisational decision making and the safety and reliability of rail engineering work.

3.5.1. Defining planning and scheduling

In essence, planning is related to the unavoidable finite nature of resources. Because materials, time and money (among others) are always limited and therefore, cannot be made available whenever desired, priorities must be anticipated so that resources can be allocated accordingly. Increasingly complex organisational endeavours require equally complex work devoted to the forecasting of possible scenarios, so that resources and people are made available, either as a primary course of action or a contingency solution. Jorna & Kiewiet (2007) define planning and scheduling as the assigning of different kinds of entities, taking into account different constraints and working towards minimising or maximising various goal functions. From a human factors perspective, Pinedo (2009) considers these activities as forms of decision making supported by mathematical techniques and heuristic methods that allocate limited resources in view of the organisational goals.

In the tradition of the manufacturing industry, planning and scheduling have been approached from a relatively strict technical perspective (McCarthy & Wilson, 2001a). More recently, the high complexity organisational contexts in which frequently planning and scheduling tasks are performed has encouraged research aiming to explore other aspects such as human and organisational factors in this particular field. This has led to a more holistic view of planning and scheduling (McCarthy & Wilson, 2001a). Jorna *et al* (2005) provide an example of this research tendency by investigating planning in the Dutch Railroad Company based on the relation between the cognitive aspects, the organisational aspects and the support of computer based systems.

3.5.2. Decision making in planning

The role of humans in planning and scheduling has gained relevance over recent years. It is today recognised that improving on such functions in organisations requires more than dealing with mathematical problems. At all levels of planning and scheduling, processes still rely on people to make decisions and thus, understanding decision making, its constraints and contributing factors, becomes a fundamental step in improving the quality of planning and scheduling. In particular, naturalistic decision making approaches have been frequently used in relation to planning and scheduling contexts (Roland *et al*, 2011).

The attempts to replace human participation in planning and scheduling by computer based systems have often added new complexities to planning and scheduling tasks. Roland *et al* (2011) found that planners rely on overall knowledge of the business to solve decision problems and on efficient access to information to accurately interpret the state of affairs and planning scenarios. Although recent systems have succeeded in facilitating access to information, the nature of planning tasks remains the same. Only people can make decisions in the face of ever-changing environments using information and knowledge about the current situation, perceptions about the future and balancing a range of pressures and demands

(McCarthy & Wilson, 2001a). Given its strong emphasis on decision making, the aspects previously described in section 3.2, in particular regarding distributed decision making, have a critical impact on planning and scheduling.

3.5.3. Collaborative planning

Within large scale complex systems such as the railway industry, it has been frequently observed that planning functions extend beyond the strict boundaries of organisations (McCarthy & Wilson, 2001a). The survival of companies requires more than ever the recognition and close interaction with multileveled supply chains and customers. This has been referred to in recent literature as collaborative planning. Windischer *et al* (2009) identify the following characteristics as determining of collaborative planning processes:

- **Communication of anticipated events** by relating any uncertain information on probable occurrences and their likelihood.
- **Knowledge of reference field characteristics** through the exchange of information regarding operating conditions.
- **Agreement on common goals** and commitment to achieving such goals
- Agreement on any deviations from original plan through the **negotiation of alternatives**.
- Minimise restrictions on degrees of freedom in decision making by **recognising planning adequacy**.
- **Monitor** the execution of the agreed plan and **diagnose** and disseminate any discrepancies between the plan and actual situation.
- **Coordinate opportunistic planning** through explicit decision and agreement, and dissemination of information on resulting deviations from original plan.
- **Common reflection and decision** when the cancellation of plans becomes necessary.

3.5.4. Managing pressures and conflicts in planning

Planning is often surrounded by organisational conflicts. The way in which higher level plans are developed and how these determine production targets and the allocation of resources are often judged as unrealistic by those with visibility of problems at lower levels (McCarthy & Wilson, 2001a). This encourages deviations from prescribed schedules and practices that are often hidden from higher levels of the organisation. Within the planning of rail engineering work these conflicts are embodied by the increased volume of work necessary to respond to the enhanced capacity of the infrastructure against the reduced resources to deliver that work, in particular access to the infrastructure. The fact that decision making processes are triggered by conflicting circumstances (section 3.2) and the incidence of conflicts in planning reinforces the importance of decision making in planning and scheduling.

3.5.5. Managing uncertainty in planning

In line with the arguments presented in section 3.4.3, like rules and routines, planning can also be placed in the context of managing uncertainty, as it builds on foreseeable aspects of the business to anticipate needs (Grote *et al*, 2009). Crawford & Wiers (2001) discuss the instability and complexity of the environment as sources of uncertainty in planning and scheduling. The unstable conditions of the environment are mentioned as causes for the need to adjust or override agreed plans and schedules, which add to the instability and complexity of the planning and scheduling tasks at hand. Jorna *et al* (2005) make reference to the need to re-plan in view of unforeseen changes in operating conditions within the context of rail traffic control. They conclude that visibility and situation awareness are fundamental to support planning decisions, which requires adequate feedback both from within planning and from operations. Within this scope, Vernon (2001) describes two different types of feedback:

- Feedback to support the development of the plan, which supports planning decisions that aim to anticipate what work may be feasible given the available resources and what may exceed capacities.
- Feedback from operations that can relate how the plan is being or was carried out and report any deviations from it.

Although within a considerably different context (a manufacturing industry), Vernon (2001) highlights the importance of solid interactions between planning and operations as a way to guaranty reliable and efficient feedback sources. These interactions are described as fundamental for an efficient response from planning to operational needs.

The fact that planning is often built around continuous and discrete processes (an intrinsic characteristic of decision making processes, as discussed in section 3.2) increases complexity of planning and scheduling activities (Vernon, 2001). Crawford & Wiers (2001) present two different sources of uncertainty:

- **Internal uncertainty** originates not only from breakdown in the system, but mostly from inadequate perceptions of the company regarding operational timings and processes.
- **External uncertainty** was related to the need to initiate operational processes before details of work orders from customers were fully known and changes in dates (supply or delivery dates) or incorrect outputs at different levels of the supply chain.

3.6. Summary of literature

This chapter introduced the areas of literature relevant to support the investigation of planning in rail engineering and the application of resilience engineering concepts in this context. Section 3.1 identifies features of high complexity compatible with the description of rail engineering planning developed in chapter 2. The variability and uncertainty inherent to complex environments was highlighted and the concept of intractability introduced some its consequences to system operations (Hollnagel 2009a). The underspecification of operations in complex systems is identified as one of the most relevant aspects. The fact that operations are partly unknown, not only contributes to uncertainty, but it also generates the need for approximate adjustments to meet unforeseen operating conditions (Hollnagel, 2009a).

The concept of distributed decision making was placed in the context of complex sociotechnical systems (Schneeweiss, 2003) and described as the core element of planning and scheduling activities (Roland *et al*, 2011). As pointed out by McCarthy & Wilson (2001a), only people can make decisions in the face of ever-changing environments, such as those in which complex sociotechnical systems operate (Fujita, 2006a). As described in chapter 2, the wide range of resources and expertise involved in delivering an operational railway have generated strong interdependencies between train operators, Network Rail and engineering contractors, among others. As will later be discussed (section 5.2), decision making processes are today distributed across a multitude of stakeholders both from within Network Rail and the wider industry. This distributed nature of decision making is at the origin of the concept of collaborative planning described in section 3.5.3 (Windischer *et al*, 2009). The understanding of the role of decision making processes in planning was particularly important for the definition of performance indicators for rail engineering planning and for the subsequent quantitative analysis of planning data (analysis of planning archives as discussed in section 4.7).

Literature on resilience engineering demonstrates the importance of understanding interactions, not just within the system under analysis, but also those occurring between the system and its operation environment (McDonald, 2006). Keeping in mind that the focus of this research is the engineering planning system, the remaining engineering features and functions within Network Rail stand as the immediate environment with which planning interacts. This immediate environment was described in chapter 2 together with the main planning features. Apart from the investigation of resilience in planning and its measurement, this knowledge supported the study of planning as a complex system and the understanding of its sources of variability and uncertainty. In particular, given that resilience is a property of the system which emerges from the way in which it performs (Hollnagel & Woods, 2006), understanding planning performance becomes an important research scope.

In view of the research objectives stated in section 1.2, Table 3.7 summarises the main research questions derived from the literature. Given the exploratory nature of the work in this thesis, other questions were raised in the course of data analysis. These are discussed in the relevant data chapters.

Table 3.7: Main research questions derived from literature

Objective 1	• How is the planning process framed within Network Rail's organisational structure and within the rail industry? • What are the boundaries of planning? • What are the main trends of planning performance?
Objective 2	• What are the main constraints to planners' decision making? • What are the main resources used by planners to deal with constraints? • How do the planning process and its organisational structure support or hinder decision making processes?
Objective 3	• What are the main trends in work delivery performance? • What are the different trends in the relations between planning and work delivery?
Objective 4	• How does variability and uncertainty express itself in the planning system? • What are the sources of resilience in planning?
Objective 5	• What aspects of planning performance can potentially support the development of resilience indicators? • How can resilience in rail engineering planning be monitored?

4. Research methods

This chapter provides a description of the research methods used, in order to build a comprehensive and overall view of the project and its rationale. Based on the research context (chapter 2) and the literature background provided, a system framework was initially developed in order to place the engineering planning system within its wider organisational context. The research methods are then detailed. For each method, the specific research activities are described (within a table format) and traced back to the main objectives stated in the introduction.

4.1. System framework

The impact of planning on business decisions was clarified in chapter 2. From a resilience engineering point of view, this requires considering interactions between the planning system and business decision making functions as relevant research elements. This is also in line with the systems approach to safety as proposed by Rasmussen (1997) and previously illustrated in section 3.3.6. Following this same perspective, Figure 4.1 systematises the system framework proposed for this project and traces the planning system within its wider organisational scope. The development of this framework was based on the initial familiarisation work and contacts with daily work activities at Network Rail, and was verified against organisational diagrams available within the company's data systems. In order to make this illustration comprehensible, the hierarchical structure depicted was simplified by restricting it to the functions and system components with which planning can develop potentially relevant interactions. Boxes represent such components and functions and a brief description of their nature is provided in the bullet points alongside. Interactions are represented by arrows. Where these are predominantly based on negotiations two-way arrows are used to express the bidirectional flows of information.

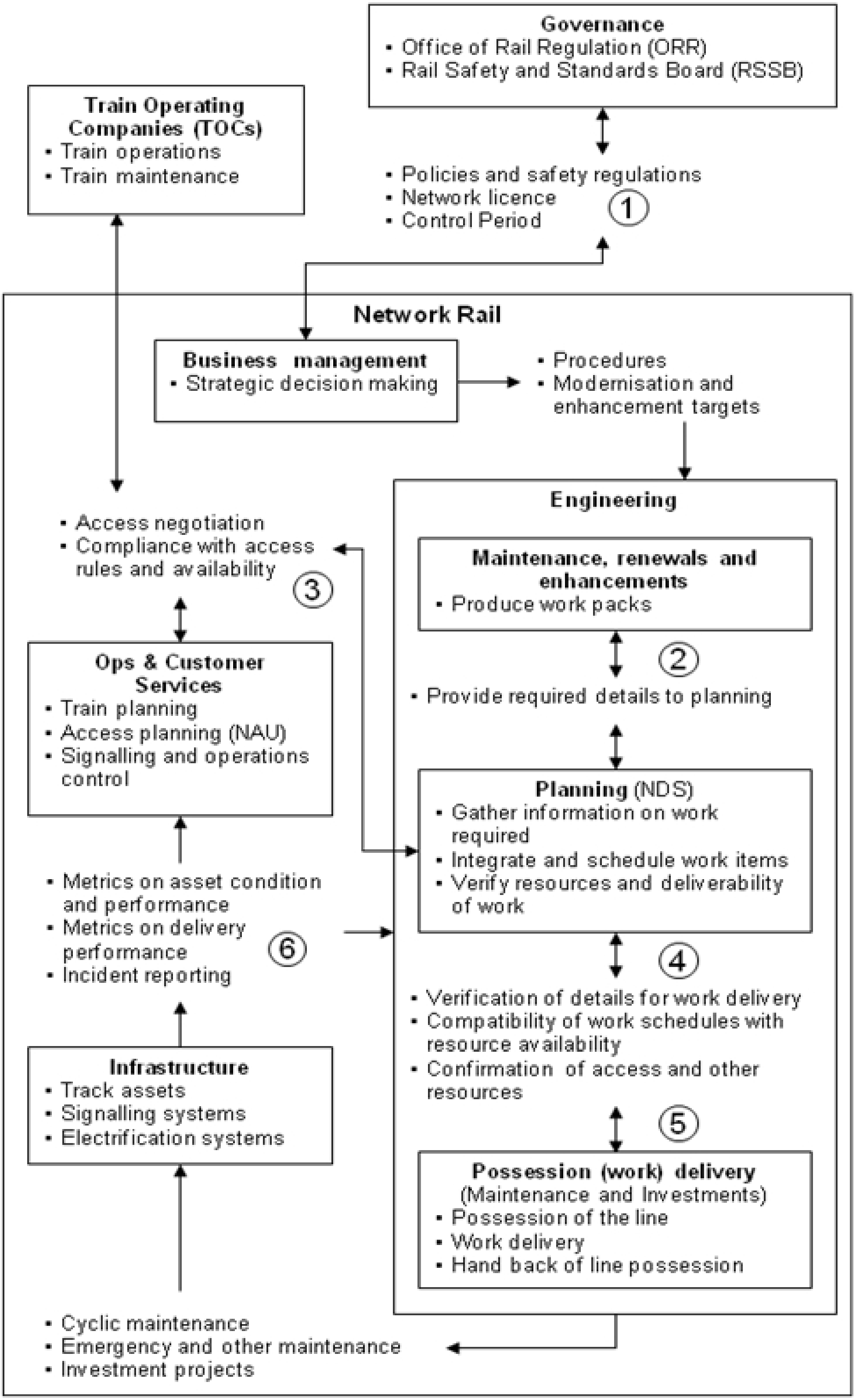


Figure 4.1: Systems framework to illustrate content and context of research

This research focuses on the engineering planning system, which from Figure 4.1, can be considered a sub-system of engineering. In the same way, the engineering function can be described as a sub-system of

Network Rail's organisational structure and of the wider hierarchical structure of the rail industry.

As discussed in section 3.1.1, the boundaries of a system are determined by the interactions considered and the scope of its description and analysis (Hollnagel, 2009a). In line with this notion, the interactions marked with numbers in Figure 4.1 are considered to be within the scope of this research and as determinants of the planning system boundaries:

1) **Safety regulations** and standards that work delivery must comply with and therefore, planning must enforce. For instance, this means that planning must contemplate the need to set up the necessary site protection arrangements before work can commence.
2) **Maintenance, renewals and enhancement** work packs details, in line with both maintenance standards and investment plans.
3) **Network access** negotiations with TOCs and the resulting volume of access available for engineering work.
4) **Reconciliation and negotiation** of work envisaged for delivery and the available volume of engineering access.
5) **Development** of work delivery plans, **allocation** of resources and **verification** against resources availability (including access).
6) **Feedback** on success or failure of delivery, and on condition of infrastructure assets.

4.2. Participant observation

As stated in the introduction, the planning of rail engineering work remains relatively unexplored, particularly when considering its important role in critical business decisions and impact on the service Network Rail provides to its customers, as this directly depends on the conditions and performance of the infrastructure. From a methodological point of view, the low level of previous knowledge developed on planning justified an emphasis on exploratory work, in order to achieve adequate familiarisation with various structures, roles and functions involved in planning, as well as identifying its critical issues and problems. The full time presence of the author at Network Rail's central offices, as a member of the Ergonomics National Specialist Team (NST), itself placed functionally within Engineering, facilitated access to data at all levels of the organisation and offered the necessary conditions for ample exploratory studies. This presence and the daily contact with numerous railway activities that it made possible, led to the development of research methods around the perspective of a participant observer.

Given the importance of participating, listening and observing daily activities, in particular for the development of the interview processes, the methods used in the course of this research can be considered as of an ethnographic nature. As stated by Hammersley & Atkinson (2007), participation and observation are necessary conditions for ethnographic studies. The following aspects of the methods used in this research are consistent with what Hammersley & Atkinson (2007) describe as features of ethnographic work and the perspective of a participant observer:

- All studies developed focused on everyday contexts (“in the field”), as opposed to conditions created or simulated by the researcher.
- A diverse range of data sources was used and data collection was relatively unstructured in the sense that it did not originate in a fixed and detailed research design. This is perceptible in the interview processes (familiarisation and semi-structured interviews - sections 4.3 and 4.5). Both the design of interviews and the analysis of its data were grounded on the participative and observational work and therefore, are strongly context dependent.
- All methods aimed at facilitating in-depth analysis of issues, in contrast to large scale studies. In this sense, the interviews and questionnaire (section 4.10) approaches used relatively small samples and data analysis was strongly oriented to qualitative methods. The analysis of planning meeting minutes (section 4.7.1) favoured the interpretation of the identified sequences of planning activities, rather than the quantification of any aspects. Although archival data analysis, including safety data, was aimed at developing a more quantitative approach, the investigation of control logs (section 4.8) greatly relied on interpretative work and focussed on descriptive rather than inferential statistics.

This methodological approach clearly contributed to more in-depth understanding of planning and its problems, and allowed for its interpretation in view of the larger system context. However, despite the support of formal methodological approaches, at some points access to information was possible merely by the presence and participation of the author in meetings or other daily work activities of the Ergonomics NST, such as contributing to other on-going projects in which the team was involved. As pointed out by Murphy (2002), this creates difficulties in tracing back sources of information and reproducing a clear methodological approach.

4.3. Research conceptual framework

With the approach of participant observation as a main methodological background, several other steps were developed towards achieving the main goals stated in section 1.2. As argued in section 2.3, the purpose of the planning process is to produce information that can support a safe and efficient delivery of engineering work. Thus, investigating resilience in planning must also be placed in perspective of the way in which planning supports work delivery. Within this frame, research methods aimed to develop an in-depth understanding of planning whilst interpreting its main issues in view of their relations and potential impacts on work delivery. This approach would then support investigation of resilience in planning.

The three chapters presenting results derived from of several methods emphasise this orientation of the research methods:

- Understanding engineering planning (Chapter 5)
- Understanding engineering work delivery (Chapter 6)
- Understanding and measuring resilience in planning (Chapter 7)

Figure 4.2 shows the different methodological steps developed in this research according to this structure.

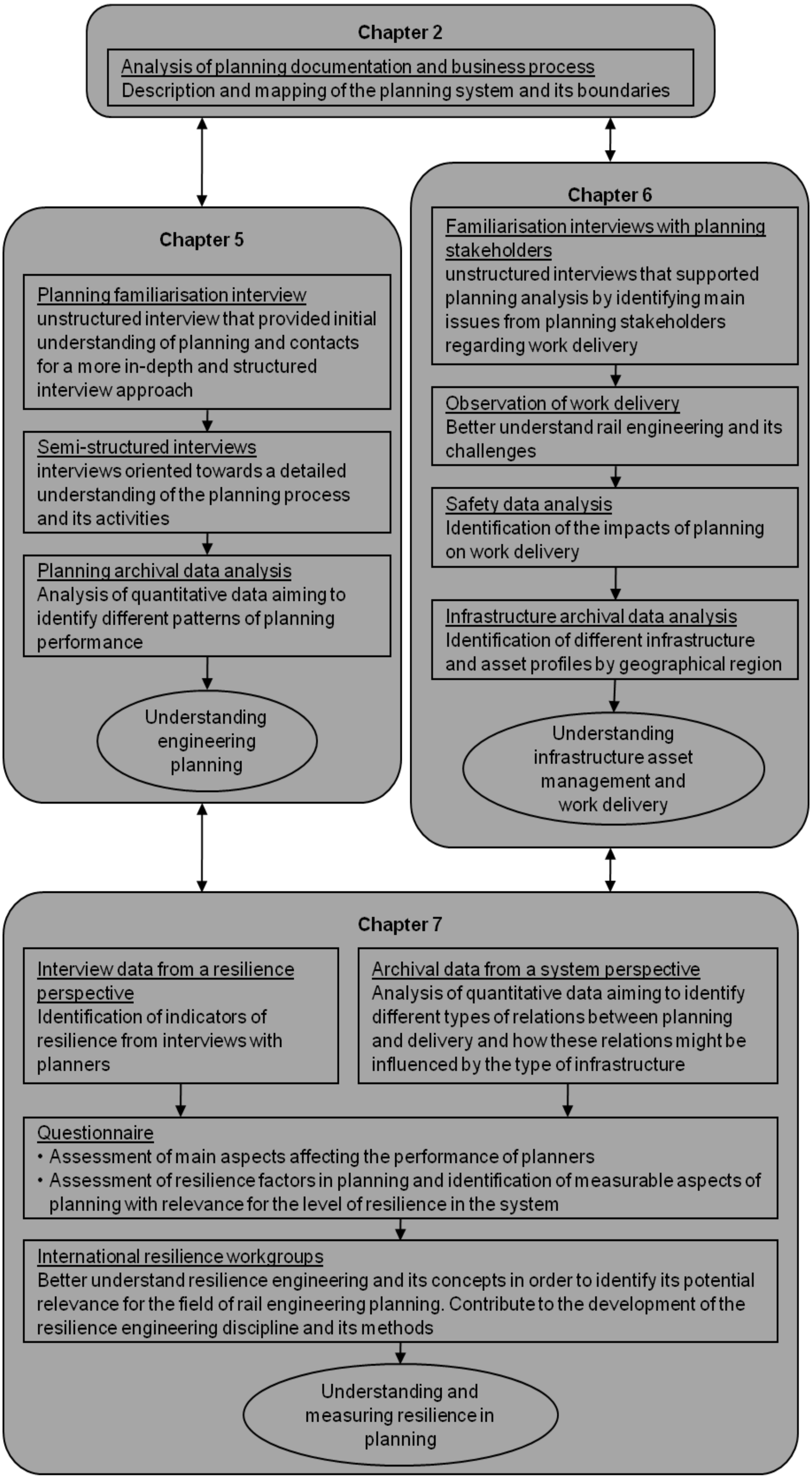


Figure 4.2: Research conceptual framework

The arrows in Figure 4.2 illustrate how methods used earlier in the project supported the following ones, leading to the understanding of the three main data areas. A basic description for each method is given in the subsequent sections of this chapter and where relevant, additional details are provided in chapters 5, 6 and 7.

4.4. Familiarisation interviews

Familiarisation interviews used an open structure, aiming to capture key aspects in both planning and work delivery on broad topics of discussion. The following two sub-sections present the details of each interview approach.

Specific objectives	• Broad description of engineering planning (1) • Initial steps towards identifying critical human factors and organisational issues (2) by supporting the development of the semi-structured interview process • Understand the point of view of stakeholders on planning (3)

4.4.1. Familiarisation interview with planning

One interview was carried out with a senior planning manager at NAU. This particular contact was suggested by members of the Ergonomics Team as a planning expert. The person in question had several decades of experience in planning and a “life time” of work in the railway industry. This interview formed the base of initial contacts with the planning organisation and its members, and provided an overall understanding of the process and its main issues.

The documents produced by Network Rail for the management of planning were used as guidance in this first step. In particular the business process document PL0056 (Work & possession planning for the railway infrastructure – ref. NR/SP/MTC/0056) provided an overview of roles and the range of steps involved in planning. This document presented a set of 17 formal meetings as the core of the planning process. Through these meetings, engineering work is progressively detailed towards its delivery. The interviewee was asked to describe planning “step-by-step”, following the process embodied in these 17 meetings. Information was collected on the base of a “paper and pencil” register of the main characteristics given by the interviewee for each of these 17 meetings. Diagrams of the planning structure taken from Network Rail internal working documents were provided by the interviewee and also used to write down additional details regarding the its overall organisation. The following specific objectives were considered for the interview:

- To better understand the formal planning process and the roles played by each of the stakeholders.
- Understand the information flows and identify the main interactions within the planning process and between planning and its operating environment.

4.4.2. Familiarisation interviews with planning stakeholders

A total of **10 interviews** were carried out, oriented towards obtaining support information and general guidance. The purpose was to capture the views of people dealing with the output produced by the planning organisation (delivery plan published in the WONs). Three different roles were considered relevant, which in practice, can be considered as the "end consumers" of planning:

- **PICOPs** are responsible for the management of the "engineering side" of delivery. Three PICOPs from London Bridge MDU were interviewed.
- **Signallers** are responsible for implementing all operations and must coordinate with PICOPs during engineering work. Signallers are the individuals granting the PICOP access to the infrastructure and guaranteeing that all the necessary safety conditions to carry out work on the line are met. Two signallers from London Bridge signal box and four from Liverpool Street signalling centre were interviewed.
- **Route controllers** oversee all aspects of operations and therefore, must be kept informed on the development of any on-going work delivery, including incidents or irregular occurrences. Control centres maintain records on all aspects potentially affecting operations, which include registers on requests for late changes (proposed after T-6) submitted by the planning system. One manager from Anglia route control was interviewed.

Interviewees were asked to comment on the main issues regarding the output produced by the planning organisation and its impacts on work delivery. A “paper and pencil” register of information was also used for these interviews. No specific structure or questionnaire was developed for these interviews but three major topics were used as guidance:

- What are your views on the planning process? What do you know about it?
- Does planning support you in performing your duties? What are the good and bad things you see in it? What information would you consider useful as a plan?
- Any additional comments

4.5. Semi-structured interviews with planners

Engineering planning remains a relatively unexplored area of the business. Although familiarisation interviews provided initial guidance, a more thorough and oriented approach was needed to clearly identify planning problems and general issues. In line with the concepts discussed in section 3.5, this should aim to explore aspects of system complexity in planning and how planners cope with the inherent variability and uncertainty of high complexity.

Specific objectives	Detailed description of the planning system (1) Identification of main issues and understanding what problems are experienced by planners (2) (3) Develop an initial understanding of the scope for resilience in planning (4) Understanding the relations between planning and other areas of the business related to engineering, in particular the impacts of planning on work delivery (6)

The purpose of this interview process was to investigate and explain planning activities and their main problems. This is in line with the approach of participant observation previously described (section 4.2), and with the principles of grounded theory in qualitative research, as the method and the analysis of the data obtained were constructed from the “immersion” of the researcher in the context under study (Hayes, 2000). Stratton (1997) further considers that even when a constructivist approach is used (building on methods as knowledge and data accumulates), some kind of framework or theory about the context under analysis is necessary to perceive and understand that context. From this perspective, the outcome of the familiarisation interviews was used as a framework, not only to develop the structure of these interviews, but also to trace back the meaningfulness of the subsequent analysis process.

15 semi-structured interviews were carried out with members of the planning organisation based on the 10 topics of discussion shown in Table 4.1. These topics were mainly derived from the outcomes of the familiarisation interview with NAU planning manager and consultation with subject matter experts within the Ergonomics Team.

Table 4.1: Questions generated for interviews with planners

1	Can you tell me about your job (daily tasks, duties)?
2	Can you explain the planning process from your point of view? How would you describe your influence/role in the process?
3	How often would you say your job changes? How does it change? Have the tools changed? The information sources or formats? The decision-making?
4	Do you normally feel confident regarding the outcome of the planning activities in which you take part? Can you identify any recurrent uncertainties that you are faced with? (If so) How do they manifest themselves? How do you deal with them? Do you look to obtain feedback? How do you ensure you have reached your goal?
5	What would you say are your main skills and competencies? Do you feel they improve with your job experience?
6	How would you describe the overall set of rules and procedures applicable to the planning process? Are there any which you would consider to have a particularly significant impact over the planning process (safety critically or otherwise)? Do you feel these rules and procedures support you in the performance of your duties?
7	What type of information do you use most? How important is it in your job? What sources you mainly use? Would you consider that the production of information for others is an important part of your job?
8	What do you consider the current major challenges to be for track work delivery? How does the planning process respond to those challenges? In particular, what are your views in the way changes in the planning emerge and how they are managed?
9	What does resilience mean to you? Considering resilience as a property that enables the system (engineering work) to resist and recover from unexpected variations and pressures from its environment, how would you characterise the planning and work delivery processes in these terms?
10	Throughout your professional experience in this area, what do you consider the major achievement within the planning process? What success stories come to your mind? What failures?

Interviewees were selected based on recommendations and contacts provided by the NAU planning manager. As a complement to these contacts, the initial aim was to interview people for each existing planning job and, where possible, from different regions of the country. However, because job titles and roles were found to vary significantly from one part of the country to another, this sampling method could not be used. Using Network Rail's internal address book, emails were sent to all people in identifiable planning jobs. Based on received responses, attempts were made to schedule meetings for interviewing, giving priority to either jobs described by the NAU planning manager as more relevant, or to those on which little information was available. Overall, the aim was to cover as thoroughly as possible:

- Different levels of the planning process (long, medium and short term)
- The key planning jobs and functions
- Different geographical structures of planning

Interviews were audio recorded for later transcription and analysis. A tabular analysis approach (Tukey, 1977) was developed for data analysis, using the 10 topics as an initial grouping structure. This process gave way to a more systematic organisation of information, which, following the approach outlined by Stratton (1997) in terms of attribution, supported the extraction of recurrent issues in the interviews, as well as disparities. To ensure the accuracy of data, the information extracted from recordings was reviewed by the researcher and whenever necessary, the person interviewed was contacted again for additional clarification. This gave way to an iterative process of analysis and revision, which allowed further detail on significant issues.

This iterative reviewing also informed upcoming interviews. Although the 10 topics of discussion were maintained throughout the entire process, significant issues were highlighted and used for additional discussions with other interviewees to verify their pertinence and further develop them. This approach did not necessarily increase the duration of interviews as the added information improved familiarisation with planners' terminology and personal views, which helped to make discussions more focused. Again, this is consistent with a grounded approach, as interviews were oriented by inductive principles, rather than deductive ones (Hayes, 2000).

4.6. Observations of engineering work delivery

Observation of real work contexts was earlier described as a fundamental research approach. Following up on processes of work delivery contributed to the understanding of what work details and needs must be anticipated and thus foreseen by planning. Together with the knowledge on planning, this can support better understanding of the relations between planning and work delivery.

Specific objectives	Understanding the impacts of planning on work delivery (3) and what could define successful planning (6)

Observations of work delivery provided opportunity for familiarisation with processes and broad issues, mainly around the following activities:

- **Taking possession of the line** and setting up of protection arrangements
- **Control of train and machine movements** in, out and within possession
- **Hand back of line possession** and removal of protection arrangements

Observations were carried out during site visits made by the researcher and other members of the Ergonomics Team, in cooperation with trials for new engineering work protection arrangements (see Schock 2010). In total, 7 different trial scenarios and 2 “rule book” possessions were visited. Each of these scenarios provided from five to seven hours of observation. Observations were centred on the roles of the PICOP and signaller and oriented by recording of incoming and outgoing communications during these activities. Hence, although some time was spent out on site (on the line), observations were mostly carried out in the PICOPs’ office within the MDU facilities or within the signal box for signaller observations. Whenever communications were taking place, their time and duration were registered in an Excel spreadsheet, together with a broad description of the purpose of communication. Purpose was normally deduced from the information transmitted. Whenever clarifications on the contents of communication were necessary, the people being observed were queried on the issues, once communication terminated. These trials were also an opportunity to carry out informal and open interviews with people performing these duties.

4.7. Planning archives analysis

Archival information gave access to a historical perspective of planning. As discussed in section 3.5.2, decision making plays a crucial role in planning and scheduling activities. The analysis of records on all decisions reached in the process of building work items into an Annual Integrated Work Plan (AIWP), and in their detailing towards delivery, produced valuable insight on planning performance. Using a similar approach to archives on work delivery, planning performance trends were then investigated against delivery performance. Keeping in mind that planning must aim at supporting work delivery, this supported the investigation of what could be identified as successful planning.

Specific objectives	Understand (1) and Assess planning performance (3) and identify performance trends in planning that could indicate higher or lower degrees of success (4)

An overview of the contents of engineering data available within Network Rail systems, together with insight provided by planners during the interviews, identified two main sources with potential for a retrospective analysis of different aspects of planning performance: Planning meeting minutes and Possession Planning System (PPS). While meeting minutes provided a relatively small sample of data but with extensive details on changes made and their actual sequence throughout the planning process, PPS provided higher level and less detailed information but on a systematic and national base to produce performance comparisons. These sources were earlier described in section 2.4.

4.7.1. Planning meeting minutes

Meeting minutes contain a detailed record of all changes from one planning meeting to the next. The Analysis of these records supported the reconstruction of the sequence of planning changes in detail. The level of detail available made it possible to rebuild the decision making processes leading up to the sequences of planning changes for any given possession and its worksites. At each planning meeting, based on printouts from the Possession Planning System (PPS) which resemble the contents of the WON (Appendix 1), planners noted all the additions, amendments and cancellations to the listed items.

The decision processes traced back were represented as a timeline within an Excel spreadsheet, as illustrated in Appendix 3. Following the perspective of Kirwan (1998), this could be considered a task analysis approach that can contribute to understanding the implications of decision making for safety management. Hence, despite the difficulty in processing hand written information, due to occasional lack of clarity in presentation and writing, there was ample added value in this approach towards better understanding of planning.

Given the level of detail involved in this analysis and the time necessary to process all the information, this approach was developed based on data regarding a part of the planning process and for one section of track within a given engineering area. As each ADPU is required to maintain these records within lever arch files for a period of several years, a sampling method was necessary to filter the volume of information available. The support of the Milton Keynes ADPU was fundamental for this process. Informal discussions and consultations with planners at this ADPU provided the necessary initial guidance for the sampling of a relevant period of time and of appropriate stages within the planning process. Planners were asked to identify any outstanding periods of the year for planning, whether by having to face higher demands or increasing problems, or having to plan for higher volumes or more complex work.

4.7.2. Possession Planning System

Although providing fewer details, PPS maintains records for all changes made to possessions and worksites formally submitted to planning at national level. The fact that it is a software database allowed a simpler and more systematic data collection. Records for all the changes made for the planning of three different delivery weeks and at national level, were extracted from this system to quantify several aspects of planning performance. This supported the identification of planning trends by comparison amongst the different geographical structures of planning.

The records extracted from PPS essentially consisted of a list of the inputs made (created, amended or deleted) together with the corresponding parameter (details, Blocked line, route, isolations and on-track requirements) and the entry date. The information extracted was considered sufficient to respond to the stated objectives, as it gave way to a quantification of the main types of changes and the calculation of the duration of planning for each possession and worksite.

Table 4.2 recalls the types of information previously described in section 2.4.1 (Table 2.3) and introduces three other parameters used to quantify the duration of planning.

Table 4.2: parameters used for the analysis of PPS data

Planning changes	
Details	Additional remarks regarding traffic (time and head codes of engineering trains scheduled for a given possession) or any specific work details (key staff contact numbers, critical safety or deliverability issues)
Blocked line	Line which will be blocked to train services during possession (up or down line, fast or slow line, among other designations)
Route	Section of route on which work will be taking place and therefore, will be blocked to train services
Isolation	Input only required for worksite entries, providing details for electric isolations whenever these are required to carry out the work in question
On-track requirement	Input only required for worksite entries, providing details of any on-track machinery that will be operating within the given worksite
Duration of planning	
Created	The number of weeks before delivery at which the referenced item was inputted into PPS
Closed	The number of weeks before delivery at which the referenced item registered the last change in PPS
Duration of planning	The number of weeks during which the item was undergoing planning, calculated as the difference between the week of creation and the week of closure

The parameters and their respective input were listed by columns in Excel. Figure 4.3 represents the columns created and their contents. To better illustrate the data produced, Appendix 4 shows an extract from the tables created for the Anglia area.

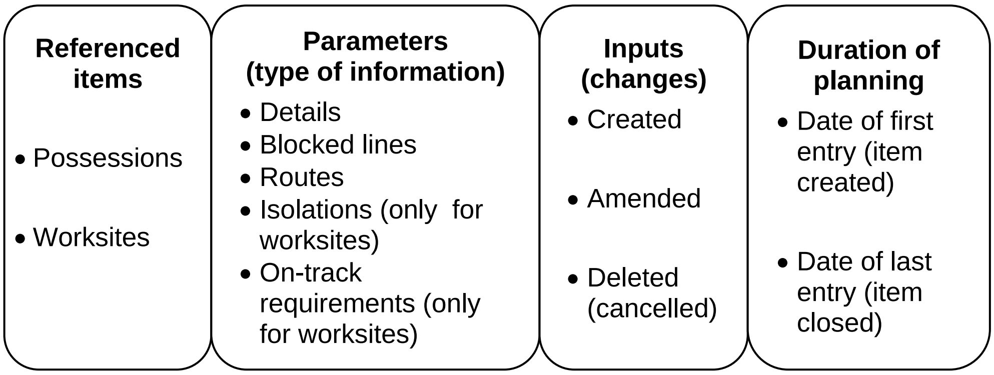


Figure 4.3: Excel structure of PPS historic data

The quantification of the listed data was achieved by means of Visual Basic programming. The program was designed to count not only the number of worksites associated with each possession extracted, but also the numbers and types of changes made to each of these. Using the dates for the first and last entries, the duration of planning of each item was then calculated in the same spreadsheet. The counts made by the Visual Basic programming were registered in a table within the same Excel Workbook. Table 4.3 represents the structure of the tables generated in Excel. The Visual Basic program would generate the count corresponding to each parameter and for each of the WON areas (listed across the columns to the right in the Excel worksheet).

Table 4.3: Structure of the tables generated by the Visual Basic programming

<table>
<tr><td>Planning changes</td><td colspan="2">Type</td></tr>
<tr><td rowspan="14">Possessions</td><td rowspan="2">Possessions</td><td>created</td></tr>
<tr><td>amended</td></tr>
<tr><td colspan="2">Changes / possession</td></tr>
<tr><td rowspan="3">Blocked line</td><td>created</td></tr>
<tr><td>amended</td></tr>
<tr><td>deleted</td></tr>
<tr><td colspan="2">Changes / block</td></tr>
<tr><td rowspan="2">route</td><td>created</td></tr>
<tr><td>deleted</td></tr>
<tr><td colspan="2">Route deleted / created</td></tr>
<tr><td colspan="2">Overall volume of change</td></tr>
<tr><td rowspan="7">Worksites</td><td rowspan="2">Worksite</td><td>created</td></tr>
<tr><td>amended</td></tr>
<tr><td colspan="2">Changes / worksite</td></tr>
<tr><td rowspan="3">Blocked line</td><td>created</td></tr>
<tr><td>amended</td></tr>
<tr><td>deleted</td></tr>
<tr><td colspan="2">Changes / block</td></tr>
</table>

	route	created
		deleted
	Route deleted / created	
	Isolation	created
		amended
		deleted
	Changes / isolation	
	On-track requirement	created
		deleted
	Overall volume of change	
Total number of WS		
Average number WS / Pos		
Duration of planning	In weeks before delivery	
Possessions	Created	Average
		Max
		Min
	Closed	Average
		Max
		Min
	Duration	Average
		Max
		Min
Worksites	Created	Average
		Max
		Min
	Closed	Average
		Max
		Min
	Duration	Average
		Max
		Min

The quotients between the changes made (amendments and deletions) and each parameter created, provided a ratio of the **volume of changes** that could be used to compare all areas. The **overall volume of change** gave the number of amendments and deletions against all items, blocks and routes created (plus isolations and on-track requirements for worksites). The number of changes per possession or worksite reflects the amendments made to the traffic and general remarks or other specific delivery information, as detailed above in Table 4.2. An estimate for the total number of worksites planned by each area was produced, based on the product of the number of possessions published by the number of worksites per possession in the sample. This offered an overview of the volume of planning work carried out by each area.

The identification given to each worksite was also extracted from PPS, as it provided a broad description of the type of work to be delivered. Although this broad engineering identification gave little information regarding the actual planning of each type of work, this was thought to provide an additional basis for comparison between areas. The different types of work initially extracted from PPS were then grouped into major categories in order to facilitate analysis. This grouping aimed to distinguish different degrees of planning complexity rather than types of work from an engineering perspective. To this purpose, it was assumed as a basic principle, that the more resources are required and the larger is the scale and complexity of a type of work, the more complex its planning tends be. For instance, according to this principle, structures and major projects work is assumed to impose more demands on planning rather than inspection and patrolling work. Table 4.4 establishes the correspondence between the different types of work identified in PPS and the major categories created on the base of this principle. The familiarisation work previously carried out (interviews and observations) and the understanding of engineering work it provided supported the creation of these categories.

Table 4.4: Categories for the type of work planned

Major categories	Type of work	Description
Asset related work	Ballast work	Work involving cleaning and replenishing or replacement of ballast
	Cable work	Repairing or replacement of electrical or signalling cables
	E&P work	Work involving installation or repairing of electrical and power supply systems
	OHL work	Work on the Over Head Line electrical equipment
	Rail changing	Small scale rail renewal
	Rail stressing	Management of continuous welded rail stress
	S&C maintenance	Maintenance of line Switches and Crossings
	S&C work	Renewal or installation of line Switches and Crossings
	S&T work	Work on Signalling and Telecoms equipment
	Stone blowing	Clearing of ballast to prevent it from blocking the movement of points or causing other damage to assets

	Tamping	Mechanical tamping of straight line or S&C areas
	Track maintenance	Unspecified maintenance work on straight line assets
Asset inspections and patrolling	Patrolling	Line walk-through work by maintenance
	P-way inspection	Inspection of Permanent-Way (line) assets
	URFDO inspection	Inspection of rail condition by means of Ultrasonic Rail Flaw Detection Operators
Stations and structures work	Station work	Work in stations, usually affecting platforms or substantial structural modifications, requiring protection of the line
	Structures work	Work on structural elements on or near the line such as bridges
	Tunnel work	Work within tunnel areas
Project related work	Follow-up work	Work related to major projects that involves the finishing of details on renewed assets and clearing of project areas
	Preparatory work	Work carried out in relation to projects aiming to prepare areas for major work (clearing access points, delivering materials, among others)
	Survey work	Work normally associated with major projects that aims at collecting site information necessary to support detailed planning of delivery
Major projects	Major projects	Major asset renewals or constructions
	Re-signalling work	Replacement of signalling assets
Non-asset related work	Litter & graffiti	Clearing and cleaning of the line and line side
	Vegetation clearance	Clearing of vegetation on or near the line
	Off-track work	Work carried out near the line (line-side) and therefore, requiring protection arrangements

4.7.3. PossMan

PossMan also manages planning information, in particular, engineering details that are necessary to coordinate delivery of work within the possession (i.e. train and machine movements, among others). Despite the relevance of such information, PossMan only records the final arrangements for delivery, which means that the detail of decisions and changes made during this stage cannot be traced back. Also the extraction of data from PossMan required editing privileges, which could not be granted to non-planning staff. Hence, PossMan was consulted on different occasions, aiming to better understand the type of support it provided to the last stages of planning, but it was not considered as a primary data source. A sample of the contents of PossMan which were made available for consultation is shown in Appendix 5.

4.8. Safety data analysis

As observed in section 2.3, the purpose of engineering planning is to produce information that can support an organised, safe and efficient work delivery. Hence, the success of planning can only be interpreted in view of the support it provides to delivery. Safety data sources were investigated in order to assess the extent of the impacts of planning on work delivery. Together with planning archival data, this supported the investigation of different trends in the relations between planning and work delivery based on a geographical comparison amongst areas.

Specific objectives	Understand the impacts of planning on delivery and support the understanding of planning performance (1) (3)

In collaboration with work carried out by the Ergonomics Team for on-going engineering projects (TOP - Track Occupancy Permit, in Schock, 2010), safety data sources had already been studied by the researcher, focusing on the identification of human factors issues as causal factors for possession irregularities and incidents. The outcome of this study was included in confidential reports submitted by the Rail Human Factors Group of the University of Nottingham to Network Rail. The work developed then, recognised **control logs** as the most suitable data source. As with many safety data systems in the large majority of industries, very little attention is devoted to causality factors such as human factors issues and system level interactions. As a consequence, most planning implications for the safety of track work delivery are overlooked in the safety records of the rail industry. Hence, despite the increased difficulty in interpreting free text descriptions of events and the potential ambiguity of such sources, in most cases, control logs provided enough information on events for tracing back to relevant planning issues. The contents of control logs are illustrated in Appendix 6.

Control logs concerning possession failures were extracted from Network

Rail's data systems. The structure under which control logs are published provided four sections with potential relevance for this scope:

- Irregular working – Maintenance
- Irregular working – Investment
- Irregular working – NDS
- Significant possession problems

Most work delivery failures are registered under the "possession problems" section. The remaining three sections, although specifically dedicated to the register of irregular work, were considered useful, as often the description of irregularities would provide details on planning related causal factors.

Because of their free text format, control logs frequently contain insufficient information to develop a thorough causal analysis and in particular, to clearly identify planning related issues. In order to make the most use of the information available, two different levels of coding were used to distinguish between what were clearly stated facts and the interpretation of log contents:

- A first level classified clearly stated facts drawn from logs in terms of **cause** and **outcome** of the described events.
- A second level of coding was used to classify **planning issues** that could be deducted in light of the overall understanding of engineering work.

The second level of coding provided a less meticulous classification method. However, based on the understanding of the railways already acquired, the interpretation of control logs contents was considered sufficient to produce useful insights on planning issues. As earlier discussed, this is in line with the principles of ethnographic studies and the inherent interpretative work. Whenever information was deemed insufficient, logs were classified as being non-related to planning or providing insufficient evidence to support any such relation. Table 4.5 describes the three categories created for the two levels of coding.

Table 4.5: Categories created for the analysis of control logs

Causes (first level)	Description
Planning failure	Control log clearly identifies the insufficiency of planning as the main or an immediate cause for possession failure
Equipment failure	Track equipment and machinery or train failures
Extreme weather	Possession disruptions caused by severe weather
Staff shortage	Severe possession staff absences
Points run through	Damage to points caused by irregularities during the movement of engineering trains and on-track plant within the possession
Cable damage	Damage caused whilst carrying out other work such as digging or ballast work
Other asset damage	Damage to other infrastructure assets in course of unrelated work
Late start	Possession is taken or work is started late due to late running service trains or late arrival of staff or engineering machinery, among others
Other	Unspecified planning causes
Outcome (first level)	**Description**
Possession overrun	Possession extended beyond its duration
Additional work	Additional work was needed to repair or recover from original possession failure
Work cancellation	Work planned for possession cancelled as a consequence of the failure
Problem mitigated	Possession failure was adequately recovered
Planning issues (second level)	**Description**
Worksite planning	Failures caused by poor planning of work delivery (within worksite)
Possession planning	Failures caused by poor planning of possession arrangements
Staff rosters	Rostering of staff Inadequate to possession needs
Haulage / machine routing	Poor planning of routes for engineering or on-track plant into or out from possession, or even within possession
Haulage / machine planning	Equipment supplied to possession not according to possession requirements
Non related / no evidence	No evidence of planning related failures

Given the time necessary to extract information and categorise it, a more extensive analysis of control logs was not viable within the timeframe available. To complement the outcome of control logs analysis, numbers of possession failures were extracted from the **Asset Incident Trends** database. As mentioned in section 2.4, this database provides information on a wide range of events that more or less directly affect the condition of assets, including occurrences during possession of the line. Of the 51 types of incidents recorded by this database, the ones shown in Table 4.6 were considered most relevant to describe the occurrence of possession delivery related incidents.

Table 4.6: Possession delivery incidents taken from asset incident trends to support control log analysis

Code	Type of incident	Description
106A	Track Patrols & related possessions	Incidents related to maintenance inspections
107A	Possession over-run and related faults	Failures which caused possessions to run beyond their available access time
107B	Possession work left incomplete	Incidents which led to possessions being handed back to operation with planned work incomplete

As shown by the descriptions given in Table 4.6, this database does not explicitly refer to any planning related issues. However analysis was considered useful to support area comparisons in relation to planning data.

4.8.1. The Christmas period of 2007

During the Christmas period each year, the rail engineering organisation plans for an increased time of access, taking advantage of a reduction in passenger numbers that characterises this holiday season. This often represents a unique opportunity to deliver complex work and major projects that require the possession of the line during several consecutive days (blockade).

In particular, the Christmas of 2007 (ORR, 2008) was described as the most intensive period of engineering activity in the history of the railways since privatisation. Amongst all the planned work, three major possession overruns occurred, causing serious disruptions to train services. Given the volume of work delivered throughout the country within this period of time and the complexity of some of the projects involved, this was considered a valuable opportunity for the investigation of the impacts of planning on delivery under conditions of extreme production pressure.

The overruns occurred at Rugby, Liverpool Street and Shields Junction, Glasgow. The focus was set on the events taking place at Rugby, where the work being delivered was not only particularly complex, but also critical for its impact on the most important rail route in the country (West Coast Main line) and the enhanced timetable that was due to come in place in January 2008. While special attention was be given to the Rugby project, events taking place throughout the country and in particular within the Liverpool Street and shields Junction projects, were also investigated to provide a description of the overall national delivery programme for that period.

Control logs were used as a main source of data for the analysis of events which, from the start of this intensive period of engineering work led to the overruns. The relevant logs were extracted from national information systems and used to build a timeline of events. The formal report on the investigation carried out by the Office of Rail Regulation – ORR (2008) was also used as a source for additional details on occurrences and to identify relevant actions taken by Network Rail and the stakeholders involved in the project.

4.9. Infrastructure and asset data analysis

As earlier mentioned (section 2.1), the UK rail industry possesses a wide diversity of infrastructure profiles and traffic characteristics. This diversity is likely to impact differently on planning, not just in terms of the volume of engineering work to be planned, but also in terms of the constraints and options for access to the infrastructure. Archival data from engineering statistics provided insights on the different infrastructure profiles of the national rail network. The analysis of this data against planning and work delivery data complemented the investigation of planning performance trends and the understanding of relations between planning and delivery.

Specific objectives	Understand the influence of different infrastructure profiles on the volume and type of work planned (1) (3)

Network Rail's Engineering Information Team provided guidance on possible sources of data to support the investigation of the disparities between geographical areas in terms of infrastructure profile. Two different aspects were analysed: The **complexity of the infrastructure** and an

estimate for the volume of emergency maintenance work as a source of disruption to planned work. As earlier stated in section 2.2, emergency maintenance work is a major source of disruption, not only for train services, but also for planned engineering work. Often work that has gone through the planning process is thrown out close to its date of delivery because engineering interventions with higher priority have emerged. Three different data sources were used:

- **Asset incident trends** provided an extensive range of quantitative data. Numbers for categories of incidents, other than the ones previously used to complement safety data, were extracted to support an estimate of the unplanned maintenance interventions required in each area.
- The **equated track mileage** together with **asset counts** aimed to provide an overview for the profile of the infrastructure in each area, in terms of the number, type and concentration of assets.

4.9.1. Incident categories taken from asset incident trends

From the 51 types of incidents classified, 14 were considered more likely to result in the need for maintenance emergency responses and thus be a potential source of disruption to planning. This selection was made based on the description of each type of incident and in view of the general knowledge already acquired regarding rail engineering. Apart from equipment failures, two other types of incidents were included. The incident type designated as “TSR due to condition of track” was considered particularly relevant. Temporary Speed Restrictions are put in place by delivery units whenever there is an inability to respond to maintenance requirements that affect normal operation. These were considered useful data to assess the capability of delivery units to respond to maintenance needs in light of the resources available to them (including available access). Weather related incidents were also used in order to understand the serious impact that severe weather may have on the infrastructure and how this may vary from area to area.

Table 4.7 shows the 14 types of incidents that were considered to have a more direct relation with either planning or delivery.

Table 4.7: Asset incidents taken from asset incident trends to support comparison of different infrastructure profiles

Code	Type of incident	Description
101	Points failures	Apart from mechanical failures, this also includes loss of signalling detection of points
104A	TSR due to Condition of Track	Temporary speed restrictions applied when the condition of track does not meet the standards required for line speed
104B	Track faults	General plain track faults including broken rails
104C	Gauge corner cracking	Metal fatigue cracking occurring on the running (gauge) corner of a rail. It is a form of Rolling Contact Fatigue
108	Mishap - infrastructure causes	Unspecified incidents for which there is a causal relation with infrastructure assets
110A	Severe weather	Weather impact on infrastructure beyond design capability
110B	Other weather	Weather impact on infrastructure or network operation
201	OLE/Third rail faults	Incidents related to electrification, either with Overhead Line Equipment or with third rail
301A	Signal failures	General signalling equipment faults
301B	Track circuit failures	Failure of a track circuit or associated equipment
302A	Signalling system and power supply failures	Power failure related faults
302B	Other signal equipment failures	Failure of signalling systems
303	Telecoms failures	Failure of track side or in-cab communication systems
304	Cable faults	Failure of signalling and communications cabling

Engineering areas were compared based on the average number of incidents for each of the categories in Table 4.7. For the same 14 categories, the total number of incidents per period and by areas was extracted from the database for the year 2008/2009. This provided an overview of the variability of occurrences throughout the year and how these variability patterns changed from area to area.

4.9.2. Asset data

Complexity was assessed by means of Equated Track Miles (ETM) and asset counts. As a basic principle emanating from maintenance standards, the more assets there are and higher their concentration per mile of track in a given area, the more maintenance work is required. By definition, it can be assumed that an area with a higher ETM will be responsible for the planning of higher volumes of maintenance work than an area with a lower ETM.

Although the number of assets by section of track is contemplated in the calculation of ETM, having additional information on the actual type and number of assets was considered useful to better understand possible impacts on planning. The two most recent counts were obtained from the Engineering Information National Specialist Team, which corresponded to periods 3 and period 4 for the year 2009/2010. Although this time scale represented a sample entirely different from the one used for the other data sources, according to the Engineering Information NST, despite being refreshed every period, the contents of these counts do not vary significantly. For the periods concerned, the majority of the Delivery Units show variations of less than 0.5%. Thus, the disparity of timescales with the rest of the data sources used in this research was not considered a problem. Similar to ETM data, asset counts were provided by delivery unit and then summed to produce numbers for engineering and WON areas.

Asset data were supported by the identification of differences between areas in terms of infrastructure profile. These differences were then discussed in view of the outcome of asset incidents analysis, in order to study possible relations between the profile of the infrastructure and the occurrence of incidents.

4.10. Questionnaire

This method constituted a source of subjective assessment for two different thesis topics. While part 1 of the questionnaire focused on the assessment of resilience factors in planning, section 2 focused on the further evaluation of the planning issues identified throughout the interview processes. Although integrated within the same questionnaire different basic methods were used in the development of each questionnaire section. The questionnaire used is shown in Appendix 7.

4.10.1. Development of part 1 of the questionnaire

As debated in section 3.6, literature provided ample support for the definition of rail engineering planning as a complex sociotechnical system. Section 3.4 defined resilience engineering as a safety management approach with particular relevance for such high complexity domains, as it focuses on better coping with variability and uncertainty. A range of related concepts were also introduced as potential measurable aspects of resilience. These concepts were used to develop a subjective assessment approach, aiming to better understand how resilience may express itself in rail engineering planning and investigate possible means of measuring it.

Specific objectives	Support the definition of resilience factors in engineering planning (4) and investigate potential means of measuring resilience (5)

The first section of the questionnaire addressed both objectives 4 and 5. It was used to test a set of statements, derived from resilience literature and an in-depth understanding of rail engineering planning, as to their meaningfulness as measurements for resilience in planning. The responses were used in turn to assess the extent of resilience within the rail engineering planning process.

Mendonça (2008) referred to the concepts provided by Woods (2006a) and Wreathall (2006) as a starting point towards measuring resilient performance. He developed a framework for measurement factors which was then analysed in view of observational data regarding the restoration of infrastructures in New York City, following the attacks on 11 September, 2001. In line with this approach, the most recurrent keywords and notions found in the definitions presented in section 3.4.1 (Table 3.3) were used as grounds for the investigation of resilience measures within engineering planning. Table 4.8 includes these concepts and provides a description.

Table 4.8: Resilience concepts taken from relevant literature

Concepts	Description
Ability to adapt to changing conditions	The system has to be flexible enough to respond to external changes and pressures
Ability to cope with complexity	The system must be capable of maintaining normal operation whilst coping with changing conditions
Ability to manage continuous stresses	The system must be capable of maintaining normal operation, even when submitted to extreme pressure

Ability to respond to problems by anticipations	Preparedness - The system must be able to react before problems cause any disruption to normal operation
Ability to recover quickly to a dynamic stability	The system must be capable of recovering normal operations with minimal impact on performance, once disruptions occur (survival)
Learning culture	Willingness to respond to events by reforming and adapting as opposed to denying the need for change. System does not give in to complacency
Just culture	Support on reporting of issues throughout the organisation avoiding behaviours of culpability attribution
Ability to steer activities	The system must be able to control activities regardless of operating conditions
Appropriate level of information about performance	Awareness - The system must make available to its management appropriate levels of information regarding performance
Appropriate level of resources	System must maintain availability of resources necessary to respond to all operation requirements
Communication and coordination	Flows of information facilitate distributed decision making. problem solving is not fragmented
High enough devotion to safety	Safety must be considered alongside other system goals
Buffering capacity	The system must have available the resources necessary to respond to arising problems and complex issues

An initial set of 30 statements was developed, aiming to embrace all the perspectives given by the factors in Table 4.8 within the context of engineering planning. This initial group of statements was peer reviewed by six members of the Network Rail Ergonomics Team. As people not familiar (or with little contact) with the notions of organisational resilience and yet knowledgeable on a wide range of aspects of rail operations, this provided a test for the comprehensiveness of the statements, as well as their meaningfulness concerning the intended concepts. This gave rise to an iterative process of revision and piloting that was concluded when the format of each question was found to be strongly related to the underlying resilience concepts. The initial set was brought down to the 22 statements shown in Table 4.9.

Table 4.9: Final set of statements for part 1 of the questionnaire

Proposed statements	Resilience concepts
I can adjust my way of working according to external pressures	Ability to manage continuous stresses
I have the information necessary to deal with unexpected situations	Ability to adapt to changing conditions
I have enough time to do my planning thoroughly	Appropriate level of resources
I have all the information I need to do my work	
I can solve problems even when pressured to deliver fast results	Ability to manage continuous stresses
I can solve problems even when faced with unexpected situations	Ability to respond to problems by anticipations
I have the information needed to detect potential planning failures	Appropriate level of information about performance
I can communicate my decisions promptly to those that rely on them	Communication and coordination
I have the support of my manager to make decisions	
I feel in control of my work activities	Ability to steer activities
I manage to finish whatever plans I start	
I take into account a balance between safety and efficiency in my planning decisions	High enough devotion to safety
I can detect failures or errors in my planning before they create problems	Ability to recover quickly to a dynamic stability
I can identify when my planning decisions are pushing the boundaries of safe performance	Ability to respond to problems by anticipations
I assess the potential safety impacts for each of my planning decisions	
I have a clear picture of how my planning contributes to the building of an integrated national delivery plan	Ability to cope with complexity
I have enough time to reflect on my planning	Buffering capacity
I am encouraged to reflect on my planning	
I receive feedback on the outcome of my planning	Learning culture
I revise my planning whenever new information arises	
Because something has always gone well before, I feel confident that it will continue to go well in the future	
My management does not blame me for any poor outcome of my planning	Just culture

Planners were asked to give their rating on a Likert scale of six levels (1-Strongly disagree, 2-disagree, 3-Slightly disagree, 4-Slightly agree, 5-

Agree, 6-Strongly agree). No neutral (middle) point was provided in order to force choice.

The outcome of delivering this section was then submitted to a principal components analysis (Kline, 1994), in order to reduce the set of 22 statements into a coherent subset of more or less independent factors. These factors were then discussed as a possible source of measure for resilience in planning. The specific methods used in this process are outlined in chapter 7 (Resilience in planning).

4.10.2. Principal components analysis

Part 1 of the questionnaire provided an assessment of aspects derived from resilience engineering literature. Principal components analysis was used as an approach to reduce these aspects to a set of factors, which could be more easily managed and assessed within the scope of planning performance. The meaningfulness and applicability of the extracted components as measurable aspects was investigated in order to better understand resilience in rail engineering planning and its sources.

Specific objectives	Improve knowledge and investigate methods on resilience engineering and related concepts (4) (5) (6)

Principal component analysis, in comparison with factor analysis aims to reduce a large set of items into a coherent subset of more or less independent factors. When comparing these two methods, the fact that principal components analysis takes into consideration all the variance in the observed items, rather than just the co-variance (Tabachnick & Fidell 2007), was considered a more suitable approach for the goals set out in this study.

The Statistical Package for the Social Sciences (SPSS) was used as a support for all the necessary statistical methods. The main advantage in the use of this software resides in the ability to rapidly test a large number of different component extraction solutions. In total, 10 different principal components solutions were tested from the original set of data of part 1 of the questionnaire. The criteria used for the selection of the most suitable solution and the methods used for the interpretation of the extracted components are discussed in chapter 7.

Following the principles of the analysis of historic data, the comparison of different geographical regions was used to identify possible trends on the extracted components. SPSS was used to compute new variables that reproduced each of the extracted components.

4.10.3. Development of part 2 of the questionnaire

Part 2 of the questionnaire was developed based on the main issues emerging from the semi-structured interview process. Having identified these issues and understood their sources and relevance for the scope of this research in terms of studying resilience in the planning system (approached in section 7.1), the aim was to assess the impact of these issues on the performance of planners in a larger sample. This not only contributed for the better understanding of planning, but it also supported the investigation of resilience and its sources.

Specific objectives	Identify the magnitude of planning problems and better understand their sources (2) (3) in order to understand how resilience engineering can be an useful approach for the success of planning (4) (5)

Table 4.10 summarises the relevant issues to clarify the support used for the development of this questionnaire section. These issues are discussed in detail in section 5.2.

Table 4.10: Aspects supporting the development of statement for part 2 of the questionnaire

Aspects	Description
Management of planning changes	Managing planning changes emerged as the most critical aspect in planning. Each change was found to have a planning decision at its origin
Organisational and geographical barriers	The performance of the planning system greatly relies on the relations between different organisational and geographical structures
Variability of inputs to the planning process	Planners have to manage and deal with a great diversity of sources of information to support their decision processes
Formal and informal flows of information	While a formal flow of information supports negotiations are between numerous organisations across the industry planners rely on informal contacts to support their decision processes

Uncertainty and unpredictability	The great diversity of sources of information and the complexity of planning system weakens planners ability to foresee the outcome of their decision making
Planning experience	Experience and overall understanding of how the rail industry operates helps to recognise when and what information is required to support a given decision
Reliable work relations within the planning organisation	Work relations support informal discussion of issues and improves access to information
Understanding the impact of decisions on delivery	Understanding the constrains and needs of work delivery improves planners ability to anticipate and solve potential problems
Development of contingencies	Contingencies (spare time or extra capacity) are integrated into planning to minimise the risk of delivery failure

Using the interviews as a foundation, a set of questions was developed and submitted to the same iterative process as the one used for the first section of the questionnaire (peer reviewing by six members of the Network Rail Ergonomics Team). Planners were asked to rate each of the statements in Table 4.11 according to how much they felt these influenced their performance. A rating scale of six levels was also used in this section (1-Not at all, 2-Very little, 3-Little, 4-Some, 5-Much, 6-Totally).

Table 4.11: Set of statements for part 2 of the questionnaire

Mark how you feel the following factors influence your performance as a planner	
1	The organisational division of planning units (NDS, NAU, II, IM…)
2	The range of inputs (formats, type of information and timings) to the planning process
3	Difficulties in obtaining accurate information
4	Working with incomplete or inaccurate information
5	Planning experience
6	Geographical knowledge of the railways
7	Having trustworthy work contacts within the planning organisation
8	Informal flow of information by means of phone calls, e-mails
9	Informal face-to-face discussion of issues
10	Understanding the impact of planning decisions on delivery

Following the descriptions later given in section 7.1 and summarised here in Table 4.10, it became evident that while some of the aspects were presented by planners as having a negative impact on their performance, others were considered to contribute positively. This means that while some of the derived statements in Table 4.11 will aim at assessing a negative impact on performance, others will be directed to the assessment of more positive influences. For instance, “having difficulties in obtaining accurate information”, if rated highly by planners, will clearly represent a negative impact on performance. Conversely, statements like “geographical knowledge of the railways”, if rated highly, will suggest that having such knowledge facilitates performance. Within this scope, and according to the descriptions in Table 4.10, while statements 1 to 4 are aimed at the assessment of negative influences on performance, the remaining statements are targeted at more positive contributions.

4.10.4. Questionnaire implementation and delivery

The questionnaire was implemented in each of the territory and area delivery planning units in the country. Following the description provided in section 2.3, this amounted to 21 different locations (5 TDPUs and 16 ADPUs), which constituted an estimated population of 210 planners (due to ongoing reorganisation processes no exact numbers were available).

In order to ensure the desired levels of response and due to time constraints, meetings were arranged with each planning unit during which the questionnaire was distributed and collected upon completion. Meetings were initiated with an introduction of the research scope and the specific purposes of the questionnaire. Whenever possible, brief discussions with planners followed the completion of the questionnaire, which provided the opportunity to collect informal feedback on the relevance of the questionnaire.

In some units, the number of respondents was limited by absences due to leave of absence or unforeseen work issues that required part of the teams to be away from their location at the time of the visits. Also 6 of the existing 21 planning units did not reply to the initial requests for meetings and in particular, an arranged meeting with an area planning unit had to be cancelled by the unit manager, which voided any possibility of gathering data for the Sussex region. In total, 105 planners responded to the questionnaire (50% of the estimated population of respondents). There is no reason to suppose that this is a biased sample, nor that they do not represent the views across the whole planner population.

4.11. International resilience workgroups

Resilience engineering is a recent field of research with little application to date in the railway context. Within the scope of participating in the development of this discipline, scientific workshops and other working meetings were attended. These activities led to the integration of the author in an international working group on the development of resilience engineering. These group discussions supported the development of the methods earlier presented in terms of addressing resilience engineering in planning.

Specific objectives	Improve knowledge and investigate methods on resilience engineering and related concepts (4) (5) (6)

4.11.1. Participation in workgroups

Participation at the advanced course on resilience engineering (22-24 July, 2009) offered a wide range of opportunities to debate on resilience concepts and methods with other experts. The course took place relatively late in the duration of this project. Nevertheless, given its focus on managing and measuring resilience and the opportunity to explore these aspects based on concrete cases, this course provided valuable support for various stages of research and became crucial in the development of the questionnaire process. A considerable part of the knowledge acquired in this course was put to practice in the work described by Ferreira *et al* (2011).

Three annual workshops (2008, 2009 and 2010) dedicated to the development of the Functional Resonance Analysis Method (FRAM) were attended. Based on the concept of functional resonance introduced in section 3.4.5, this tool supports the analysis of complex sociotechnical systems. The initial designation was “Functional Resonance Accident Model”, as it targeted the investigation of events retrospectively (Hollnagel, 2004). More recently, this tool has evolved towards a prospective application in risk assessment and system monitoring, which accounts for the use of the designation “Functional Resonance Analysis Method”. The use of FRAM in this research followed this latter approach, aiming to support the investigation of interactions within the planning system, based on the understanding of the existing flows of information and decision making processes. This work was then presented and debated with the international group attending workshops, which provided additional input for the "FRAMing" of the planning system. The experimental work developed with FRAM is documented in Section 7.3.

4.11.2. Function Resonance Analysis Method - FRAM

FRAM is essentially a non-linear analysis tool in the sense that it aims to reproduce concurrent phenomenon in the system, rather than building cause-effect sequences of events in time. As outlined in section 3.4.5, FRAM is based on the principle that accidents in complex sociotechnical systems are produced by unexpected combinations (resonance) of "normal performance" variability. Hence system safety can be achieved by understanding and controlling (damping) sources of variability. Understanding ETTOs and the decision making processes that these shape, plays a crucial role in preventing undesired sources of variability. Trade-offs are at the core of every performance adjustment that people develop, aiming to match the perceived operating conditions (section 3.4.4). Therefore, ETTOs are both a response to, and a source of variability (Hollnagel, 2004).

FRAM is based on four basic principles, which were earlier explained in section 3.4.5:

- **Success and failure are equivalent** in the sense that they both emerge from performance variability.
- Variability becomes necessary as a way for people to **adjust** tools and procedures to match operating conditions.
- **Emergence** of either success or failure is not the direct result of variability within a given task or function, but rather to the unexpected combination of variability from multiple functions.
- The unexpected "amplified" effects of interactions between different sources of variability are at the origin of the phenomenon described by **functional resonance**.

The fundamental step in the use of this method is the identification and description of functions. In line with the concept described in section 3.4.5, Figure 4.4 illustrates the functional unit of a FRAM. Each function is defined by six descriptors (time, control, output, resource, precondition and input), as shown in Figure 4.4.

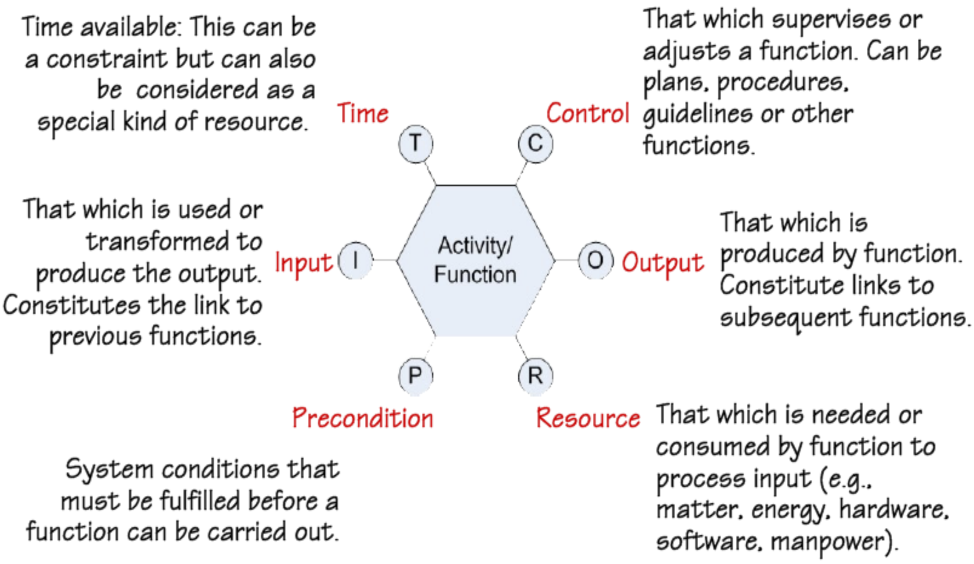


Figure 4.4: Functional unit of FRAM (from Hollnagel, 2008)

Potential sources of variability are then investigated, guided by the identification of context dependent human, technological and organisational aspects. Similar to the approach used by CREAM (Cognitive Reliability and Error Assessment Method, Hollnagel 1998), FRAM uses Common Performance Conditions (CPCs) as descriptors for the relevant context. While CREAM would aim to describe scenarios more focused on task performance, FRAM CPCs are intended for the description of the context in which system functions are produced. Throughout the three FRAM workshops attended by the researcher, different proposals were discussed in terms of the designation and use of CPCs, depending on the context of application. One of the earliest researches dedicated to the application of FRAM, Woltjer (2009), made use of the CPCs shown in Table 4.12. A description for each CPC is also given, based on work presented by Besnard (2008).

Table 4.12: Common performance conditions for FRAM

Availability of personnel and equipment	Roles and responsibilities of team members, additional staff support, availability of communication systems and other support technology, instructions and guidelines, among others
Training, preparation and competence	Quality of training provided to operators, familiarisation with new technology, refreshing old skills and level of operational experience
Communication quality	Efficiency and accuracy of information flows and processes by which information is transmitted within and across organisational boundaries

Human-machine interface and operational support	Human-machine interface in general, including information available on control panels, computerised workstations, and operational support provided by specific decision aids
Availability of procedures	Procedures and plans include operating and emergency procedures, familiar patterns of response heuristics, routines, etc
Working conditions	Nature of physical working conditions such as ambient lighting, glare on screens, noise from alarms, interruptions from the task, etc
Number of simultaneous goals	Number of tasks a person is required to pursue or attend to at the same time (evaluating effects of actions, sampling information, assessing goals etc.)
Available time	Time available to carry out a task; corresponds to how well task execution is synchronised to process dynamics
Circadian rhythm, stress	Time of day (or night) describes the time when the task is carried out, in particular whether the person is adjusted to current time (circadian rhythm).
Team collaboration	Quality of collaboration between crew members, including overlap between official and unofficial structure, level of trust, and general social climate
Organisational quality	Quality of roles and responsibilities of team members, additional support, communication systems, Safety Management System, instructions and guidelines for externally oriented activities, role of external agencies, etc

The analysis of performance conditions is not intended as a way to identify direct causes of failures but rather characterise sources of variability within functions. The potential variability of functions is then assessed by means of a qualitative rating of CPCs. The scales used in this process may also vary according to the context of application and the level of discrimination necessary for the scope of analysis. Although no specific examples were presented, workshop discussions led to admit that sources of variability may be identified by means other that the use of CPCs.

The graphical representation of functions as hexagons becomes useful for the remaining steps of FRAM. Using the six aspects of functions (time, control, output, resource, precondition and input), system interactions are studied, aiming to identify potential sources of resonance. For instance, the output of a function may be the input, a precondition or even enforce a control aspect of another function in the system. The purpose of CPCs is to help identify interactions in which the sources of the variability in one function may impact on the performance of another. This amounts to consider when, for instance, an output of a function is rated as insufficient inappropriate or unpredictable, which functions to which this output is linked may be affected and how.

This process may also lead to the identification of possible damping sources for undesired variability. As an example, if resources for a given function are rated as “more than necessary”, it could indicate the existence of a “spare capacity” that could operate as a damping barrier. To this purpose, Hollnagel (2004) describes four categories of barriers to be considered within the scope of FRAM:

- **Physical barrier systems** are intended to block or prevent the movement of mass, energy or information. These are commonly the role of structures such as walls and fences, or safety belts.
- **Functional barrier systems** recreate preconditions that must be met prior to carrying out a given task or action. Interlocking systems (such as those used in railway signaling) and passwords are included in this category.
- **Symbolic barrier systems** include all types of indications and information (signs, checklists, among others) regarding the limitations and constraints to be taken into account when carrying out a given task or action.
- **Incorporeal barrier systems** are also referred to as immaterial barriers, as they are not physically present in any form. They include all types of ethical principles, rules and laws.

The process of investigating possible connections between functions, for the identification of both potential undesired variability sources and barriers, is referred to as an instantiation of FRAM. As later exemplified in Figure 7.7 (section 7.3), this corresponds to linking functions using their six aspects.

4.12. Summary of research methods

Research methods were introduced with regard to their specific objectives, and the research issues they intend to address. These methods and the way in which they are structured are reflected in the research conceptual framework given in Figure 4.2. Methods aim to respond to the research objectives earlier stated and in particular, investigate the main research questions, as detailed in Table 3.7. This is summarised in Table 4.13.

Table 4.13: Summary of research questions and methods

	Research Questions	Research methods
Objective 1	• How is the planning process framed within Network Rail's organisational structure and within the rail industry? • What are the boundaries of planning? • What are the main trends of planning performance?	• Analysis of planning documentation and business process • Planning familiarisation interview • Semi-structured interviews • Planning archival data analysis
Objective 2	• What are the main constraints to planners' decision making? • What are the main resources used by planners to deal with constraints? • How do the planning process and its organisational structure support or hinder decision making processes?	• Planning familiarisation interview • Familiarisation interviews with planning stakeholders • Semi-structured interviews
Objective 3	• What are the main trends in work delivery performance? • What are the different trends in the relations between planning and work delivery?	• Familiarisation interviews with planning stakeholders • Planning archival data analysis • Safety data analysis • Infrastructure archival data analysis • Archival data from a system perspective
Objective 4	• How does variability and uncertainty express itself in the planning system? • What are the sources of resilience in planning?	• Analysis of interviews data from a resilience perspective • Archival data from a system perspective • Questionnaire • Functional analysis (Functional Resonance Analysis Method – International resilience workgroups)
Objective 5	• What aspects of planning performance can potentially support the development of resilience indicators? • How can resilience in rail engineering planning be monitored?	• Archival data from a system perspective • Questionnaire • Cooperation with international resilience workgroups

5. Understanding engineering planning

This Chapter describes the results obtained through the methods described in Chapter 4, relating to the description of planning, its organisational features and to the identification of main planning issues. Based on the arguments from the literature presented in section 3.6, the main purposes of this chapter are to explain high complexity in planning and describe its decision making processes. Qualitative data from interviews adds to the description of planning developed in section 2.3 and identifies sources of variability and uncertainty, as well as their impacts on planners' decision making. Planning human and organisational factors are also described. The quantitative analysis of planning archival data supports the identification of performance indicators and a subsequent investigation of different performance trends in planning, based on a geographical comparison.

Objectives	Questions	Methods
1) Develop a description of the rail engineering planning system as a complex sociotechnical system. 2) Identify the critical human and organisational factors of the rail engineering planning system.	• How is the planning process framed within Network Rail's organisational structure and within the rail industry? • What are the boundaries of planning? • What are the main trends of planning performance? • What are the main constraints to planners' decision making? • What are the main resources used by planners to deal with constraints? • How do the planning process and its organisational structure support or hinder decision making processes?	• Planning familiarisation interview • Semi-structured interviews • Planning archival data analysis

5.1. Familiarisation interview

As stated earlier in the methods chapter, this interview was carried out with a senior planning manager at NAU. This was the initial contact with the planning organisation and its members, and provided grounds for the subsequent analysis methods.

Overall, the interviewee described the planning process as a sequence of three stages, formally designated as long-term, medium-term and short-term planning and emphasised Infrastructure Investments (II) and Infrastructure Maintenance (IM) as the two main organisational functions involved in planning. An overview of the three stages was given, focusing on their goals and timings within the overall planning process. The explanations given by this planner formed the base of the outline of the planning organisation and process earlier presented in sections 2.2 and 2.3. Additional details on the outcome of this interview are given here.

5.1.1. Long-term planning

This period of planning provided a "foot print" for access opportunities to the network. At this stage, no details were established concerning the actual work to be delivered and when. This "foot print" was built based on the feedback provided by Network Rail engineering inspections and patrolling to the network, which provided a general scope of the required maintenance works. Business plans were also used to establish potential renewals and major projects. An approximate prioritisation for these work packs was also provided, although these were mostly based on assumptions and "best guesses" rather than accurate information on the status of the infrastructure. This stage of planning would be concluded with the issuing of the version 1 of the Rules of the Route (RotR), which constituted the first draft for access proposals. The Territory Delivery Planning Units (TDPU) were responsible for gathering and requesting all work proposals from stakeholders (maintenance, investments and other engineering stakeholders).

5.1.2. Medium-term planning

During this stage, the access opportunities previously created would be discussed in more detail and area teams would propose work to be slotted into the available access. Through this process, TDPUs build the Annual Integrated Work Plan (AIWP) as a broad scope national plan of delivery. At QT-38 (38 weeks before delivery), a formal meeting would take place to handover the upcoming quarter of the AIWP to the ADPUs. Meanwhile, new requirements for work and access would still be proposed and attempts made to incorporate them into the AIWP through negotiations with TOCs and engineering. These negotiations were formalised by the NAU via the publication of the version 2 of RotR. Although formally only two versions of the RotR are considered, the NAU issued three versions as follows:

- RotR V1: initial proposal based on which the NAU would get first responses from counterparts.
- RotR V2: Amendments were introduced based on the responses previously collected and re-issued as a new version for consultation.
- RotR V3: After collecting new responses on the amendments (V2) a formal decision was made and published as V3.

Based on more detailed work contents, critical resources such as haulage would be allocated and potential conflicts were highlighted, in particular regarding the routes for engineering trains. At QT-45, a meeting would be held to review and finalise the resource allocation. The interviewee mentioned that in a way, this meeting would create a problem, as it requested from the National Delivery Service (NDS) more resources than those available. Meetings at T-32 and T-31 would be held almost exclusively to solve and check for such problems by addressing conflicts based on known work priorities. It was stated that the expertise of the Area Delivery Planning Managers (ADPM) played a crucial role in these decisions, as possessions were re-arranged to try and meet the needs of all the industry partners as best as possible.

5.1.3. Short-term planning

This stage was mostly based on verifications and confirmations of work details. Changes to work plans would be more and more discouraged and would only be accepted when safety issues were involved. Depending on the changes proposed and their timing, different control change processes and authorisations would be required, as described in the Business Process Document PL0086 – Work & possession planning for the railway infrastructure: Change control (NR/SP/MTC/0086). The interviewee added that change control represented one of the major challenges for the planning organisation, mostly due to the lack of specific criteria, beyond the principle that no changes other than safety critical ones should be accepted. The acceptance or refusal of work depended mostly on decision makers and their interpretation of this principle.

It was also mentioned that planning in this period becomes more localised (area level and delivery units) and that differences between regions become more relevant, in particular the way in which planning meetings and decisions are managed. It was the interviewee's opinion that different practices in managing PICOP briefings (last formal planning meeting) might be one of the main causes for different levels of delivery performance throughout the country.

During the entire planning process, information would be transmitted in many different ways. E-mail played a fundamental role, as it provided traceable and auditable records. Many informal discussions would take place to solve particular problems but formal agreements would always be demanded at each planning meeting.

In general, the West Coast Modernisation Programme was mentioned as an example that gathered particular strong competences and good practices around a common goal (a major renewal project). This was considered particularly relevant during the allocation and prioritisation of work and resources at T-32 and T-31 meetings and the way in which information was transmitted regarding late changes, and during PICOP briefings where local practices tend to be more evident. The planning of work under this programme was developed by a structure independent from the national organisation, which created particularly favourable conditions for good communication and team interactions. According to this source, at T+1 (week after delivery), when a review of work delivered would be carried out, the common practice at national level would be to simply review undelivered work and propose its rescheduling. Under the West Coast Programme, not only reported problems would be discussed, but also any other particular events that could potentially contribute to a successful delivery of forthcoming work.

5.2. Semi-structured interviews

As stated in the methods chapter (section 4.5), this interview process aimed at further exploring the outcome of the familiarisation interview with the NAU senior planning manager. Approximately 16 hours of recordings were made for the 15 interviews. Depending on how interviewees elaborated on each subject, the duration of interviews varied from about 50 minutes up to nearly 2 hours.

The time in between scheduled interviews gave the opportunity to listen to recordings from one interview to the next. This was fundamental for the iterative review process discussed earlier in section 4.5. When 6 interviews were completed and the respective recordings had been transcribed, it became clear that answers given to the first four topics would tend to converge to two broader topics of discussion. This was attributed to some difficulty in having interviewees elaborating on these topics as much as initially foreseen. Although the 10 questions were maintained throughout the 15 interviews, the tabular analysis process was restructured into eight different groups, as shown in Table 5.1.

Table 5.1: Question topics and correspondence to tabular analysis topics

1	Can you tell me about your job (daily tasks, duties)?	Job description and functions in the planning process
2	Can you explain the planning process from your point of view? How would you describe your influence/role in the process?	
3	How often would you say your job changes? How does it change? Have the tools changed? The information sources or formats? The decision making?	Job variability and levels of confidence (feedback on decisions and uncertainty…)
4	Do you normally feel confident regarding the outcome of the planning activities in which you take part? Can you identify any recurrent uncertainties that you are faced with? (If so) How do they manifest themselves? How do you deal with them? Do you look to obtain feedback? How do you ensure you have reached your goal?	
5	What would you say are your main skills and competencies? Do you feel they improve with your job experience?	Skills and job experience
6	How would you describe the overall set of rules and procedures applicable to the planning process? Are there any which you would consider to have a particularly significant impact over the planning process (safety critically or otherwise)? Do you feel these rules and procedures support you in the performance of your duties?	Rules and procedures
7	What type of information do you use most? How important is it in your job? What sources you mainly use? Would you consider that the production of information for others is an important part of your job?	Information and communication
8	What do you consider to be the current major challenges for track work delivery? How does the planning process respond to those challenges? In particular, what are your views in the way changes in the planning emerge and how they're managed?	Challenges for the future of the system
9	What does resilience mean to you? Considering resilience as a property that enables the system (engineering work) to resist and recover from unexpected variations and pressures from its environment, how would you characterise the planning and work delivery processes in these terms?	Resilience

10	Throughout your professional experience in this area, what do you consider the major achievement within the planning process? What success stories come to your mind? What failures?	Major ups and downs of the planning process

Following a note on the characteristics of the sample interviewed, this section presents information under each of these eight topics. All the information that would not suit any of the topics was registered as additional notes. Quotes from the interviews relevant for each topic are given at the end of each sub-section within a table format.

5.2.1. Characteristics of the sample

The age of interviewees ranged from late 20's to 50's, with an average placed between 30 and 35 years old. Even the younger planners had at least 3 years of experience in planning and the majority had 10 or more years of experience in different roles and levels of the rail industry.

5.2.2. Job description and functions in the planning process

Table 5.2 provides a list of the 15 interviewees by formal job identification, together with a brief description. From the familiarisation interview, area planning level was identified as the most critical stage. In addition, the NAU senior planner mostly provided contacts for either area or territory unit managers, as he considered that these people could provide insight on a wider range of issues and if necessary, managers could direct to members of their teams for other interviews. This accounts for the fact that one third of the interviewees are ADPMs.

Table 5.2: Jobs for which interviews were carried out

Job title	Description	Interviewees
Territory delivery planning manager	Manages TDPUs	1
Area delivery planning manager	Manages ADPUs	5
Work optimisation analyst	Review possession arrangements and resource allocation (territory)	1
Integrated planning manager	Deliverability of plan at national level	1
Possession delivery manager	Verify work details and support final arrangements for delivery (Area)	2

Resource optimisation specialist	Critical resource allocation (Territory)	1
Track section manager	Detailed planning of worksites (MDU)	1
Senior planning & delivery manager	Planning of engineering trains (NDS)	1
Possession planning Assistant	Collate worksites into possessions and support final arrangements for delivery (Area)	1
Territory plant coordinator	Verification of resource allocation	1

Despite the different roles of the people interviewed, some common tasks or functions were found. Mainly, all planners interviewed consider as part of their duties to monitor compliance with procedures and verify accordance between access, resources and work requirements at their respective planning level.

The management of change and dealing with the change control processes were rarely referred as being part of the job. Regardless of other discussions on this subject, attending to planning changes was only mentioned by three planners within the description of their duties. Only one explicit mention to "policing the requests for late changes" was made. Given that plan changes have a strong impact over planners activities (later discussed in this section), it would be expected to have this mentioned more often as a main focus of their job.

Interviewees in planning managing positions pointed out as one of their main functions the monitoring of the overall development of planning ("looking at the bigger picture") and supporting decisions towards achieving a nationally integrated plan that responds to the industry's needs. In particular, area planning managers (two of the interviewees) expressed this need as a way to maintain control over financial aspects because of their relation with contractors. Senior managers (three interviewees) also added as part of their functions the "buffering and mediating of relations" between their team and the other counterparts in the planning system.

5.2.3. Job variability and levels of confidence

It was recognised by all planners interviewed that the core elements of jobs in planning have not changed over the last few years. However, at least half of the interviewees referred to the frequent process and organisational changes as an obstacle to the development of adequate expertise and solid working relations. At least four interviewees stated that knowing the people they work with constitutes a fundamental resource to anticipate issues and work proactively. In particular, one planner stated that it took him/her some five years to develop confidence in the job and the required relations.

Dealing with uncertainty and unpredictability was recognised by all interviewees as part of the daily activity in planning (discussion on topic 4). Six of these planners characterised uncertainty as a major obstruction to reliable planning. This factor is managed, whenever possible, by working on contingency solutions and being prepared for anything that might require rebuilding plans. Job experience and overall understanding of the railways were considered crucial by the majority of planners, not only to explore different possible contingencies (i.e. different ways of delivering work) but also to adequately integrate these within the planning process (i.e. anticipate and solve potential conflicts). Regarding work relations and knowing the people they work with, planners, particularly those at the front end (APMs and PPAs), are aware that some contractors tend to be less reliable deliverers than others. For instance, depending on their experience with a given contractor, they account for more or less recovery time at the end of the possession as a buffer for potential problems (plan for contingency).

Planning changes were mentioned by all interviewees as the main cause of variability and unpredictability of the job, as well as the main obstruction to having confidence in the work they produce. Planners recognised that more than their ability to develop a robust plan, unpredictability and variability affected the performance of the planning organisation as a whole. The majority of planners tended to consider that changes are mostly originated by priorities that emanate from company board level, which themselves can cause budgets for work packs already undergoing planning not being approved or changed. At least three planners alluded to the image of a puzzle to refer to the nationally integrated plan: Optimising resource allocation both locally and nationally, means that all work to be delivered has been fitted together in an integrated plan, like in a finished puzzle. Changing work in the plan is like changing a piece of the puzzle, which means that the remaining pieces do not fit as well, resources will be wasted, or a new puzzle has to be designed (re-planning). Six planners referred to these problems as knock-on effects that impact on the entire planning structure and are beyond any control of planners. One planner at long-term level considered that changes in this period have a more strategic nature, such as reprioritising work packs or de-scoping work for lack budget or access, as opposed to short-term planning where issues are about conflicts or failures that could occur in the immediate timeframe (this week, tomorrow or even on the night).

In addition, planners at short-term mentioned the need to manage unforeseeable changes generated by work delivery failures, which can require the rescheduling of work items. One interviewee mentioned that difficulties in getting the requested access to deliver planned cyclic maintenance leads to work being carried out under emergency circumstances as assets eventually start failing, which also contributes to the knock-on effects previously mentioned. One area level planning manager mentioned that possession coordinators used to receive around 80 change control forms per week for an average of approximately 160 worksites planned. However, pressure exerted over possession managers and delivery units to invest on timely planning has contributed to a substantial reduction of Possession Change Control Forms (PCCFs) submitted. An ADPM referred having to deal with between 10 and 30 changes, from T6 down to delivery, which have little to do with safety of the line or operational priorities.

Relevant quotes	• Uncertainty plays a significant role and experience is fundamental to deal with it. but it can be demoralising having to re-do everything (as a response to changes) • The fact that there are planning teams working parallel to each other creates grey areas in terms who should be doing what • We know that some contractors usually fail in terms of reliability of their work and for that we need to account for problem recovery time at the end of the possession (plan for contingency) • After RotR changes occur not because the plan is not robust enough but because the company changes its priorities, budgets are not approved or approved late and failures at delivery produce a knock-on effect. These are all external factors that we cannot control • We have to manually cross check our plan against every version of RotR to make sure they're aligned. There is no way to mitigate mismatches apart from checking. Anything could go wrong (high uncertainty) • When going to functions (stakeholders) regarding the work they intend to develop for upcoming timetable year, information tends to differ a lot and often not in a controlled format. You trust the people and go to them rather than the process or the system • Contractors are allowed to plan with little detail and to change things at their convenience • At some point it comes down to a judgement call as to whether or not the detail provided with work banks is solid enough to go ahead • Because the requested access to deliver planned cyclic maintenance is not granted much of it ends up being solved under emergency possessions. this causes a knock-on effect of late changes

5.2.4. Skills and job experience

Experience and overall industry knowledge were mentioned by all planners as an important resource to realise what information is required at each step to support planning decisions (discussion on topic 5). According to planners, this enables an understanding of what the impact of planning decisions might be on the “day of the race”. Particularly in regards to the role of possession coordinator, two interviewees considered that having a minimum of experience in the rail sector is fundamental to develop a perception of what resources different jobs may require and of the constraints and limitations that must be taken into account.

Referring to skills and competence in general, three planners considered that the organisation has not always been able to “allocate the right people to the right job”. One planner mentioned that frequent reorganisations do not allow sufficient time for new people to be adequately trained for new jobs. As a result, often people have little knowledge regarding the area for which they are planning for, or do not understand the capacities and limitations of machinery they are requesting. Overall, the planning organisation was described as operating in “silos” and hampering any ability to share expertise and good practices.

Experience also becomes relevant for the building of solid relationships with stakeholders (II, IM, customers, contractors and operations, among others). As previously mentioned, by knowing how people work and respond under different circumstances, planners are able to anticipate potential problems. In addition, these relationships establish levels of confidence and mutual trust that support informal discussion of issues and problem solving.

Overall, the following attributes were mentioned as being important to achieve good planning:

- Ability to communicate and work with different people and under different challenging circumstances, such as time pressure or uncertainty of information
- Ability to uphold decisions during discussions with stakeholders and customers
- Having a clear perception of one’s role and objectives within the planning process
- Good geographical knowledge of the territory
- Being able to adequately plan and manage a diary

Two main types of background experience were identified amongst the interviewed planners:

- An operations background, mostly acquired through signalling experience
- An engineering background that is usually related to previous work with contractors and trackside work as PICOP, ES or COSS

Although throughout interviews all planners recognised that background greatly influences the way in which they prioritise issues and make decisions, more detailed information is required to understand its real impact over the planning process as a whole.

Relevant quotes	
	• It's taken me some 5 years to gain confidence in the job • Planning requires flexibility to respond to different people and situations • Being able to communicate and working with other people and properly build your arguments to deal with confrontation • Experience and understanding of the industry is fundamental to know what information to look for and to use as support for decisions. Understand what the impact of things might be • A lot of it is understanding how long it takes to deliver a job • Often people work in silos and don't have the right understanding of the commercial aspects or other business related issues. to actually understand what their decisions might affect • The majority of the planning managers have a signalling background. Some lack the experience that allows them to understand how a renewals is delivered

5.2.5. Rules and procedures

The business process PL0056 was considered by all people interviewed to be a major contributor to the integrity of planning (discussion on topic 6). Having this formal support, planners were able to impose common milestones and deadlines to stakeholders. All interviewees described this as a gradual process through which they had to force stakeholders to provide the right information at the right time, or face access being denied. Although PL0056 was useful to enforce a “working to one way” at national level, none of the planners use the document as guidance for their daily work. Only the key meetings, the documents that must be produced, and the timelines are used to impose minimum requirements to stakeholders. Three people stated that failing to comply with the planning process was one of the major factors contributing to the erosion of planning robustness. One planner added that the control of change (PL0086 and Planning Change Control Forms - PCCFs) has reduced the amount of late changes and has brought in accountability for ones actions and decisions.

When discussing Rules and procedures as whole, people at short-term planning (possession and worksite planning) mentioned difficulties in keeping up to date with frequent changes to the rulebook and understanding how those changes actually affect their activities. All planners in managing positions (TDPMs, ADPMs and PDMs) added that following procedures and rules is a safeguard when facing conflicts with stakeholders. Despite this support, most ADPMs interviewed referred that on occasions, they had been confronted with instructions from higher management levels (route management or maintenance directors) to agree on late changes to the plan, mostly in the sense of accepting additional work, which was then described as business critical.

It was stated by one planner that peoples' common practices, although based upon knowledge of the rules, are often based on an inaccurate interpretation, which can lead to serious consequences. At least four planners felt that rules and procedures might be inapplicable in view of the complexity of some scenarios and that “common sense” and experience are often necessary to overcome conflicts.

Relevant quotes	• As a manager, following procedure is a safeguard • Rules and procedures do not adjust to reality but to have a common ground for everyone to work to is fundamental • There's often abusive use of rules through interpretations according to their own convenience • In all the time the PL56 is been in place, I have never referred to it. it hasn't really helped with our problems from TT-80 • Throughout my experience (7 years in planning) late changes in the plan have never been limited to safety of the line. A decision should be made as to whether keep trying to push that as a procedure or just admit that changes will have to be accepted even after T-6

5.2.6. Information and communication

All interviewees pointed out information and communication channels as a crucial resource for planning. One ADPM stated that this job consisted of collecting and delivering information for 90% - 95% of the day. Two different trends in information problems were identified:

- At long-term planning, issues with information are mostly related to the great diversity of formats and sources that have to be dealt with, as well as the differences in time lines of functions inputting to work packs. Three of the planners interviewed referred to this high variability in information as a major cause of time loss and of some frustration due to the duplication of work which it often incurs.
- Within short-term planning, in particular at pre-possession stages, the lack of up-to-date and accurate information and frequent uncontrolled late changes are the main cause for concern. One planner at this level considered that communication between planning, onsite staff (PICOP), control and operations managers can greatly improve reliability and efficiency of work delivery. Several planners stated that having accurate and prompt information at this level can prevent a possession from

overrunning or even incurring in serious losses or injuries.

There is a consensus amongst all planners towards the fact that the organisation is able to generate the necessary information to develop a reliable and detailed plan. However, planners were also unanimous when considering that the way that information is made available and processed does not support them adequately. All interviewees mentioned the frequent need to cross check and chase accurate information. The following main issues were mentioned by the majority of interviewees as causes for this lack of support:

- A lack of feedback information from outside ones team prevents planners from developing any kind of visibility over planning performance as whole. Planners often mentioned not knowing what happens to planned work beyond their own sphere of intervention, as constant changes at all levels are the only certainty.
- Stakeholders tend to deliver incomplete information and often late in the process. This inputs frequent changes and generates conflicts, which planners have to manage having little visibility over priorities and criticality of each work pack. The use of a great variety of information formats adds to the difficulty in integrating work packs.
- Information is often imprecise and requires cross-checking of details from different sources. Issues usually have to be chased, which dramatically increases the amount of communications needed (particularly e-mailing) and the risk of planning failure. To avoid missing critical details, planners tend to consider all information as valuable until proven otherwise.
- The use of different IT systems throughout the process that yet do not exchange data among themselves imposes a constant need to "translate" information from one system to the other. When changes are imported to the plan, information has to be updated into several systems individually. Some of the properties of these systems may not be aligned with the actual constraints and needs of planners, due to specific methods and organisations of work that vary amongst territories and areas, even within compliance with the process. One planner added that supporting planning with adequate information systems would considerably reduce the need for meeting attendance and

communication, which the sole purpose is often to cross check information.

- Each function within the organisation has its own timings and business pressures to deal with, which do not necessarily align with planning commitments. This alignment becomes more difficult as planners have to deal with suppliers (contractors) and customers (TOCs), which inevitably have different business goals from Network Rail.

Planners demonstrated being aware of the fact that at some point, making decisions comes down to a judgement call as to whether or not the information provided is solid enough to go ahead with planning. They try to mitigate poor quality information issues by developing solid relations with people working with stakeholders (namely TOCs) they feel they can rely on. All planners valued these work relations and more often resort to them, rather than relying on the formal communication channels. Informal discussion of issues is common practice but although highly valued, it is not seen as something that could replace the importance of formal agreements and documentation of decisions. Emphasis was given to the importance of keeping accurate records of all information formally brought into planning meetings as evidence and safeguard. This way of working strengthened relations between planning teams and some stakeholders, and was mentioned by all planners as a significant contribute to solving complex issues and adding robustness to planning. The following circumstances were mentioned as examples of this:

- Improved cooperation and communication between TDPU and ADPU created an ability to anticipate problems and follow up on the planning of complex jobs with more accurate and detailed information to support it.
- When solving planning conflicts and dealing with complex issues, having operations control, contractors or even TOC's sitting through final planning meetings helped with better contingency planning.
- Better detailed information for PICOP's has contributed to improvements on possession performance and a decrease of irregularities. Initiatives such as granting PICOP access to network drives where possession details are stored and updated or publishing possession details under the general instructions of the WON were mentioned as successful approaches.

Relevant quotes	• There's no information regarding the planning as whole. there's no visibility of the other levels • Information that helps anticipate could mean the difference between overrunning or not or someone being killed or not • Decisions and actions are usually initiated based on trusted informal communication channels • The lack of information and communication through integration of change creates problems for decision and prioritisation of issues • There's a lot of e-mailing and communication (with NAU...) that would not be required if it would not be for the need to cross check data. information has to be chased • As ADPM 90% - 95% of the day is spent on collecting and passing on information • When having to coordinate territory level requirements with other territories it is difficult to know who is your counterpart in those other territories to which you ought to be talking to • We usually work with specific contact persons, internally and externally. we know who takes care of what and where • Having a ROS (Resource Optimisation Specialist) and PCMR (Program Control Manager for Resources) allows planning to start requesting precise information from costumers and stakeholders a lot sooner in the process. Having this information from all 5 territories gives way to a more robust national plan • More specific walkouts that can provide detailed support information for planning are needed to reduce the chances for changes • We know that often new trains are late planned without that being discussed with us which often disrupts worksites that have gone through the planning procedure • We have to go back and request more details and review information on work banks. there's usually meetings to obtain detailed work banks • TDPU and ADPU as whole are working a lot more closely, mostly due to improved communications and decisions. this allows a much better understanding of the plan and supports a much more efficient problem solving • Issues that access planning teams (at territory level) see as a potential problem for possession delivery are straight on communicated and discussed • For very complex jobs, NDS and/or LOMs (Local Operations Managers) could be invited to participate in planning meetings held specifically for that job • Information like level of priority, budget and risks for delivery are not integrated into planning • Through the complex relations between Network Rail and stakeholders, details of information and the actual priority of requests gets lost • The whole planning organisations discusses what to do in the infrastructure but they only involve the person that is actually in charge of it when they want access or not even then • We usually have to chase information although people will come to us because they need us to sort things out for them

5.2.7. Challenges for the future of the system

The ability to respond to the demands brought in by the new timetables (2008 enhanced timetables, particularly in the West Coast Mainline) was pointed out by all planners as the major challenge ahead. Several concerns were raised regarding the preparedness of the organisation to deliver the necessary volume of engineering maintenance and enhancement projects under considerably reduced access time. Some planners provided further explanation of this by adding what they saw as requirements to achieve this:

- Empowerment of front line staff (at delivery level) to make decisions and manage contingencies, as well as having people committing to the changes that need to be made to the planning process
- Network Rail being able to be more present on site and better enforce the delivery of contracted work within schedule and plan
- Eliminate organisational barriers (not working in “silos”) and fragmentation of key processes
- Achieve better integration at national level (local problems versus route, national or political commitments)
- Having people attending planning meetings and prepare for them accordingly
- All planners referred to having people delivering the right kind of information at each level of planning. This includes improving the quality of the information provided by site visits, in order to support detailed worksite planning and prevent the need to solve issues on the night
- Development of training and corporate induction programs for planners in order to improve competency and overall understanding of the organisation

Relevant quotes	
Relevant quotes	• Network Rail being able to be on site and enforcing work delivery. Making sure contractors work as they should • EEA (Efficient Engineering Access) changes. For resource planning it should improve because potentially there will be more mid-week use of haulage as opposed to massive use of resources during weekends. It may become more balanced • Having people delivering the right kind of information • How to put the big picture in the right frame (local problems versus route problems and national or political commitments) • Getting people to attend meetings and properly prepare for them

5.2.8. Resilience

The majority of the planners showed little awareness of the concept of resilience, when questioned about its meaning. However, after a brief description of the research field of resilience engineering, all interviewees related resilience to the way in which the system is able to reliably and efficiently manage planning changes. The organisational barriers with which the planning process operates, attributed by planners to its division between investments and maintenance as well as territory and area level teams, was mentioned by all interviewees as "an obstacle to planning efficiency and reliability".

Three planners associated resilience with the ability of people in planning to deal with adversities created by business and operation pressures. The planning organisation operates under considerable exposure to business and operation pressures, as it deals directly with critical decisions regarding the delivery of Network Rail's service to its customers. Planners generally expressed this pressure through the need to solve conflicts created by insufficient access to respond to all maintenance and enhancement work needed. All interviewees recognised having experienced pressures from stakeholders to get their requests prioritised through planning and optimise resource availability to deliver the job in question. Given that often stakeholders are unable to meet planning requirements, planners are also pressured to facilitate procedures and allow jobs to go through.

Planners made several observations regarding the reliability and efficiency of planning. The following issues were considered more relevant as contributing positively to this end:

- Having a Resource Optimisation Specialist (ROS) at TDPU level has allowed planning to start requesting precise information from customers and stakeholders a lot sooner in the process. The integration of this information from all five territories contributes to a more robust national plan.

- The adoption of more standardised blocking points for possessions (using the same track mileage whenever possible) contributes to a more structured local knowledge and better understanding of local constraints whenever possessions have to be reviewed to incorporate new worksites.
- For area possession planning, attending depots planning meetings gave way to a better understanding of work scopes and needs, and allowed for problems to be discussed within an engineering forum.

On the other hand, the following issues were mentioned as deterrents to reliability and efficiency of planning:

- In addition to the previously mentioned organisational barriers, numerous obstacles to communication were mentioned. In particular, two planners referred to the need to formalise all decisions involving TOCs through NAU as an obstacle.
- Incompatibilities between the Annual Integrated Work Plan (AIWP) and RotR may occur, despite the thorough cross-checks carried out at different stages of planning. Such mismatches can compromise work delivery and credibility with customers. Due to the high frequency of changes, planners often have to rebuild plans two or three times over
- Long-term planning used to consist on an outline of access and within that, work items were slotted. Currently the process states that higher level of detail should be developed earlier on, which means that changes later imposed cause more disruptions to plan and even access (RotR) is frequently changed
- Project teams (Investments) tend to bring contractors in as late as possible as a way to reduce costs. This means that when project teams start negotiating terms with contractors, delivery arrangements already agreed with planning are bound to require change.
- When conflicts arise, the information necessary to prioritise work and make decisions on what should go ahead and what should be rejected is often not available

Because of insufficient track access opportunities for all work demands, investments and maintenance compete with each other for priority. Planners stated that the fragmentation of the process is the main cause for this competition, leading to occasional conflicts and tensions, as each team attempts to minimise the impacts of business and operation pressures over their own performance. Nevertheless, most planners recognised that the adoption of a national integrating process, together with improved informal communication, have minimised these issues.

Relevant quotes	• There is already some resilience in the system, greatly on the account of the people in it • To have knowledgeable people capable and empowered to make decisions. It has to be given to the right people at the right job • Because of the gaps and misses when cross checking AIWP against RotR people don't get killed on track but we lose work and credibility with our customers. we end up re-do the whole thing 2 or 3 times because of constant changes • Changes affect our safety but we manage that by facing up to people who impose on us inappropriate change • We can't have the necessary information to actually prioritise work and make decisions on what should go ahead and what should be reject when conflicts arise and work packs compete for access • We develop a robust plan but cannot accommodate change • Having a ROS (Resource Optimisation Specialist) allows planning to start requesting precise information from costumers and stakeholders a lot sooner in the process. Having this information from all five territories gives way to a more robust national plan • Project teams are unable to plan to the process because they tend to bring contractors in as late as possible as a way to cut costs • Historically, to get access sorted out has been the priority and resources were to be looked at after that was resolved. Since the introduction of ROSs progressively resources are being worked on together with access. Initially, it was necessary to run after the access planners and try to keep up with then but now team work practices are arising

5.2.9. Major ups and downs of the planning process

None of the planners mentioned any significant event as a breakdown or major failure of the planning organisation (discussion on topic 10). Those that worked under the "West Coast Programme" described the splitting up of access from possession planning and between territory and area level independent teams as a setback for the efficiency and reliability of the planning organisation. One of the planners in question stated that without the structure that existed under West Coast, the amount of work and the level of integration of jobs within access opportunities would have never been achieved.

Overall people interviewed considered that the planning organisation has improved more or less continuously. The following issues were mentioned as major steps forward for the planning organisation:

- Formalising a process that establishes a "one way" of doing things at national level
- Bringing in-house critical roles for safety and efficiency of work delivery (PICOPs)
- The building of solid and closer relations with contractors and other stakeholders

Relevant quotes	• To have one single team planning, developing and delivering the plan was far better than the current process. It provided a much bigger sense of ownership and accountability (West Coast Programme planning team) • West Coast project operated outside the national process. When the WC project was delivered the board decided to bring it all under one single national process. This was due to happen in 2006 but the project would not be delivered on time and a plea to the board was made to extend the one single team way of work • No training and poor corporate induction often results in low levels of competency in planning • When under Railtrack the management of major projects was brought in-house because of problems with contractors, each possession manager would have 2 contractors under its supervision on a regular basis. Major projects management then started to include contingency plans and everything necessary to make sure that work was completed. When the in-house project management was implemented they found that there were problems both on the side of contractors and Railtrack (50/50)

5.3. Planning archival data

This section approaches the analysis of planning performance by looking at possible differences between areas in terms of the changes made and the duration of planning. As described in section 4.7, two different steps were considered. Meeting minutes were initially used to develop an understanding of the planning sequence and PPS provided data for the identification of planning trends in different geographical divisions. Prior to the presentation of data on each of these steps, details on the sampling methods are also provided. Section 5.3.1 discusses the sampling of meeting minutes and section 5.3.3 explains the extraction of PPS data.

5.3.1. Sampling of meeting minutes

The purpose of this approach was to develop a timeline of planning in order to capture the sequence and different types of changes made to possessions and worksites, as work is further detailed towards delivery date. As observed in section 4.7.1, this approach could only address part of the planning process and a particular section of track. Planners from Milton Keynes ADPU recommended the period of planning extending from the Area Development Meeting (ADM - 32 weeks before delivery) down to delivery as the most relevant one. This formed the core of ADPUs' planning responsibilities. Keeping in mind that during the familiarisation interview, planning at area level was also described as the most critical period, the sampling of these stages of planning were considered appropriate.

Regarding particular periods of the year, the feedback obtained from planners did not provide sufficient criteria for the selection a particular timing. Overall, planners considered that planning activities have no outstanding periods throughout the year. For the reasons earlier presented in section 4.8.1, the planning of work for the Christmas period of 2007 was considered a pertinent starting point for this analysis.

Because these meeting minutes use no specific format or method, each planner tends to record information in a slightly different way. Despite this variability, the majority of notes taken concerned changes made to timings and locations of work, which could be easily interpreted on the base of a minimum of familiarity with the industry terminology. Regarding other types of changes to possessions or worksites, such as work or movement details, referring to the support of planners whenever clarification was necessary, enabled the interpretation of all the coding formats found in the course of this study. In addition, whenever records were unclear, it was also possible to check the information in the minutes against records inputted into PPS using the reference numbers of each work item.

Following the outcome of discussions at Milton Keynes ADPU, meeting minutes for the planning of work to be delivered in the Euston to Madeley section (MD101) during week 39 (from 22 to 28 December 2007) were considered a valid sample. The following planning meetings were surveyed for this given week:

- 32 weeks before delivery (ADM)
- 14 weeks before delivery (T-14)
- 6 weeks before delivery (T-6)

- 3 weeks before delivery (T-3)
- 1 week before delivery T-1)

The “data freeze” created prior to each meeting was transcribed into an Excel spreadsheet. The notes taken by planners and showing on the kept records were then added on the file against the corresponding data freeze. This gave way to the identification of the changes proposed and agreed in the course of a meeting, as well as those discussed in between two consecutive planning stages. This amounted to a comparison between input and output from one meeting to the next. In total, nine separate timeframes were analysed (the output of T-3 matched the input to T-1). The following types of changes were identified:

- Creation or deletion (cancellation) of possessions and worksites, and any changes regarding the possession managers or details about the type of work within a worksite.
- Blocked lines added or deleted (cancelled) from a possession or a worksite, and any changes made to their time, date or location.
- Changes to the limits (extension or shortening back) of worksites and to their protection locations.
- Creation or deletion (cancellation) of electric isolations associated to worksites, and any changes made to their time, date or location.
- Introduction of general remarks. Depending on the areas and type of work being planned, these consist on specific possession delivery details such as contacts for key staff, critical delivery timings or equipment on site, among others.
- Introduction of traffic remarks. These provide the identification and times for any machinery or engineering trains operating within the possession.

5.3.2. The planning sequence

During the planning period analysed and for the area studied (Euston to Madeley) with resource to meeting minutes, a total of 41 possessions and 164 worksites were undergoing planning. Table 5.3 shows the number of items registered at the start and finish of this period. These figures show that four additional possessions were created while three were cancelled and that 63 worksites were created against 33 cancelled.

Table 5.3: Changes from T-32 (ADM) to T-1

Pos	Initial number of Possession	37
	Final number of Possessions	38
	Total number of Possessions planned	41
WS	Initial number of Worksites	101
	Final number of Worksites	131
	Total number of Worksites planned	164

Table 5.4 summarises the categories of changes identified throughout the planning stages analysed. In total, 705 changes were made during this period. Approximately 66% of these were changes to worksites (468 changes to worksites against 237 to possessions).

Table 5.4: Categories of changes identified

Possession	Possession created	4
	Possession cancelled	3
	New Blocked line	53
	Cancelled Blocked line	30
	Block location amended	32
	Block Time & Date amended	47
	Traffic remarks	13
	General remarks	55
Worksite	Worksite created	63
	Worksite cancelled	33
	Worksite limits amended (mileage)	43
	Details of work amended (including linkage to possession)	169
	Details for engineering trains (i.e. times)	18
	Electric isolation created	14
	Electric isolation cancelled	6
	Electric isolation amended	17
	Worksite protection location created	16
	Worksite protection location cancelled	12
	Worksite protection location amended	77
Total number of changes		705

The creation, deletion and changes to possessions are mostly associated with the type of work, duration and location for the worksites linked to that particular possession. In particular, traffic and general remarks are added as work delivery within worksites becomes more detailed. Thus, most possession changes reflect changes made to worksites and to the delivery details for their work contents.

The sequences of changes identified during this planning period, indicate that decisions to include larger areas within items were reversed at a later planning stage in the sense that these same items were then shortened back. These sequences not only suggest a need to review or even reverse planning decisions, but they also support the uncertainty and unpredictability aspects identified throughout the interview process. In the light of the evidence given by planners during these interviews and the information collected through the observation of planning meetings, the following sequences of changes can be considered as indicators of uncertainty and unpredictability in planning decision processes:

- Three possessions were maintained all the way through delivery but were never linked to any worksites. This suggests that access was created to deliver work, which subsequently did not receive approval. In particular, one of these three possessions was disruptive to train operation and was created within the analysed planning period at approximately T-31 weeks (after ADM meeting).
- Three worksites were submitted to mileage changes at least twice within this planning period and other two were submitted at least three times to this type of change. This indicates that either the work contents or their details of delivery were considerably modified consecutively.
- Six possessions were submitted to changes to the location of their blocks at least twice and other seven possessions were submitted to this type of change three or more times. One possession had changes to its blocks at least six times within this planning period.
- Of the 33 worksites cancelled, five were created within the planning period analysed.

Table 5.5 shows the previously described categories grouped into major types of changes. This table provides an overview of the main trends of planning decisions.

Table 5.5: Major types of changes by percentage

Time and date changes	7%
Limits changes (line blocks, protection locations and mileages)	37%
Isolation changes	5%
Worksite details of work	24%
New item creations and item cancellations	15%
Other changes (Traffic and other details, General remarks and engineering trains)	11%

Within these last 32 weeks of planning, 15% of the identified changes were creating or cancelling items. Although approximately 40% of this type of changes was proposed at the ADM stage, this shows that throughout the short-term planning fundamental changes to engineering access are still occurring, whilst planners attempt to focus on providing specific details to support work delivery. This can also account for the relatively large proportion of changes regarding the limits of possessions and worksites (37%). As the work items are added or cancelled, the areas to be taken under possession also tend to change.

Information obtained from Anglia route control centre supports this conclusion. As later discussed in section 6.1.4, the Anglia control centre manager stated that for week 43 (from January 4 to 11), 17 requests for late changes were registered, of which 11 requests concerned amendments to existing possessions, including changes to isolations, possession limits and additional work, and the remaining six requests were for additional possessions.

5.3.3. Extraction of data from PPS

The previous step, although focusing on a specific time and location, provided a detailed timeline of planning changes. The goal at this stage was to produce a sample of quantified planning data that would cover all geographical areas and for the largest possible time scale. Using audit privileges, records of planning history were extracted from PPS onto Excel spreadsheets. Data was used to produce parameters as described in Table 4.2.

Data from PPS can be obtained by searching its historic records using geographical references and dates. However, this would require an in-depth understanding of the method according to which the rail network is divided and organised, in addition to a detailed knowledge of the national territory. In order to extract data from PPS more practically, reference numbers for possessions and worksites were obtained from previously published WONs. By referring to the WONs, it not only became easier to limit data to a precise week, but also the known geographical structures (described in the framework) could be used.

Although the analysis of meeting minutes provided useful insights on planning performance and the management of changes, no criteria were identified to support further data sampling. The decision was to randomly select WONs from weeks within the timeframe of data available. At the time of this study, the widest possible timeframe made available by Network Rail's online records was the second semester of the year 2008/2009 (from 29-03-2008 to 28-03-2009). Given that there are 11 different WONs published nationally for each week of the year, the volume of data to be process for every week sampled constituted the main limitation for the sampling method. A sample size of three weeks was considered a reasonable compromise between the largest possible sample and the time necessary to process and analyse data.

Possession reference numbers were taken from each of the 11 WONs published nationally and inputted to PPS in order to extract their history and the one of every linked worksite. The following three weeks were randomly selected:

- Week 16: from 12-07-08 to 18-07-08
- Week 24: from 06-09-08 to 12-09-08
- Week 36: from 29-11-08 to 05-12-08

A minimum of 10 possessions from each WON and all the linked worksites, was established. It is estimated that around 300 possessions are planned for each week and approximately 15000 per year. This means that the analysis of 330 possessions (10 from each of the 11 WONs and for each of the three weeks) represent 36% of the total 900 possessions that predictably were planned for the three weeks, and 2.2% of the estimated yearly total. Within the 330 possessions extracted, 1341 worksites were planned and 41053 changes were inputted to PPS.

5.3.4. Possession planning level

Table 5.6 provides an overview of the statistics produced from the data extracted from PPS on possession planning. The average values for the three weeks are given for each parameter showing in these tables.

Table 5.6: Planning data for possessions by area

Planning data for possessions (Pos)	Changes / Pos	Changes / Block	Changes / Route	Overall volume of change	Duration of planning in weeks	Start of planning (weeks before delivery)	Close of planning (weeks before delivery)	Number of Pos published (WON)	Number of WS / Pos in sample	Estimated total number of WS
Western	15.8	2.0	0.4	3.3	56.8	64.5	7.7	241	3.8	916
Wessex	4.1	1.4	0.3	1.5	14.4	31.6	17.2	155	1.3	202
Anglia	13.6	1.5	0.4	2.1	28.6	37.0	8.4	223	5.9	1316
Kent & Sussex	6.0	1.9	0.3	1.8	24.1	36.8	12.6	250	2.1	525
Scotland	13.5	1.6	0.3	2.3	14.1	16.8	2.7	436	3.6	1570
LNW (S)	12.7	1.9	0.1	2.6	22.5	29.8	7.3	242	5.5	1331
LNW (N)	24.0	1.9	0.3	3.0	25.5	30.7	5.2	447	7.5	3353
LNE (S)	13.4	2.0	0.3	2.9	38.0	41.9	3.9	89	3.0	267
LNE (Central)	9.5	0.5	0.3	1.1	20.6	23.7	3.2	198	3.5	693
East Midlands	13.1	1.8	0.2	2.7	32.6	40.0	7.4	109	4.7	512
LNE (N)	12.7	0.2	0.4	1.8	27.1	32.5	5.4	86	4.1	353
National average	12.6	1.5	0.3	2.3	27.7	35.0	7.4	225	4.1	1003

Within data in Table 5.6, four areas revealed patterns in terms of volume of change and duration of planning with relevance for the description of differences in planning activity:

- Despite an averagely duration of planning, **LNW (N)** shows one of the highest overall volumes of change, mostly motivated by a volume of change to possession details considerably higher than other areas. In addition, this area is estimated to produce more than double the worksites of all the others (3353 worksites). Hence, within a relatively short period (planning duration), LNW (N) produces higher volumes of planning change and outputs more planned work. This can be interpreted as LNW (N) demonstrating a level of planning activity higher than other areas. This discrepancy may be explained by the work undertaken within the West Coast Route Modernisation Programme, which was ongoing during this period.

- **Scotland** shows the shortest planning duration whilst producing an average volume of change (2.3 changes per possession), which makes it the area with the highest number of planning changes per week of possession planning (approximately 22.1 changes/week against 16.6 changes/week for LNW (N)). Scotland plans for approximately the same number of possessions as LNW (N), but registers a number of worksites per possession considerably lower and therefore, the estimated total number of worksites planned is close to half as the one for LNW (N). This suggests that although Scotland may have a relatively high level of planning activity, it plans for less work than LNW (N). It also indicates that Scotland plans for smaller possessions as it tends to integrate fewer worksites in each possession.
- Contrary to LNW (N), data suggests that **Wessex** has one of the lowest levels of planning activity. Not only it registers the lowest estimated total number of worksites (202 worksites), but also one of the lowest durations of planning (14.4 weeks) and one of the lowest volumes of change (4.1 changes per possession and an overall volume of 1.5 changes per parameter created).
- The **Western** area stands out as the one with the highest volume of change (3.3) and the longest duration of planning (56.8 weeks). In particular, the start of planning shows a difference of approximately 45% more than the average number of weeks (35 weeks). Although not shown in Table 5.6, the data collected revealed that Western had a possession under planning for a period of 112 weeks (for week 36), which constitutes the maximum duration of planning registered. These features also suggest a low level of planning activity as the one described for Wessex. However, it must be taken into account that Western produces an amount of planned work close to average (estimated 916 worksites), which distinguishes it from Wessex.

In general, areas with higher durations of possession planning also tend to have higher volumes of change (overall volume). Figure 5.1 shows the graphical position of the four areas previously discussed in relation to the remaining ones when plotting the duration of planning against the volume of change. While Wessex, Scotland and LNW (N) are more or less in line with the trend shown by the majority of areas, the duration of planning suggests a different pattern of planning activity for the Western area.

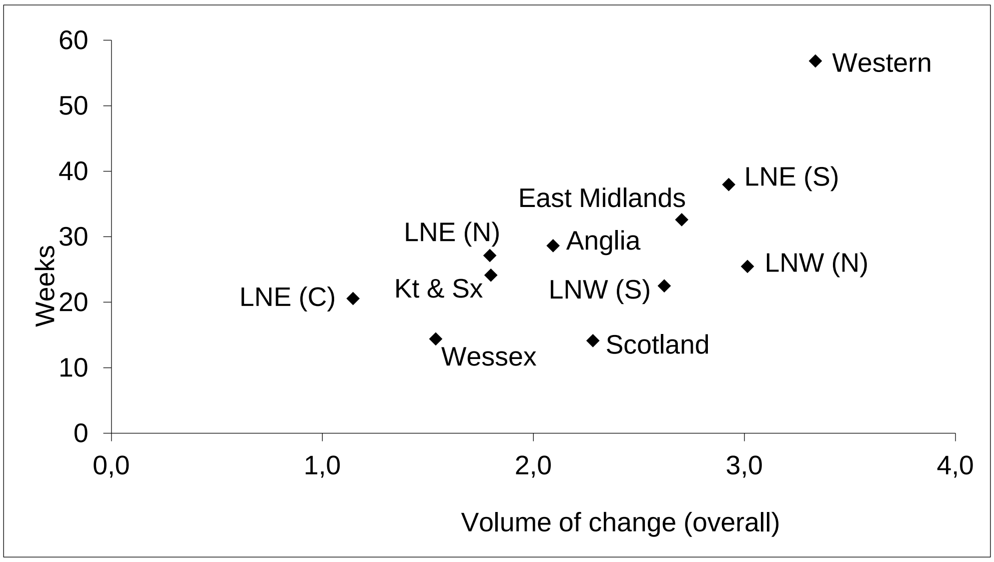


Figure 5.1: Relation between duration of planning and overall possession volume of change

LNW (N) and Scotland were identified as areas with a higher level of planning activity. This designation was given on the base of the high volume of change registered, the amount of work planned and the relatively short time window in which this planning was developed. However, these areas registered a clear difference in terms of the amount of work planned and in particular, the number of worksites integrated in each possession.

Integrating progressively more worksites into possessions is likely to require a higher number of changes to possession details, in particular to the possession limits. For instance, as discussed in section 4.7.2, the possession details in PPS, apart from general and traffic remarks, also reflect the linkage of worksites to possessions. Hence, whenever a worksite is allocated or taken out from a possession, a change input is registered in PPS under possession details. Within this frame of mind, the differences between areas in terms of the volume of changes to possession details (Changes / Pos) and the number of worksites per possession were explored, as shown in Figure 5.2.

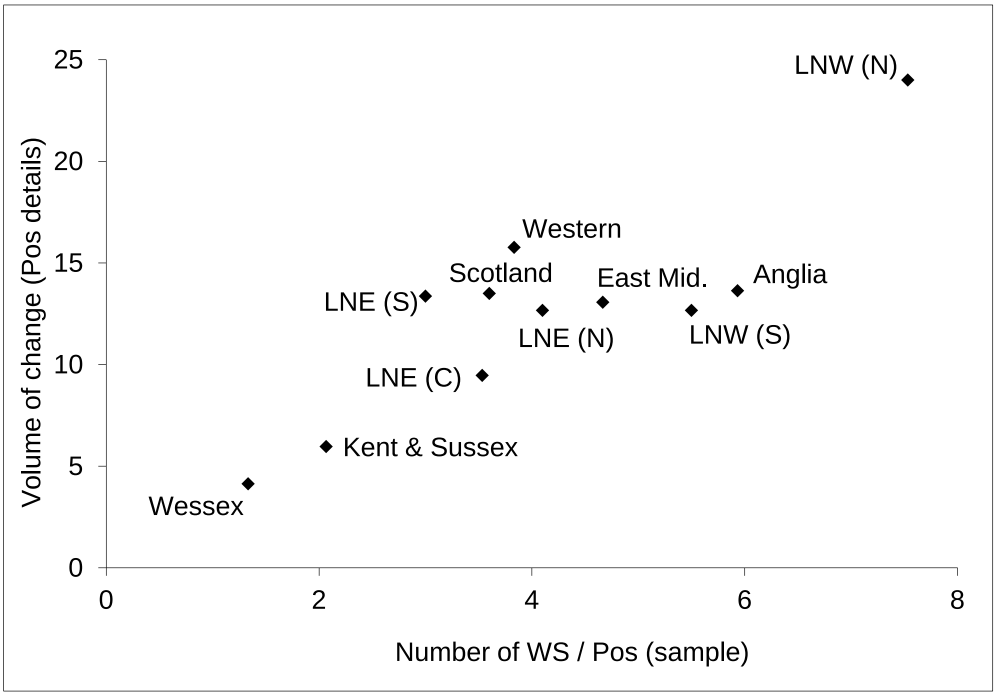


Figure 5.2: Relation between volume of changes to possession details and number of worksites per possession

The plotting in Figure 5.2 indicates that the volume of change to possession details tends to increase as the number of worksites per possession also increases. While LNW (N) produces 24 changes per possession, Wessex produces 83% less changes of this type (4.1 Changes / Pos). LNW (N) is clearly the area with the highest number of worksites per possession (7.5). Scotland shows one of the highest numbers of possessions published (436), while its number of worksites per possession is below average (3.6). This suggests that Scotland, despite having a considerably high volume of work planned (1570 worksites), tends to plan for smaller possessions with as few worksites as possible. Overall, Figure 5.2 and in particular the trend shown by LNW (N), suggests that making possessions larger to include as many worksites as possible may impose an increasing volume of planning changes.

The plotting in Figure 5.3 was produced to verify if the number of possessions published (and therefore planned), regardless of the amount of work integrated into possessions, would demonstrate a similar relationship with the volume of change.

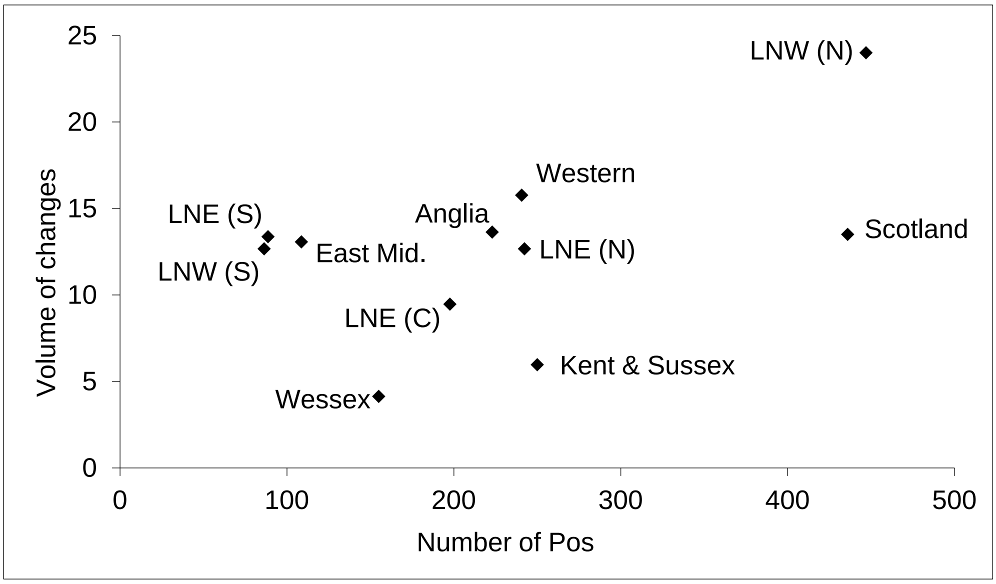


Figure 5.3: Relation between the volume of changes to possession details and the number of possessions published

The graphic shows a considerable dispersion of areas, which suggests that in fact, the complexity of possession planning is more related to the size and amount of work integrated into each possession, rather than the actual number of possessions planned.

5.3.5. Worksite planning level

Table 5.7 summarises the statistics generated from data extracted for worksite planning. In general, less clear differences are registered between areas and none of the patterns identified for possession planning are reflected at this level of planning.

Table 5.7: Planning data for worksites by area

Planning data for worksites (WS)	Changes / WS	Changes / Block	Changes / Route	Changes / Isolation	Overall volume of change	Duration of planning in weeks	Start of planning (weeks before delivery)	Close of planning (weeks before delivery)	Number of WS in sample
Western	6.4	0.5	0.5	0.9	1.6	8.1	20.0	11.9	38
Wessex	8.3	0.9	0.6	0.9	1.6	7.3	31.5	24.2	13
Anglia	6.3	0.4	0.6	1.7	1.0	8.3	20.9	12.6	59
Kent & Sussex	7.7	1.2	0.4	0.7	1.8	6.4	23.0	16.6	21
Scotland	8.4	1.1	0.6	0.6	1.8	7.1	15.7	8.6	36
LNW (S)	10.1	0.9	0.4	1.1	2.5	16.1	23.5	7.4	55
LNW (N)	10.7	1.0	0.4	1.2	2.1	10.4	19.6	9.2	75
LNE (S)	10.4	1.6	0.5	1.4	2.3	13.2	23.3	10.1	30
LNE (Central)	6.5	0.5	0.3	1.1	1.0	9.5	26.5	17.0	35
East Midlands	6.8	0.9	0.4	1.3	1.8	11.0	18.3	6.6	47
LNE (N)	7.1	0.7	0.3	1.2	1.3	12.7	29.1	16.4	41
National average	8.1	0.9	0.5	1.1	1.7	10.0	22.9	12.8	41

Table 5.7 shows that volumes of change have different trends then the ones made evident for possession planning. LNW (N) remains the area with the highest number of items but with a less distinct difference from the remaining areas. LNW (N) is the area with both the highest volume of change to possessions and the highest number of worksites planned, which seems to be reflected in the volume of change to worksite details, where LNW (N) also shows the highest value (10.7 Changes / WS). Numbers for East Midlands suggests that this area plans worksites closer to delivery date that most other areas. This area finishes planning the closest to delivery (6.6 weeks before delivery), despite having an averagely duration of planning (11 weeks) by also starting later than most other areas (18.3 weeks).

As detailed in section 4.7.2, the identification of worksites were also extracted from PPS and grouped under major categories according to the expected degree of complexity involved in the planning of the work in question. Table 5.8 provides the average number of worksites (from the three weeks) that areas planned under each of the derived major categories. In order to establish a comparison between areas, these numbers are shown as percentages of the total number of worksites planned.

Table 5.8: Main types of work planned by each area

Main categories of work	Asset related work	Asset inspection and patrolling	Stations and other structures work	Project related work	Major projects	Non-asset related work
Western	55%	18%	6%	8%	3%	10%
Wessex	23%	40%	15%	5%	8%	10%
Anglia	53%	13%	8%	3%	15%	6%
Kent & Sussex	52%	15%	15%	8%	10%	2%
Scotland	43%	28%	4%	6%	12%	7%
LNW (S)	39%	18%	8%	17%	15%	4%
LNW (N)	55%	11%	12%	16%	2%	4%
LNE (S)	58%	3%	13%	18%	1%	7%
LNE (Central)	70%	8%	14%	2%	0%	5%
East Midlands	44%	10%	17%	14%	6%	8%
LNE (N)	60%	13%	15%	7%	0%	4%
National average	50%	16%	12%	10%	6%	6%

As expected, asset related work is clearly the main category. It should be noted that because PPS offered little information on the actual nature of the work, this category not only contemplates maintenance, but also minor renewals projects often managed by the maintenance organisation. Although not shown in Table 5.8, it was possible to determine that maintenance of track assets (plain track and S&C) accounts for approximately 55.5% of this work.

LNE (S) area stands out by having nearly no inspection and patrolling work registered. The data available offered no justification for this trend but it is evident that any given area is required to perform higher volumes of patrolling and inspection work than an average of one worksite per week.

Thus, it can only be assumed that either it has been registered under other descriptions or in fact, it has no register, and patrolling and inspection work within this area is normally included under other worksites with little formal reporting to planning.

Three categories predictably involve more planning work than the remaining ones:

- Work on stations and particularly other structures such as tunnels and bridges, are likely to involve more equipment, which not only requires a number of specific inputs to planning, but also may impose higher constraints on delivery.
- Major projects are normally delivered as a sequence of possessions throughout several days, weeks or even months. The sequence of work initially scheduled is likely to require more or less significant adjustments as work delivery evolves, which will import changes into planning.
- Project related work, as described in Table 4.4 (section 4.7.2), consists on work necessary to either prepare for or conclude details related to major pieces of work. In particular, the work under the designation of “follow-up work” is frequently used to refer to work necessary to adjust the schedule of major projects. Hence, these items are often the source of numerous inputs to planning. Approximately 31% of worksites registered as follow-up work were submitted to major changes beyond the date of publication of the WON and its supplements (three days from delivery). Despite being linked to possessions, five of these worksites were still showing a status of “proposed” rather than “approved” and four others were moved to a different possession within this timeframe.

In order to investigate how the type of work may affect planning, the percentage of worksites planned by each area under these three categories was plotted against the worksite volume of change, as shown in Figure 5.4.

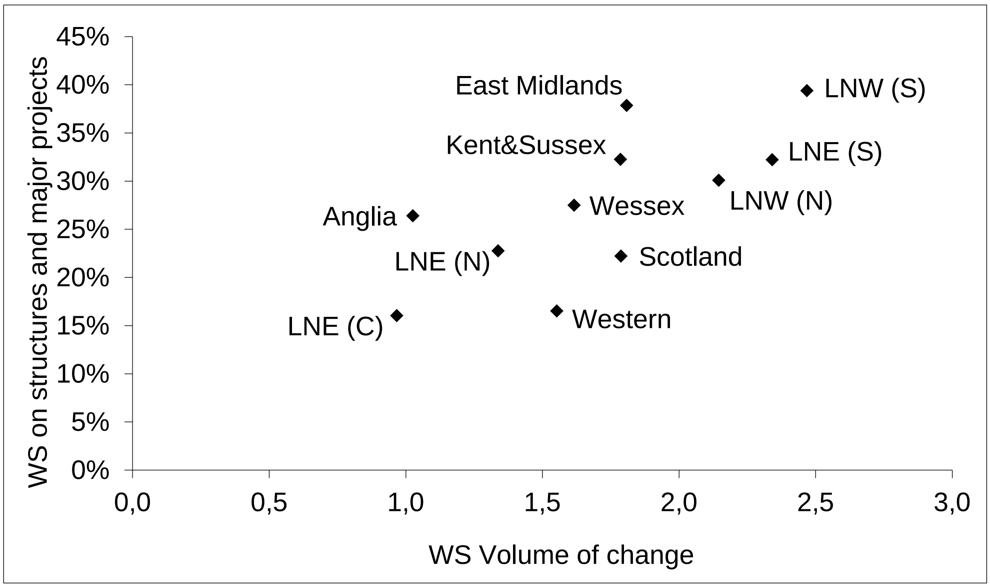


Figure 5.4: Relation between worksite volume of change and the percentage of worksites dedicated to structures work and major project

LNW (S) and East Midlands are the two areas with higher concentration of work under the previous three categories (39% and 38% respectively). Overall, Figure 5.4 suggests that areas that plan more complex work also tend to register higher volumes of planning changes, which indicates that a higher complexity of the work to be delivered tends to impose higher demands on planning.

Overall, planning data indicates that the complexity of either the possession arrangements or the contents of worksites lead to an increased volume of planning change. On the one hand, as shown in Figure 5.2, the volume of changes to possession details increases with the number of worksites per possession. Although the size of possessions and the way in which they may become larger as more worksites are slotted in was not taken into consideration, this suggests that more complex possession arrangements with higher volumes of work contents also impose more planning work. On the other hand, as discussed in section 5.3.5 (worksite planning level), the type of work being planned influences the volumes of changes made to worksites. Data has shown that the planning of complex work, such as major projects and structures, tends to be subject to higher volumes of change. Major projects normally extend throughout several days of work and are subject to adjustments from day to day as unforeseen elements arise. Project teams often request worksites for follow-up work, which late in the planning process may change in nature and volume, or it may even become an unused access opportunity.

Interviews indicated that there is a considerable degree of informal planning activity, which becomes more relevant during the final stages of planning when details of delivery are defined. The consultation of PossMan outputs provided useful insight on planning activity during these stages. For instance, the WEN for week 8 which is sampled in Appendix 5, showed that for a possession to be delivered on the weekend of 16 and 17 May 2009, for the 21 worksites (as referenced in PPS) integrated, approximately 17 changes, were being introduced about four weeks before delivery. The changes noted concerned mostly times and mileages but cancellations and changes to equipments and machinery were also registered.

5.4. Chapter conclusions

Overall, the findings in this chapter are compatible with the literature background on system complexity and decision making. Like many other planning and scheduling activities documented in literature (McCarthy & Wilson, 2001a), rail engineering planning can also be fundamentally described as a form of decision making that aims to allocate limited resources in view of organisational goals (Pinedo, 2009). The large organisational and geographical scale of the planning process is clearly at the source of both the distributed nature of decision making processes (Woods, 2006b) and the variability and uncertainty that result from high system complexity (Leveson, 2004).

The interviews provided detailed information on a broad range of planning issues. The initial interview was particularly relevant for the understanding of the planning process as a whole and how it relates to the remaining engineering functions. This knowledge is part of the information presented in section 2.3. Planners demonstrated being aware of the fact that planning must above all, support work delivery with reliable information. This became clear by the statements of interviewees regarding the need to understand the impact of their decisions on delivery and their concerns towards the impacts of frequent and late changes in planning. The following themes were considered the most relevant within the scope of this research:

- The planning organisational structure is characterised by a considerable degree of fragmentation. Planners identified this as a problem and placed at its origin the different organisational functions and various geographical divisions that participate in the planning process. As described by Carayon (2006), the interactions among people who work across organisational, cultural and temporal boundaries are major sources of complexity in sociotechnical systems.

- Dealing with frequent planning changes was described as one of the major problems. Changes were described by planners as the source of unpredictability in process and of uncertainty towards the decisions made. Both internal and external sources of uncertainty were identified (Crawford & Wiers, 2001). While the fragmentation of the planning process constitutes an internal source, external uncertainty is mainly generated by the fact that planning relies considerably on inputs from its operating environment (stakeholders).
- Experience was regarded as a key factor towards reliable and efficient planning. Planners described experience as the source of confidence in the decisions made and the base for developing reliable work relations within the planning organisation. A as argued by Svenson (1996), accumulated experience in a given environment or task reduces the level of complexity of decision making within that same context. Roland *et al* (2011) also found that planners rely on overall knowledge of the businesses to solve decision problems and on efficient access to information to accurately interpret the state of affairs and of planning scenarios.
- Information related issues were often mentioned during discussions with planners. Not only does incomplete information about system behaviours generates uncertainty, but also the volume of information that is generated and transmitted throughout the system creates potential for information loss, imprecision or incompleteness, which can lead to severe physical and financial losses (Leveson, 2004). As observed by Kirwan (1998), communications and group factors become dominant as decisions become distributed across increasing numbers of people and larger organisational and geographical areas. Planners regarded informal means of communication as a fundamental resource to, not only respond to planning needs with efficiency and anticipate potential planning conflicts, but also understand the potential impacts of planning decisions on delivery and develop appropriate

contingency plans.

- The ambitious capacity enhancement targeted for the near future (to be delivered during CP4 and CP5) was considered a major challenge. The impacts of these targets on the volume of engineering work to be planned and on the available access to deliver it were often discussed by planners as a cause for concern. The transformation of planning, and the engineering organisation as a whole, were also mentioned as a challenge and a necessary step to respond to the upcoming demands.
- Planners related resilience in planning to the ability of people to manage conflicts between business pressures and the conditions necessary for the deliverability and protection of the engineering work submitted to planning. This is consistent with the arguments of McCarthy & Wilson (2001a) in terms of the need to manage pressures and conflicting circumstances within planning and scheduling activities.
- The reference made to planning under the West Coast Mainline Project (section 5.1.3) provides initial indications of potential sources of resilience in planning. The NAU manager interviewed described a cohesive planning team under this programme with an increased ability to deal with issues through an efficient information exchange and shared good practices. This is compatible with the information needs previously mentioned and with some of the aspects referred to in Table 3.6 (section 3.4.6) as characteristics of a resilient system, in particular the willingness to learn from, and respond to, events (T+1 meetings) and the use of this as feedback information that can improve awareness (Jorna *et al*, 2005).

Through the analysis of PPS data, considerable differences between areas became apparent in terms of planning change patterns and duration of planning. The exploratory work carried out led to the identification and quantification of different factors that may influence planning performance. Data for all areas suggests that planning is subject to a considerable degree of variability. The reversing of planning decisions identified through meeting minutes (section 5.3.2) and the variability of PPS data (sections 5.3.4 and 5.3.5) confirm aspects of variability and uncertainty in planning. In particular, the fact that planning changes appear to intensify as delivery approaches, supports the notion of the need for adjustments to local operating conditions (Grote, 2004 and Hollnagel, 2009a). The graphical illustrations of the volume of change against the remaining indicators gave way to a better understanding of how planning “behaves”. Rather than the actual amount of planning work, the determining factors seem to be related to the way areas manage their own planning needs.

At possession planning level, change appears to be generated by a higher density of possessions. While areas such as LNW (N) that tend to plan for larger possessions register higher volumes of change, others such as Scotland tend to plan possessions with fewer worksites and register lower volumes of change. LNW (N) was considered the area with the highest level of planning activity, as it produced one of the highest volumes of changes to possessions, while having a relatively short duration of planning and planning for the highest number of possessions. At worksite level the contents of work seem to be the determining factor. Areas with higher concentrations of more complex work (work on structures and major projects) have registered higher volumes of change, which suggests that in fact work that can be more complex to deliver also imposes higher demands on planning. Complex organisational endeavours also require complex planning work to forecast possible scenarios and allocate resources and people accordingly, either as a primary course of action or a contingency solution (Jorna & Kiewiet, 2007).

The analysis of meeting minutes offered a better understanding of planning than PPS data, as it facilitated the detailed description of a planning timeline. Based on the description of planning changes and their sequence, this approach showed that decisions are often reversed and that fundamental changes to access are made, even at the last stages of planning. The similar way in which planners referred to changes during the interviews suggests that the trends identified in the analysis of meeting minutes may be common to other areas. This would mean that differences between areas are more relevant in terms of timings and volumes, rather than specific types of change. Thus, although changes and duration of planning may be valid as indicators of performance, a level of detail beyond what PPS data allows is necessary to produce more conclusive results.

6. Understanding asset management and work delivery

As observed in the conceptual framework (section 4.3), understanding the success of planning needs to recognise its relationship with engineering work delivery. This chapter studies the performance of work delivery through the analysis of possession delivery related incidents. A study of the main characteristics of the infrastructure in each area was also carried out to identify possible impacts of the infrastructure profile both on planning and delivery of work. As discussed in section 3.6, understanding system resilience requires the investigation of interactions within the system and between the system and its operating environment. Overall, this chapter develops an understanding of the wider system environment in which planning operates, in order to support the interpretation of planning performance.

Objectives	Questions	Methods
2) Identify the critical human and organisational factors of the rail engineering planning system. 3) Investigate relations between planning and engineering work delivery and identify the impacts of planning on work delivery.	• How do the planning process and its organisational structure support or hinder decision making processes? • What are the main trends in work delivery performance? • What are the different trends in the relations between planning and delivery?	• Familiarisation interviews with planning stakeholders • Safety data analysis • Analysis of infrastructure and asset archival data

6.1. Familiarisation interviews

These interviews provided an overall understanding of engineering work delivery and any issues emerging from its relations with planning. As discussed earlier in section 4.4.2, the purpose was to obtain insights from people whose work relied on the output produced by planning. 10 unstructured interviews were conducted with PICOPs, signallers and route controllers, as these could be considered the “end consumers” of the information produced by the planning process. Following the presentation used in sections 5.1 and 5.2, relevant quotes of interviewees are given in a table format at the end of each sub-section.

6.1.1. PICOPs from London Bridge Maintenance Delivery Unit

All three PICOPs demonstrated little knowledge and concern towards the planning process. Their visibility of this part of the organisation appeared to be limited to pre-possession briefings. A senior PICOP acknowledged not being aware that planning consisted of a process with an approximate duration of 18 months. PICOPs admitted giving little consideration to the information discussed at these briefings, as too often it is subjected to late changes. Going over a list of possession limits, machines, trains and names was considered little added value to prepare for possession. Having an accurate local knowledge and up-to-date information on site conditions were considered by all PICOPs as the most valuable assets to manage delivery. In this regard, the use of “white board” representations was regarded a useful exercise to review possession details.

The most significant remarks were made in regard to frequent late changes. All PICOPs stated that they often found discrepancies between what is discussed at the PICOP briefing and what they are provided with in the PICOP possession packs. Such changes concern blocking points, trains and their paths, and even the numbers and types of on-track plant booked. The interviewed PICOPs admitted being confronted on the night with the addition or cancellation of trains or machines, for which they had no record of in their packs, even though the ES may have had the required paperwork. This was mentioned as a major cause of disruption to PICOP work, as it forces them to review the entire possession management, which, under more complex delivery scenarios, can be a cause for failures. Unexpected changes were also brought up as a source of stress during delivery, as PICOPs are aware that communications with staff on the ground are not always as reliable as they would feel necessary to manage such issues.

The maintenance organisation was pointed out as the major source of such disruptions. Despite recognising recent improvements in the maintenance organisation, two of the PICOPs interviewed felt that the lack of coordination and communication between the different maintenance sections remained a critical issue.

PICOPs stated that they are rarely asked to input on planning, even at T-3 or T-10 days stages. They considered it of limited use for them to take part in these planning stages or earlier ones. All PICOPs have identified night rosters as one of the difficulties to having any participation in planning. They sometimes have to extend their night shifts and stay in during part of the morning to attend PICOP briefings.

Relevant quotes	• At PICOP meetings things get re-planned and sometimes on the night we get changes to mileages and other things • We always pickup discrepancies (in possession documentation) when taking possession • I need to take my own time (out of rosters) to prepare for the night and go to PICOP meetings • Departments in maintenance don't talk to each other • I have no idea what planning does

6.1.2. Signallers from London Bridge signal box

Similar to PICOPs, signallers also expressed little awareness of the planning process. Although the majority of their complaints were directed to the delivery of work, the frequent need to verify a succession of supplements for several possessions was referred to as a burden imposed on signallers by planning. Both signallers stated that the possession granting processes would be improved considerably if items in the WON were entirely re-issued when more than one amendment had been made. This would prevent having to chase information, as amendments may not sometimes be delivered to the signaller on duty. This creates a potential for irregularities and failures, as PICOP and signaller may go through possession arrangements using different sets of information. As a standard precaution, both signaller and PICOP always verify and crosscheck supplements by number.

Signallers considered that planning errors are frequent and that these are mostly related to machine and train routes. These errors often cause delays in the process of taking or handing back possession of the line, as routes have to be re-checked for possible conflicts with train services. In general, the information published was considered sufficient, although specific characteristics of the area may not be mentioned, such as the need to protect possession flanks (lines alongside of those taken under engineering possession, which remain open to traffic). Experience as a signaller and local knowledge were described as critical assets to realise any additional requirements. Taking part in planning meetings was considered useful for complex scenarios and a good practice to be further encouraged.

Access under T2 protection arrangements (section 2.3.4) was considered a cause for higher concerns. These tend to be less planned and contain poor details, which imposes a higher number and longer communications for protection arrangements. In addition, the possibility of coordination between work to be carried out under T2 arrangements and work requiring possession of the line (T3 arrangements) is rarely considered. As stated by a signaller, “T2 requests are poorly aligned with work planned under T3 arrangements”, which constitutes a source of conflicts that signallers have to manage.

Relevant quotes	• There’s too much paper and too much information we don’t need (regarding the WON) • We always have to be checking and double checking references • T2 requests are poorly aligned with work planned under T3 arrangements

6.1.3. Signallers from Liverpool Street from signalling centre

The signalling centre at Liverpool Street is one of the busiest ones in the London area due to the complexity of tracks under its control and the volume of traffic it manages. All four signallers presented similar views on the information produced by the planning organisation. The main issues were related to the fact that information on possessions is scattered through different sections of the WON, whenever it involves different route areas. One signaller suggested that, similar to PICOPs, having “information packages” prepared beforehand would support them in anticipating issues and thus, considerably reduce their workload peaks (for instance, having to grant possessions simultaneously) and increase the efficiency of possession granting processes.

The number of amendments to published items was also considered a problem by these four signallers, despite showing some appreciation for the fact that changes cannot always be anticipated. All signallers expressed concern in regards to non published changes and the way these can affect their performance by imposing time consuming verifications and additional demands on operations under their control. Signallers admitted often finding conflicting information between the WON and train notices (information on schedules and routes of all trains) regarding possession limits and train routes. The lack of planning for work under T2 protection arrangements was also considered a problem by all four signallers.

Signallers considered that the complexity and high volume of work that characterises this area often makes it infeasible to grant each possession on time, due to the short time window between possessions that is contemplated in planning. Under such circumstances, signallers have to establish priorities, having little information regarding the criticality of the work within each possession. Thus, all four signallers welcomed any additional information regarding possession details, in particular, on train movements, as it created the possibility to anticipate issues and better prepare for granting possessions on time. One signaller added that having wider possessions, rather than multiple short blocks, could limit such problems, as well as reduce the amount of paper to be kept on the signalling desk.

Being called into planning meetings was also mentioned by all signallers in this box as a valuable good practice. In the same scope, interviewees added that having the PICOP in the box could increase reliability and efficiency of communications, particularly for possessions involving several workstations.

Relevant quotes	• The information we need is scattered in the WON. We have to be going back and forth • We can't always take possessions on time because that would mean having to respond to calls simultaneously. The time between possessions is often too short

6.1.4. Anglia route control centre

Control centres are not directly involved in the processes of protecting and carrying out work on the infrastructure. However, control centres must be kept informed of all activities carried out in the infrastructure which may affect train operations. This is clearly the case of possessions of the line. An interview with an Anglia route control manager was arranged in order to collect additional evidence on the views expressed by PICOPs and signallers.

Late changes generated by the planning system were also the mentioned as the major concern. The interviewee offered as evidence, the register of late changes for week 43 (from January 4th to 11th), during which, apart from six additional possessions, 11 requests for amendments to existing possessions were made, ranging from changes to isolations, possession limits and additional work (repair of rail defects). One of the main consequences of such levels of change pointed out by the controller, were the conflicts generated between train paths and possession limits, which tend to occur every night.

Similar to what was stated by signallers, this interviewee also considered the poor alignment between T2 arrangements and possessions as a source of problems and conflicts in access.

Late running trains were also mentioned as a frequent problem for possessions. Nevertheless, a reduction in possession overruns has been observed in the last few years, which the interviewee attributed mostly, to maintenance being able to plan to a more adequate level of detail. Despite noticeable improvements, the controller expressed concern towards what he described as a significant shortage of staff, access and budget to respond to the volume of maintenance work to be delivered. To some extent, this volume of work was attributed to an aging infrastructure. It was mentioned that repairing rail defects and crossovers is one of the most frequent maintenance work requirement.

Regarding communication and information, it was mentioned that the triangle between PICOP, signaller and controller works well within this route. Some problems may occur with renewals and projects, as PICOPs are usually working under a contractor. This means that, instead of communicating informally with signallers and control centre, because they are not “in-house” staff, PICOPs relate to National Delivery Services (NDS), which may cause delays in information reaching control or other stakeholders.

Relevant quotes	• The triangle between PICOP, signaller and control works well here and has solved many problems • Maintenance is living serious resource limitations to respond to all work necessary

6.2. Safety data analysis

Work delivery incidents were analysed using data from the national control logs and incident categories extracted from the asset incident trends database. The analysis of control logs was based on interpretative work, aiming to identify evidence for the impact of planning on work delivery. Asset incident trends provided more precise statistics to support the interpretation of control logs.

6.2.1. Control logs

Control logs referring to the same three weeks used as a timeframe for the analysis of planning data were reviewed. Nine incidents were registered during these three weeks sampled (Week 16: 3 incidents; Week 24: 2 incidents; Week 36: 4 incidents). Considering the diversity of the contents of logs, the size of this sample was considered too small to support a valid discussion. An additional period of three months (from January to March 2009) was surveyed to produce a more reliable sample. Within this additional period, 43 relevant incidents were identified.

Table 6.1 shows the main outcome of this analysis according to each of the categories and the two levels of coding described in section 4.8. Because of the different timeframes, the nine events that occurred within the three weeks for which planning data were analysed were kept separate from the remaining data. The distribution of these nine events is shown in the columns designated as “Planning weeks”. Whenever the log contents provided information relevant for more than one category, the event in question was registered simultaneously in the categories concerned. This was particularly important to improve the level of detail of cause analysis, as logs would often offer evidence for several relevant causal relations. Hence, when summing up numbers in the first part of Table 6.1 (first level of coding – causes) this will actually correspond to the total of causal factors identified and not the 43 incidents analysed.

Table 6.1: Analysis of control logs

Causes	Jan – Mar 2009		Planning weeks (16, 24 and 36)
Planning failure	11	26%	3
Equipment failure	14	33%	3
Extreme weather	2	5%	
Staff shortage	4	9%	
Points run through	8	19%	2
Cable damage	5	12%	
Other asset damage	2	5%	
Late start	1	2%	
Other	5	12%	1

Outcome	Jan – Mar 2009		Planning weeks (16, 24 and 36)
Possession overrun	34	79%	8
Additional work	17	40%	2
Work cancellation	1	2%	
Problem mitigated	2	5%	
Planning issues	**Jan – Mar 2009**		**Planning weeks (16, 24 and 36)**
Worksite planning	20	47%	3
Possession planning	4	9%	
Staff rosters	3	7%	
Haulage / machine routing	5	12%	1
Haulage / machine planning	1	2%	1
Non related / no evidence	16	37%	4

Overall, there appears to be coherence between the distribution of incidents registered during the three planning weeks and the one observed from January to March 2009. The categories showing higher percentages, as well as the distribution per route (Table 6.2), coincide with the distribution of the nine incidents observed within the planning data period. This improves confidence in the fact that the robustness of the comparative studies will not be affected by the difference of timescale between the planning and the possession delivery topics.

Based on the coding method used and considering the three months period together with the planning weeks, control logs offered evidence of planning failures as a causal factor for 14 (11+3) out of the 52 incidents under analysis (43+9), which corresponds to 27%. Although not shown in Table 6.1, within this category, six incidents were attributed to worksite planning issues and another four incidents were attributed to possession planning. Moreover, according to the criteria of the second level of coding, Table 6.1 shows that planning issues were identified on the description of 38 incidents, which corresponds to 73% of the total 52 cases.

The damage to assets during work delivery appears as the main cause for possession failure. 32% of the events involved either points being run through, cable damage or damage to other assets. However, of the 15 logs concerned in this percentage, only six show evidence of planning related issues. Beyond the fact that 10 out of these 15 incidents resulted in a possession overrun, additional repairing work was needed in all cases, which often meant requesting new access. This suggests a potential knock-on effect of incidents on planning.

Worksite planning is clearly the most important planning issue, with 20 of the logs from the three months analysed (47%) showing evidence of such problems. These 20 incidents represent 74% of all planning issues identified (excluding “non related / no evidence” cases). The contents of these 20 logs revealed the following main issues:

- Site access or terrain conditions not properly assessed in view of planned delivery details.
- Inadequate machinery or equipment planned for in view of work delivery requirements.
- Sequential nature of work not properly assessed in terms of deliverability risks.

Table 6.2 shows the distribution of events by route. While only 43 incidents were identified during the three months period, because two of these incidents affected two different routes, the total for the possession failures' column is 45. Additionally, Table 6.2 shows the distribution by route for the main categories illustrated in Table 6.1.

Table 6.2: Analysis of control logs – route comparison

Routes	Possession failures			Planning failures			Worksite planning			Possession overruns		
	Jan – Mar 2009		Pl W	Jan – Mar 2009		Pl W	Jan – Mar 2009		Pl W	Jan – Mar 2009		Pl W
Western	8	19%		1	9%		5	25%		8	24%	
Wessex	6	14%		3	27%		3	15%		5	15%	
Anglia	6	14%	1	1	9%	1	4	20%		4	12%	
Kent	2	5%		2	18%		0	0%		2	6%	
Sussex	3	7%		0	0%		1	5%		1	3%	
Scotland	5	12%	2	0	0%	1	2	10%	2	5	15%	2
LNW	10	23%	4	4	36%	1	5	25%	1	7	21%	4
LNE	5	12%	2	0	0%		0	0%		3	9%	1

LNW stands out as the route with the highest numbers across all the categories. The Western route shows a similar trend, except for planning failures as a main cause. Although following the second level of coding, worksite planning issues were identified in five of the logs from the Western route, only one of these logs provided evidence towards a planning failure as a main cause (first level of coding).

6.2.2. Asset incident trends (possession delivery incidents)

The three types of incidents discussed in section 4.8 and considered relevant for this scope of analysis, are shown in Table 6.3. The average number of incidents per period is given for the year 2008/2009 and is presented both by route in order to maintain the same structure as the one used for control logs, and by WON areas for comparison with planning data. Because this database is organised by engineering areas and the WONs for LNE (S) and LNE (central) correspond to one single area, they are shown in Table 6.3 together.

Table 6.3: Average possession delivery incidents per period by WON area and route

<table>
<tr><th>WON</th><th>Track Patrols & related possessions</th><th>Possession overrun and related faults</th><th>Possession work left incomplete</th><th>Total</th><th>Route</th><th>Total</th></tr>
<tr><td>Western</td><td>18.6</td><td>27.0</td><td>0.9</td><td>46.5</td><td>Western</td><td>46.5</td></tr>
<tr><td>Wessex</td><td>44.5</td><td>20.1</td><td>3.8</td><td>68.5</td><td>Wessex</td><td>68.5</td></tr>
<tr><td>Anglia</td><td>31.1</td><td>28.3</td><td>5.8</td><td>65.2</td><td>Anglia</td><td>65.2</td></tr>
<tr><td rowspan="2">Kent & Sussex</td><td>30.0</td><td>19.2</td><td>5.9</td><td rowspan="2">88.8</td><td>Kent</td><td>55.1</td></tr>
<tr><td>15.0</td><td>11.4</td><td>7.3</td><td>Sussex</td><td>33.7</td></tr>
<tr><td>Scotland</td><td>0.5</td><td>13.5</td><td>0.4</td><td>14.4</td><td>Scotland</td><td>14.4</td></tr>
<tr><td>LNW (S)</td><td>40.5</td><td>33.5</td><td>4.7</td><td>78.7</td><td rowspan="2">LNW</td><td rowspan="2">135.7</td></tr>
<tr><td>LNW (N)</td><td>27.8</td><td>26.2</td><td>3.0</td><td>57.0</td></tr>
<tr><td>LNE (S & central)</td><td>16.8</td><td>22.5</td><td>1.2</td><td>40.4</td><td rowspan="3">LNE</td><td rowspan="3">111.8</td></tr>
<tr><td>East Midlands</td><td>23.2</td><td>12.8</td><td>0.5</td><td>36.5</td></tr>
<tr><td>LNE (N)</td><td>10.5</td><td>22.7</td><td>1.8</td><td>34.9</td></tr>
</table>

Data in Table 6.3 reveal a similar trend as the one mentioned in the discussion of control logs regarding the LNW route. According to the types of incidents analysed here, both LNW and LNE show numbers that are close to double of those for all other routes while Scotland registers considerably less incidents than any other route. Despite this tendency, the Wessex area shows the highest number of patrolling incidents. It should be kept in mind that both LNW and LNE routes are composed of four different engineering areas, while most other routes are only divided into two areas.

Across all routes, work left incomplete registers considerably lower numbers than the other two types of incidents. This difference might be motivated by a tendency from work delivery to favour a possession overrun, rather than leave work incomplete when the schedule of the possession is compromised. The numbers for Sussex illustrate a different pattern, as the three types of incidents in Table 6.3 have considerably lower differences between them. While showing some of the lowest numbers for track patrol and possession overrun, Sussex leaves as much work incomplete as LNW.

When considering the analysis of control logs together with the data taken from the asset incident trends database, LNW clearly stands out as the route with the highest number of failures in terms of both the actual delivery and the incidence of planning issues on delivery. Regarding Scotland, there appears to be a different tendency between the outcome of control logs analysis and data from the asset incident trends. While according to control logs, Scotland registered a considerable number of incidents, mostly resulting in overruns, asset incident trends confirmed this route as the one with the lowest incidence of possession related incidents. From a planning perspective, based on the first level of coding, no evidence of planning failures as a main cause was found on control logs.

For both sources of data, the volume and type of work planned by each area must be taken into account as a contributing factor for the incidence of possession failures. An area that plans and delivers higher volumes of work will necessarily have a higher exposure to incidents than other areas. Similarly, areas delivering more complex work or work with higher deliverability risks should also be expected to register higher rates of possession incidents. These aspects will be later explored in the context of the interactions between planning and possession delivery in section 7.2.1.

6.2.3. The Christmas 2007 overruns

As described in section 4.8.1, the events surrounding the severe possession overruns that took place during the intensive period of engineering work of Christmas 2007 were considered an important source of evidence on issues regarding the relations between planning and work delivery. Between 24 December 2007 and 2 January 2008 more than 1000 pieces of work were delivered. The following figures demonstrate the scale and complexity of this national plan:

- More than £123 million were invested
- 414 possessions and 2300 worksites
- Over 1.2 million man hours were worked, which equates to 5000 people working on the railway at any time in a 24-hour period
- Among other types of work, 35km of track were renewed, and 77 S&C units were delivered
- Throughout this work, only one very minor ‘reportable' accident occurred

Appendix 8 summarises the different work scopes that occurred simultaneously throughout the country during this period.

Work at Rugby was part of the West Coast Route Modernisation (WCRM) and was aimed at delivering improved capacity and performance in the area of Nuneaton – Rugby. The work to be delivered over the Christmas period was deemed crucial to allow an enhanced timetable to come into place in the New Year. It should be pointed out that the planning team to which the NAU manager referred to during the familiarisation interview (section 5.1) was no longer in place when most of the work delivered in this period and within the area of the West Coast Main Line were submitted to planning.

An initial scheme from 2002/03 consisted on demolishing and relocating Rugby station. In 2004 this was replaced by a less costly scheme that worked around the current location to rebuild the station and reconfigure track layouts. Despite reducing costs, this new project introduced technical challenges with a degree of complexity never before experienced by the WCRM programme. This work included:

- Installing more than 5km of overhead line

- Bringing into use 5.3km of new track,15 new sets of points and 18 new signals
- Making 16 new track connections
- Installing 9 new signalling 'booster' cabinets

Table 6.4 summarises the information reported by means of control logs since the start of work related to the Rugby. Reports on the remaining possession overruns were also collected and are presented in Appendix 8 to provide a perception of the chain of events at a national level.

Table 6.4: Timeline of events based on information from control logs

Control log date	WON /Item	Event description
22-12-07 (Sat)	39 / 6	S&T work overran. A number of trains were trapped as a result
01-01-08 (Tue)	39 / 25	Possession continued to overrun with a completion date of 05:00 Thursday 03/01. Prior to the start of the blockade over the Christmas period, it had been determined that the work could not be completed during the planned timescales and the possession had been extended to be given up at 05:20 Tuesday 1st January
		10:00 (Mon): Overhead Line Equipment (OLE - electrification) work was 6 hours late with no chance of recovery and the possession would overrun until 12:00 on 1st January 11:00 (Thu): OLE work was behind the revised schedule. Further conferences with the Project teams determined that there had been very little progress and it was estimated that the possession would now overrun until Wednesday 2nd January. Additional OLE staff were transferred to the site 11:50 (Thu): tamping operations would not be completed until 08:00 Wed 2nd January and the OLE renewals programme was in disarray. Further investigations revealed that at least 24 hours of work was required, with no detailed assessment of actual work completed available, no confirmed resources determined and no rectification plan formed 14:00 (Thu): the status of the overrun would transfer to that of recovery from an operational incident and an Incident Management structure was put in place Arrangements were made for engineers to attend at 07:00 Wed 02/01 to carry out a complete walkthrough of the entire worksite

02-01-08 (Wed)	39 / 25	Work on completing outstanding track and OLE renewals continued through the day, with the 16:00 conference reporting that ballast unloading and associated tamping operations would be completed by 22:30. Lists of outstanding OLE tasks had been compiled and allocated to the additional OLE teams on site, estimating that OLE Section proving work would commence by 22:00. By 04:00 track work was almost 90% complete. OLE work continued with section proving expected to commence at 08:00 Thu 03/01. A test train was arranged to be on site from 13:00 Thu
03-01-08 (Thu)	39 / 25	22:32 (Wed): Possession handed back. All test runs were completed at 0318 with no further problems reported 23:40 (Wed): electric test train reported a loss of line light on the Down Fast and OLE staff were sent to site 00:45 (Thu): work required on two drapes was commenced 02:37 (Thu): work was completed, and the additional possession and isolation handed back 02:40 (Thu): electric test run over the Down Fast commenced and no problems were found 03:18 (Thu): all test runs completed with no further problems reported 03:35 (Thu): all infrastructure signed into use

The events described in Table 6.4 clearly show how from day-to-day, work delivery progressed outside the predicted and planned schedule. In particular, it shows that whatever contingencies were put in place, these were insufficient to buffer the extent of the deviations from the initial plan. The contents of the logs further suggest that the project team management was unable to adequately monitor the work progress and act in a timely manner to prevent the escalation of problems. In order to further investigate these issues and their relations to planning, the investigation report produced by the Office of Rail Regulation (ORR, 2008) was consulted. The facts contained in this report are summarised below. Facts that contributed for the deterioration of work delivery and for the seriousness of the overrun are listed beforehand, followed by a list of facts that attempted to mitigate problems.

Facts that further deteriorated circumstances:

- By endeavouring to avoid a blockade extension, Network Rail came to consider that decision too late (at T-3 days) for a proper formal discussion with stakeholders
- The 12 weeks required by process could never have been met, but decision could have been addressed at least 1 week earlier

- Only after 3 consecutive weekends of lost work Network Rail came to that decision
- Informal working level discussions took place on several occasions but never developed into a formal and precise information
- Inadequate response to a considerable risk of delivery failure identified by the Schedule Quantitative Risk Assessment (SQRA), even before previous weekend possessions were lost
- Management of shift changeovers was inadequate and, other than the correction of the shift change misalignment for the machine controllers, no action appears to have been taken to rectify the problem
- Blockade overran for about 14 hours before a state of operational incident was declared and a “Gold Command” instated
- No SQRA was undertaken prior to applying for the additional day
- The SQRAs carried out were based on the assumption that weekend works to be delivered throughout November and December would be completed successfully and on time
- In addition to OLE staff shortage, a lack of contractor’s supervision on site had severe impact on its productivity
- The way in which contractors communicated with staff agencies and how they attempted to secure additional OLE staff was unclear
- Reports from contractors on work progress were increasingly inaccurate and undermined the seriousness of shortfalls
- Network Rail engineers were unable to properly monitor the situation as their attention was diverted to other pressing problems
- The fact that train operators were getting informal indications of problems through control centres at an earlier stage demonstrates the existence of indicators which were not being properly monitored
- OLE resource shortfalls were already partly responsible for the deferral of work from previous weeks into the blockade
- The level of absence verified during this blockade had not been experienced before
- Several times the blockade plan was re-configured to deliver an on-time

hand back but this continued to rely on remaining OLE staff reporting for duty, supplemented by extra OLE staff from other contractors and Network Rail OLE maintenance staff

- Despite resourcing problems NR continued to rely upon the common practice of allowing contractors to self-certify their own work
- Network Rail should have done more to test the sensitivity of its assumptions in SQRAs i.e. for the completion of preparatory work and taken appropriate mitigation measures
- TOCs complained that there did not appear to have been anyone in overall charge or taking an overview
- The difficulties from contractors in securing the necessary resources together with the criticality of the work should have driven the provision of a higher level of supervision during the blockade which would have helped Network Rail to predict and to minimise the extent of the overrun
- Given the controversies and disruptions already caused by the blockade extension it would be expected that Network Rail management would have devoted its full attention to the delivery of the project
- Weaknesses in risk assessment and risk management previously identified in connection with the overrun of the Portsmouth re-signalling project in 2007 were also present in two of the three cases investigated, each in a different part of the country and related to a different type of project
- The significant de-scoping of the Annual Integrated Work Plan (AIWP) undertaken in this period is likely to have led to wasteful levels of project development and planning work. Network Rail should work with the industry to review its own planning, looking to improve both predictability and stability
- Network Rail contracts should ensure that its suppliers take an appropriate share of the financial consequences of any risk to the projects, and equally share the financial rewards of success

Bellow are listed the facts extracted from the ORR report, which attempted to mitigate problems:

- As OLE staff shortage was detected over the initial 2 days of the blockade, Network Rail re-planned the work to create additional time for the OLE work and sought to obtain additional staff
- As it became clear to the project team that the contractor was not on course for delivery, several planned and real-time contingencies were put in place
- SQRA recognised that work was sequential and therefore, delays to the early activities would have a knock on effect on the succeeding activities
- The readiness-reviews were well structured and identified key risks (i.e. availability of key staff for both the signalling and OLE works)
- Information from contractors advised on difficulties in securing the required level of resource
- Programme management expertise and its application was deemed as “impressive” and appropriate for the project
- An allowance of +20% was considered as a contingency for the duration of works
- Network Rail requested from contractors the names of key people rostered for each work to be delivered and checked for double bookings of staff
- Network Rail reviewed all national planned OLE work and cancelled lower priority work packages
- The introduction of “Gold Command” arrangements was successful in recovering train services and communicating with operators and customers. Reviewing how and when such arrangements should be called into effect may contribute to further its effectiveness
- Within a period of approximately 2 weeks Network Rail had developed a preliminary investigation and produced actions to be taken as an outcome of that investigation (The actual effectiveness of these actions cannot be demonstrated)
- The need to seek an extra day for the possession at a late date, or failure to complete the work on schedule - were not believed to be caused by any significant failure of project or risk

management in the weeks beforehand

Overall, the facts and events here discussed clearly illustrate how the work delivery organisation, namely the project teams and the organisation that supports them, were unprepared for the scale and complexity of the work planned. From the planning side, it is also clear that planning was unable to assess the real extent of the risks and produce an adequate overall picture of what was being demanded at national level in terms of resources. The organisational fragmentation and communication breakdowns discussed by planners during the interviews were made evident by these events. Despite the information regarding the accumulation of delays and problems being available, it was never properly transmitted or given the necessary attention.

Several implications for the understanding of resilience in planning and the overall engineering system can be deducted from these events. The inability to respond to the evidence of problems, the unpreparedness to react to events and the difficulties in containing damages made apparent by the data presented are characteristics well documented in resilience engineering literature (sections 3.4.1 and 3.4.6). These are explored in detail later in section 7.2.5.

6.3. Infrastructure and asset archival data

This section investigates the influence that different infrastructure profiles may have on both planning and delivery of engineering work. This was achieved by looking at the assets within each area and the types of faults that these experienced. Three sources of historic data were used:

- Asset incident trends
- Equated Track Miles (ETM)
- Asset counts

While asset incident trends provided an estimate of the unexpected events that may disrupt planned work, the remaining two sources offer an overview of the type and number of assets that each area has to manage.

6.3.1. Asset incident trends

For the purpose of direct comparison with the planning data, the periods concerning each of the three weeks extracted from PPS were analysed:

- Period 4 for week 16 (from 21-06-08 to 19-07-08)
- Period 6 for week 24 (from 17-08-08 to 13-09-08)
- Period 9 for week 36 (from 09-11-08 to 06-12-08)

Additionally, average values per period were calculated for the 2008/2009 year and used not only to identify overall asset trends by area, but also to verify the validity of the data for each of the three periods previously mentioned.

Table 6.5 presents the average number of incidents per period for the types of incidents selected for this work and described in section 4.9 (Asset incident trends). Given the differences in timeframes between the topics discussed throughout this chapter, total numbers for the periods during which planning data was extracted from PPS are also given in Table 6.5 in comparison with the yearly total numbers of incidents.

Table 6.5: Average asset incidents per period by WON area

Types of incidents	Western	Wessex	Anglia	Kent & Sussex	Scotland	LNW (S)	LNW (N)	LNE (S & Central)	East Midlands	LNE (N)	National average
Points failures	101.3	38.2	36.1	73.0	69.2	123.3	83.8	35.4	16.6	42.5	38.7
TSR due to Condition of Track	0.8	0.0	12.2	0.4	1.6	8.5	18.2	27.2	13.7	27.2	6.9
Track faults	40.3	42.9	48.7	56.7	31.2	33.8	42.3	67.0	37.4	71.9	29.5
Gauge corner cracking	0.0	10.4	0.0	0.0	0.2	0.5	0.5	1.1	0.4	0.1	0.8
Mishap - infrastructure causes	8.1	8.1	22.7	12.8	14.7	14.4	10.0	15.5	10.3	24.8	8.8
Severe weather	32.8	9.3	14.8	33.5	22.5	11.5	15.6	7.9	5.0	10.8	10.2
Other weather	8.7	4.5	8.5	17.8	9.3	5.4	12.8	3.8	4.1	9.4	5.3
OLE/Third rail faults	0.5	5.5	27.6	10.3	12.4	15.3	11.8	10.9	5.5	4.9	6.6

Signal failures	79.6	21.7	32.2	59.5	69.8	69.4	83.3	31.8	15.5	41.8	31.5
Track circuit failures	65.3	46.4	25.3	59.2	55.0	109.2	84.8	19.5	12.8	20.6	31.1
Signalling system and power supply failures	21.5	19.6	29.5	33.5	33.0	28.7	32.4	31.4	18.6	39.3	18.0
Other signal equipment failures	19.5	8.2	5.5	9.9	8.2	11.2	10.2	9.5	7.3	9.0	6.2
Telecoms failures	19.1	5.5	12.1	10.6	17.7	5.2	4.5	10.2	4.8	13.9	6.5
Cable faults	1.9	3.5	1.8	3.5	6.7	3.1	4.4	8.2	2.4	8.4	2.7
Average for 2008/2009	399.6	223.8	276.9	380.6	351.5	439:4	414.5	279.3	154.4	324.6	202.8
Average for periods 4, 6 and 9 (planning data)	405.3	218.7	274.3	343.7	349.7	425.7	429.7	300.3	148.0	354.7	203.1

At national level, 3244.6 incidents per period were registered. The LNW route and in particular the LNW (S) area, shows the highest number of incidents, while East Midlands registers a clearly lower number from all other areas. Track circuit failures are the type of incidents in which the difference between LNW and the other routes appears to be most relevant, in particular for LNW (S) with 109.2 incidents. Although with smaller differences, LNW (S) is also the WON area with the highest number of points failures, which on average, are the most frequent type of incident.

The use of TSR is more frequent on the west and east coast main lines and Anglia. Given that these are known to be considerably busy routes, the wear out of the infrastructure and reduced access can be considered probable causes. Despite being recently submitted to an extensive modernisation programme, the LNW route maintains considerably high numbers of TSR and the highest total number of failures.

The impact of weather related incidents varies considerably from area to area. While in LNW (S) these only represent 4%, for Kent & Sussex weather is responsible for 13% of the total of incidents registered. Western and Scotland registered a number of severe weather related incidents similar to Kent & Sussex but a much lower number for other weather related problems.

Gauge corner cracking is the type of incident with less importance. However, while most areas have one or less incidents of this type per period, Wessex shows 10.4 corner cracking incidents per period. An overview of the existing data since 1999 suggests that gauge corner cracking and track faults are the incidents for which numbers suffer stronger variations from period to period. While for the year under analysis here (2008/2009) only Wessex registered such a variation, the database showed that approximately from October 2000 to February 2001 there was a significant increase in the number of these incidents across all engineering areas. In some cases like in the East Midlands area, an increase from zero to 139 incidents was registered in two consecutive periods. Given the extent of data involved, the numbers for these features are not shown here. The causes of such variations could not be accurately identified from the data available but based on the understanding of rail engineering this is likely to be derived from either variations in the type or volume of traffic or significant variations of temperature due to weather changes.

Sudden increases in the incidence of any type of incident are potentially unforeseen and therefore, are likely to generate higher volumes of planning changes. To offer a better perception of these variations, Figure 6.1 shows the total number of incidents (for the 14 types initially considered) for each of the periods of the year 2008/2009.

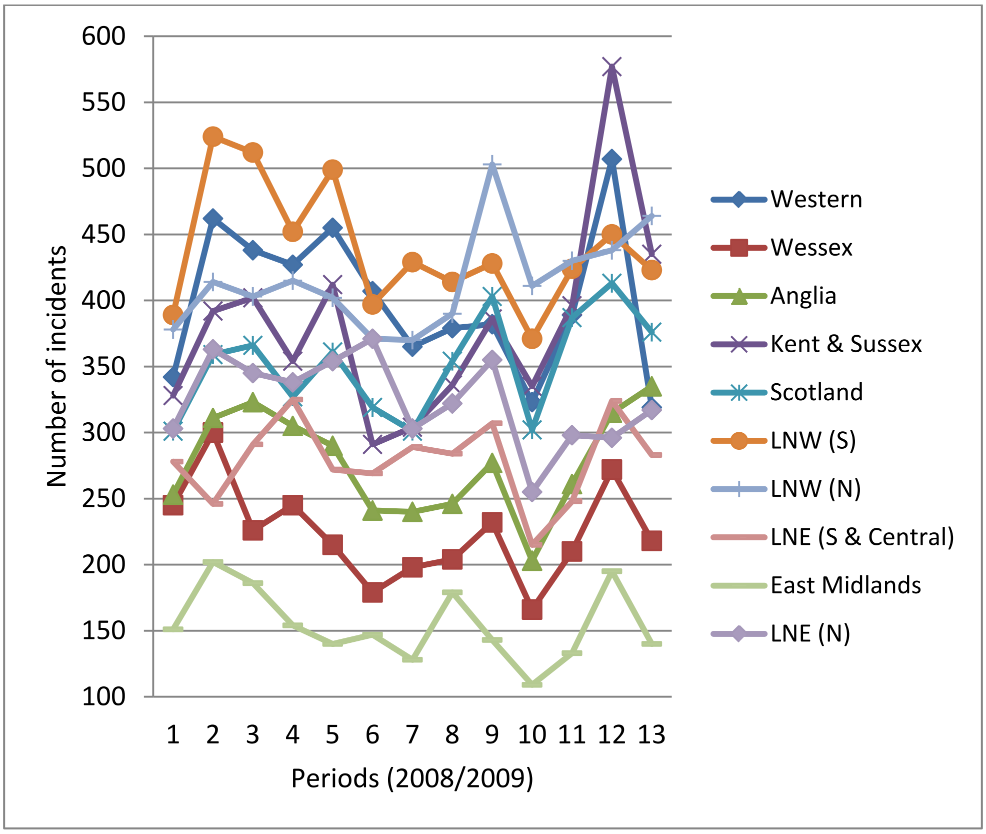


Figure 6.1: Variation of the number of asset incidents by area

Figure 6.1 was considered a relevant illustration for the strong variations registered by all areas at different periods of the year. Except for LNE (S & Central), all areas registered significant increases from period 1 to period 2. While from period 9 to period 10 a reduction of incidents occurred across all areas, the most significant increases and highest numbers were registered between periods 10 and 12. Given that these periods correspond to the winter months, weather conditions could be one of the factors accounting for this heighten number of asset incidents. The strong variations also visible during other periods of the year suggest the contribution of other factors to the occurrence of asset incidents.

6.3.2. Asset data

This section focuses on the analysis of data regarding the assets that exist under each area. The purpose is to establish what type and number of assets each area is required to maintain, in order to investigate possible impacts that this may have on planning performance. The Equated Track Miles (ETM) and asset counts were used in this assessment. While the number of ETM is useful to understand the volume of maintenance work required, asset counts provide a more precise estimate of the infrastructure complexity.

The distribution by MDU of data from both sources is shown in Table 6.6 together with its correspondence to the engineering areas, as these represent the geographical structure of the planning organisation. The correspondence to the WON areas is also shown to facilitate the comparison with data from the other two topics discussed in the course of this chapter. In addition to ETM and the total number of assets, this table shows the standard mileage of each MDU and offers the number of assets per mile of track as a base for comparison between areas in terms of density.

Table 6.6: ETM and asset count per MDU and correspondence to WON areas

<table>
<tr><th>MDU</th><th>ETM</th><th>Std. Track Miles</th><th>Total asset count</th><th>Asset / Mile</th><th>Engineering Area</th><th>WON Area</th><th>ETM</th><th>Std. Track Miles</th><th>Total asset count</th><th>Asset / Mile</th></tr>
<tr><td>Bedford</td><td>798.2</td><td>589.3</td><td>7079</td><td>12.0</td><td rowspan="2">Midlands & Continental</td><td rowspan="2">East Midlands</td><td rowspan="2">1424</td><td rowspan="2">1090</td><td rowspan="2">15084</td><td rowspan="2">28.0</td></tr>
<tr><td>Derby</td><td>625.8</td><td>500.4</td><td>8005</td><td>16.0</td></tr>
<tr><td>Hitchin</td><td>804.1</td><td>508.5</td><td>5842</td><td>11.5</td><td rowspan="4">Great Northern</td><td rowspan="2">LNE (S)</td><td rowspan="2">1208</td><td rowspan="2">964</td><td rowspan="2">9689</td><td rowspan="2">19.9</td></tr>
<tr><td>Lincoln</td><td>404.3</td><td>455.3</td><td>3847</td><td>8.4</td></tr>
<tr><td>Doncaster</td><td>614.3</td><td>323.2</td><td>4994</td><td>15.5</td><td rowspan="2">LNE (Central)</td><td rowspan="2">1014</td><td rowspan="2">722</td><td rowspan="2">11460</td><td rowspan="2">31.6</td></tr>
<tr><td>Sheffield</td><td>399.8</td><td>399.2</td><td>6466</td><td>16.2</td></tr>
<tr><td>Leeds</td><td>718.5</td><td>649.0</td><td>11642</td><td>17.9</td><td rowspan="3">North Eastern</td><td rowspan="3">LNE (N)</td><td rowspan="3">2203</td><td rowspan="3">1860</td><td rowspan="3">27051</td><td rowspan="3">43.4</td></tr>
<tr><td>Newcastle</td><td>747.3</td><td>642.9</td><td>8281</td><td>12.9</td></tr>
<tr><td>York</td><td>736.9</td><td>567.7</td><td>7128</td><td>12.6</td></tr>
<tr><td>Chester</td><td>482.8</td><td>564.3</td><td>9841</td><td>17.4</td><td rowspan="3">Central</td><td rowspan="5">LNW (N)</td><td rowspan="5">2808</td><td rowspan="5">2633</td><td rowspan="5">53022</td><td rowspan="5">102.0</td></tr>
<tr><td>Crewe</td><td>585.7</td><td>462.3</td><td>11740</td><td>25.4</td></tr>
<tr><td>Manchester</td><td>694.5</td><td>622.4</td><td>15902</td><td>25.5</td></tr>
<tr><td>Carlisle</td><td>736.1</td><td>676.8</td><td>9558</td><td>14.1</td><td rowspan="2">Lancs & Cumbria</td></tr>
<tr><td>Preston</td><td>309.0</td><td>306.8</td><td>5981</td><td>19.5</td></tr>
<tr><td>Bletchley</td><td>550.4</td><td>291.6</td><td>4428</td><td>15.2</td><td rowspan="3">West Coast South</td><td rowspan="5">LNW (S)</td><td rowspan="5">2789</td><td rowspan="5">1805</td><td rowspan="5">29239</td><td rowspan="5">83.7</td></tr>
<tr><td>Stafford</td><td>609.5</td><td>359.8</td><td>3417</td><td>9.5</td></tr>
<tr><td>Stonebridge Park</td><td>432.1</td><td>229.9</td><td>4556</td><td>19.8</td></tr>
<tr><td>Saltley</td><td>765.5</td><td>622.5</td><td>9747</td><td>15.7</td><td rowspan="2">West Midlands</td></tr>
<tr><td>Sandwell-Dudley</td><td>431.0</td><td>300.9</td><td>7091</td><td>23.6</td></tr>
<tr><td>Colchester</td><td>556.5</td><td>493.8</td><td>7658</td><td>15.5</td><td rowspan="3">Anglia</td><td rowspan="3">Anglia</td><td rowspan="3">1695</td><td rowspan="3">1426</td><td rowspan="3">31338</td><td rowspan="3">68.2</td></tr>
<tr><td>Romford</td><td>546.6</td><td>371.6</td><td>11471</td><td>30.9</td></tr>
<tr><td>Tottenham</td><td>591.6</td><td>560.2</td><td>12209</td><td>21.8</td></tr>
</table>

Ashford	417.7	494.2	7103	14.4	Kent	Kent & Sussex	1997	1793	42410	132.7
London Bridge	320.0	250.5	12466	49.8						
Orpington	367.0	349.1	7212	20.7						
Brighton	519.7	438.9	7765	17.7	Sussex					
Croydon	372.8	260.4	7864	30.2						
Clapham	363.8	270.7	7939	29.3	Wessex	Wessex	1606	1286	21846	57.0
Eastleigh	609.5	555.0	6883	12.4						
Woking	632.6	460.0	7024	15.3						
Edinburgh	721.7	648.5	7299	11.3	Scotland East	Scotland	2606	2588	26381	42.2
Perth	613.2	774.7	5763	7.4						
Glasgow	498.5	499.1	6949	13.9	Scotland West					
Motherwell	772.7	666.0	6370	9.6						
Reading	536.7	283.7	7281	25.7	Thames Valley	Western	3485	3197	52574	102.5
Swindon	737.1	495.9	7253	14.6						
Bristol	621.5	592.0	9478	16.0	West Country					
Plymouth	459.6	532.2	8279	15.6						
Cardiff	697.6	760.2	13307	17.5	Wales & Marches					
Shrewsbury	432.1	532.5	6976	13.1						

Overall, considerable differences are observed between MDU in terms of ETM and asset counts. As expected, the delivery units located in urban areas or around major junctions show higher concentrations of assets per mile of track. London Bridge is the MDU with the highest concentration, which reflects on the Kent & Sussex area where this concentration is also the highest. In order to maintain the base for comparison with the other two topics, prevalence was given to the distribution by WON areas. However, it should be kept in mind that Kent and Sussex have separate planning teams. At engineering area level, Kent remains the one with the highest number of assets per mile (84.8) while Anglia has one of the highest numbers of assets. The Central engineering area in LNW (N) is the one with the highest asset count (37483).

Western is the WON area with both the highest number of ETM and standard miles. This would suggest that Western is the area requiring the highest volume of maintenance work. This area is divided into three different engineering areas, which presuppose a distribution of the planning needs amongst these three areas, as these are the basis of the geographical organisation of planning. In terms of delivery, Western is also the area with more MDU. LNW (N) shows a comparable number of assets and the same concentration per mile but with approximately less 20% of ETM than Western.

The breakdown of asset counts (section 4.9) into categories is shown in Table 6.7. The numbers given illustrate the differences registered by WON area.

Table 6.7: Breakdown of asset counts by WON areas

	Stations	Bridges	Tunnels	Signal Boxes	Track Circuits	Signals	TPWS	Insulated Block Joints	Points Operating Equipment	Total
Western	399	14557	409	155	8385	7256	1951	16482	2980	52574
Wessex	209	3608	39	33	3905	3954	1377	7329	1392	21846
Anglia	239	6031	14	87	6222	5496	1261	10077	1911	31338
Kent&Sussex	357	7992	234	27	7163	7234	2040	14702	2661	42410
Scotland	347	5378	114	83	6401	5951	2143	3663	2301	26381
LNW (S)	200	8744	122	60	4802	5977	1496	5473	2365	29239
LNW (N)	406	11892	247	171	8814	7374	2223	18924	2971	53022
LNE (S)	80	812	45	57	2928	2384	427	1974	982	9689
LNE (Central)	46	1373	71	41	3101	2081	395	3391	961	11460
East Midlands	82	1576	111	38	3816	2698	547	5155	1061	15084
LNE (N)	184	5246	191	121	6038	5354	1274	6791	1852	27051

Data in this Table 6.7 indicate that the number of bridges and IBJ are the categories contributing the most for the significant differences registered by Western, Kent & Sussex and LNW (N) in terms of total asset counts. In addition, Western possesses almost the double the number of tunnels than any other area. Given the complexity of engineering work within tunnels, this is likely to impact on planning. The number of points operating equipment in areas such as Western and LNW (N) can also be interpreted as an indication of the complexity of the infrastructure within these areas. LNW (S) has less 45% of the assets and less 31% of the standard miles than LNW (N). Despite these differences, the two areas have similar numbers of ETM (2789 ETM for LNW (S) and 2808 for LNW (N)).

The areas previously identified as having the highest numbers of incidents are also the areas with the highest ETM. Figure 6.2 illustrates the relation between these two parameters.

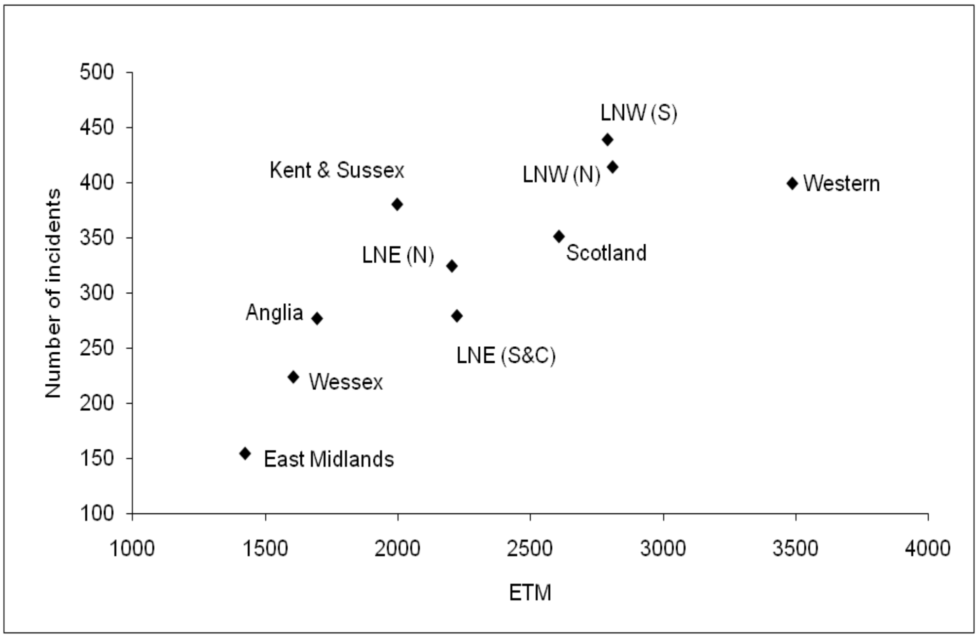


Figure 6.2: Relation between number of asset incidents and ETM

Figure 6.2 shows that the number of incidents occurring within a given area (as registered in the asset incident trends database) is related to the complexity of the infrastructure. Although LNW (S) and LNW (N) show very similar trends in this figure, as previously pointed out, LNW (S) owns significantly less assets and mileage than LNW (N) but both areas have similar ETM numbers. This indicates that beyond the number of assets, other factors taken into account in the calculation of ETM are contributing to the heighten number of incidents registered by the LNW (S) area. As previously mentioned, among other factors, the calculation of ETM takes into account the annual tonnage, which depends on the loads hauled and on the volume of traffic. Hence, where annual tonnage is higher, a more intensive use of the infrastructure is expected and potentially, not only higher numbers of incidents may be registered but also more significant engineering access constraints may exist. Both of these factors can have a significant impact on planning performance.

6.4. Chapter conclusions

The familiarisation interviews not only supported some of the main conclusions drawn from the semi-structured interviews with planners, but also provided important guidance for the subsequent study of work delivery. The following aspects were considered as the more relevant ones for the pursuit of this research:

- The little awareness that PICOPs expressed regarding the complexity of the planning organisation and its processes.
- In general, PICOPs gave little importance to the information produced by planning. Not only the contents of that information was described as having a moderate relevance on the night, but also often, after issuing the PICOP back, less than 24 hours before delivery, changes are again introduced, particularly to details of engineering trains. Keeping in mind that planning should be the source of management of uncertainty for delivery, as it builds on foreseeable aspects of the business to anticipate needs (Grote *et al*, 2009), it can be concluded that often planning is unable to appropriately manage uncertainty and transfers it to those responsible for work delivery (PICOPs and signallers).
- All interviewees offered insight on the impact of late changes on work delivery. In particular, PICOPs and signallers are confronted on the night of delivery with possession arrangements that often differ from the formal and documented details.
- The need for reliable information and efficient communications was mentioned by all interviewees. While PICOPs valued above all, the detailed knowledge of the infrastructure in their area, signallers considered as useful the opportunity to participate in planning meetings during the last stages of the process. The Anglia route controller highlighted the importance of an efficient exchange of information on the night between PICOP, signaller and control centre to guaranty a successful and safe work delivery.
- Both PICOPs and signallers recognised efficient communications while checking (and double-checking) details of possession as a safety guard against incorrect or late changed planning details.

Overall, the points taken from the interviews and highlighted above are consistent with the poor information flows and poor visibility described by planners, as well as the way in which the impacts of late changes were described. These points also reinforce the arguments introduced by the literature regarding the importance of information and in particular feedback, in the management of uncertainty. On the one hand, access to reliable information about the details of the work planned helps anticipate issues and thus, reduces uncertainty. As discussed in section 3.1.5 and previously observed in regards to planners interviews, incomplete (or inaccurate) information about the behaviours of the system generates uncertainty in operations (Leveson, 2004). On the other hand, as observed in section 3.5.5, feedback from the operational level is fundamental for the development of visibility and situation awareness in planning regarding changes in operating conditions which may require readjustments of planning (Jorna *et al*, 2005). Leveson *et al* (2003), while introducing the concept of a safety control loop (section 3.3.6), also state the importance of feedback and information flows in general for maintaining control over the system. The triangle between PICOP, signaller and operations control, as described in section 6.1.4, clearly supports the information needs discussed here.

National control logs provided useful insight in terms of possession related incidents and the relevance of planning as a causal factor. The use of asset incident data gave additional support for the identification of different performance trends between geographical structures. LNW route was identified as having the highest incidence of possession failures and of planning related issues.

The study of events leading up to the Christmas 2007 possession overruns further illustrated organisational fragmentation and the problems it creates for an efficient flow of communication between planning delivery and operations control. There is ample evidence of poor communication between the project team responsible for work delivery and other engineering stakeholders, including planning, which provide additional arguments in favour of those previously presented regarding the need for efficient information flow and the importance of feedback to create adequate situation awareness (Jorna *et al*, 2005). As pointed out by Woods (2006b), the fragmented organisational structure generates equally fragmented information flows, which leave decision makers unable to recognise the big picture and reframe their situation assessment. From this perspective, the Christmas overruns, and in particular, the Rugby project show evidence of the following:

- Production and business pressures led planning to exceed available resources and capacities.

- Although delivery teams detected problems with work progress, they were unable to properly assess the extent of the problems and adequately communicate them to operations and planning.
- The measures taken by project teams in terms of re-planning work and deploying contingencies were based on incomplete knowledge of the situation and therefore were consecutively insufficient to produce the necessary adjustments.

The changes made to the initial scheme, which as described in section 6.2.3, reduced costs but increased complexity, not only demonstrate the business pressures under which Network Rail operates, but also illustrate the kind of trade-offs which are involved in planning decision making processes. In this case, in line with the principles of an Efficiency-Thoroughness Trade-Off (ETTO - Hollnagel, 2009a), decisions clearly favoured efficiency aspects by aiming to reduce costs and the increased complexity of the option taken had clear additional delivery risks. As mentioned in section 6.2.3, the events around these possession overruns provide ample support for the understanding of resilience in the rail engineering system and will be further discussed in section 7.2.5.

The investigation of infrastructure profiles provided valuable information on different possible constraints imposed on planning. For instance, a higher concentration of bridges such as the one identified in Western area is likely to cause additional challenges for planning due to the limitations of equipment that can be used and the additional difficulties in accessing the infrastructure. The fact that ETM appears to be closely related to the number of asset incidents registered by each area further supports these conclusions. These findings are in line with the arguments presented by Jorna & Kiewiet (2007) when considering that the complexity of the undertaking entails equally complex planning, in order to predict possible scenarios and allocate resources in accordance to such scenarios.

As stated earlier, the investigation of work delivery and of the different infrastructure profiles was considered a fundamental step towards understanding the success of planning (section 4.3). This chapter explored both work delivery and the infrastructure trends in order to support the understanding of the operating environment of the planning system. These findings are brought together in the next chapter, in order to develop an understanding of what could be considered a successful planning performance and what are the sources of resilience in planning. Following the base of the geographical comparison already created, planning, work delivery and infrastructure data are confronted.

7. Understanding and measuring resilience in planning

Resilience engineering was defined in section 3.4 as a property which emerges from the way in which the system performs. Within the scope of this research, this means that planning performance must be understood and resilience engineering features must be recognised in its operations. As argued in section 4.3, the study of planning performance needs to recognise the fact that the purpose of planning is to support work delivery. Successful planning can only be understood in view of how it supports a safe and reliable work delivery. Resilience literature also demonstrated the importance of understanding interactions, not just within the system under analysis, but also those occurring between the system and its operation environment (McDonald, 2006). From Figure 4.1, the immediate environment of planning can be recognised as work delivery and the rail infrastructure.

While chapter 5 amply explored planning and aspects of its performance, chapter 6 developed an understanding of work delivery and of different infrastructure profiles. This chapter explores resilience in planning by integrating perspectives from the previous two chapters. Apart from referring to the literature discussed in section 3.4, the data presented in chapters 5 and 6 are recalled to highlight aspects of engineering planning which, in view of resilience concepts, can be described as factors either contributing or eroding system resilience.

Objectives	Questions	Methods
3) Investigate relations between planning and engineering work delivery and identify the impacts of planning on work delivery. 4) Describe resilience within the planning system and identify means to improve it. 5) Contribute to the development of a framework, methods and measures for assessing resilience in planning.	• What are the different trends in the relations between planning and delivery? • How does variability and uncertainty express itself in the planning system? • What are the sources of resilience in planning? • What aspects of planning performance can potentially support the development of resilience indicators? • How can resilience in rail engineering planning be monitored?	• Exploring of interview data from a resilience perspective • Exploring of archival data from a system perspective • Functional resonance analysis • Questionnaire

7.1. Indicators of resilience from interviews with planners

This section recalls the main findings of the semi-structured interviews and interprets them in view of resilience concepts and the related literature presented in chapter 3. The purpose is to substantiate aspects of planning that may either contribute to or erode resilience in the system, and thus better understand what could be considered resilience in the planning of rail engineering work and how it could be “engineered” in such systems. This later supported the development of part 2 of the questionnaire (section 7.4.7).

7.1.1. Management of planning changes

The management of planning changes stands out from every interview as the most critical issue for the success of planning. Every planning change has at its origin a planning decision that generates a system trade-off of some kind. This often means that in order to maximise the use of every access opportunity, an increase of the risks of deliverability must be accepted. The way in which trade-offs may contribute to a sustained and adequate balance between efficiency and thoroughness (Hollnagel, 2009a) is influenced by the quality of decision making processes (experience and skills of decision makers, available information, culture aspects that frame decisions, among others). In this sense, resilience relies on the ability of the system to develop information that can support planners in realising when a particular decision is contributing to an efficient use and allocation of resources, rather than generating unacceptable risk of planning error or delivery failure. As argued by Hale *et al* (2006), there are two faces to change: while the ability to change is an important source of resilience, as it allows to flexibly cope with unexpected circumstances, it can also erode tried and tested methods and solutions to problems. Hence, while trying to improve the efficiency of the plan and the allocation of resources it stipulates, planners also incur in the risk of dismantling important safety and reliability mechanisms already embedded in the plan, such as contingency measures for complex work.

It was pointed out by planners that the lack of reliable information generates unnecessary planning change and was identified by all as the main source of uncertainty and unpredictability regarding the performance of the planning as whole. Crawford & Wiers (2001) have pointed out that unstable conditions of the environment are a cause for the need to adjust plans and add to the instability and complexity of planning. Planners also recognised that some level of change is necessary to adjust planning to emergent engineering or business needs, as there are things that cannot be anticipated. Hence, planners are aware that some form of flexibility is needed in planning.

A higher volume of change does not necessarily imply a degradation of planning quality, as any change could at any stage, be contributing to eliminate unacceptable risk or to optimise resource allocation. Nevertheless, it is indisputable that the more changes are made to a given plan, the more complex becomes the task of maintaining its integrity and coherence. A high volume and frequency of change is compatible with a fast pace changing operational environment (Leveson, 2004) and if at the core of high complexity (Marais *et al*, 2007 and Jackson, 2010). Keeping in mind that planning archival data showed that the frequency of planning changes is intensified as delivery date approaches and therefore, time pressure increases (section 5.3.2), the volume and frequency of change normally verified in the planning system may generate a higher risk of planning failure, as it increases its complexity.

Through experience, planners develop a better understanding of their sources of information as well as of the impact that their decisions may have on the delivery of work. These two aspects of experience can then support a better balanced decision making and hence, improve the management of planning changes. Thus, planning experience constitutes a critical factor for the management of planning changes.

7.1.2. Organisational and geographical barriers

As previously mentioned, the planning system relies on the relations existing between different geographical and organisational units, which in some cases, go beyond the corporate limits. This fragmented organisation clearly generates the potential for communication breakdowns at the boundaries of different planning levels and teams. This is mainly substantiated by the poor visibility and information that planners claimed regarding how the system performs beyond the limits of their planning units.

This system complexity derives from the need to respond to specific local engineering requirements whilst ensuring that resources available at national level are used in the most efficient way possible and within the guidelines of national strategies of enhancement and modernisation of the railway. This relates to the need to balance acute and chronic goals, as discussed by Woods (2006a). Often long-term (chronic) and strategic goals define safety and efficiency targets which cannot be simultaneously achieved. As in the example previously given of a trade-off, delivering as much work as possible within the available access inevitably requires accepting higher deliverability risks. In a similar way, delivering the work necessary to achieve the envisaged enhancement and modernisation targets, whilst reducing engineering access, means that other engineering work needs must be reduced. This is often the case of lower priority maintenance work and other local and immediate (acute) engineering needs. The pressures generated by business long-term commitments are often incompatible with local and short-term or immediate maintenance needs (i.e. emergency work). This became clear in the recurrent revisions of decisions made and the way in which work that has undergone the planning might be cancelled during last stages of the process, due to factors such as budget changes or the emergence of other higher priority engineering interventions.

7.1.3. Variability of information inputs to the planning process

Information provided to planners is characterised by two major sources of variability:

- The specific geographical and organisational demands generate a significant variability of the type of information and the formats under which it is provided to planning units. Although this may impact little on the quality of the decision making process, it requires additional time to process information and a frequent need to request clarifications from sources, in particular for less experienced planners as they still lack some familiarity with the different existing methods of working.
- The second cause of variability is related to the wide range of engineering work scopes and the way in which these often struggle to work to common timings. Although the timescales defined by the national planning process try to account for this diversity, it is often

difficult to ensure that the development of major investments coincides with other less complex work such as the cyclic maintenance needs.

These sources of variability often force planners to review their decisions as information is either changed or provided beyond the established timescales. Variability is also a consequence of the broadness of the planning system in terms of, both its geographical and organisational dispersion, and the diversity of engineering needs to which it must respond. This generates a wide range of different inputs and variables which planners must manage. These characteristics of the planning system are at the origin of its complexity and therefore, also of the variability which is inherent to complex systems (Jackson, 2010).

The lack of regular and formal feedback also generates variability of information. As mentioned by planners, normally they would only receive feedback, either from planning units at later stages or from work delivery, when "something has gone wrong". As mentioned in section 5.2.6, planners attempt to compensate poor feedback by resorting to informal contacts. As discussed by Vernon (2001), there are two fundamental types of feedback for planning activities:

- Feedback to assist the development of the plan by providing information support to decision making regarding the feasibility of the plan. This information constitutes a fundamental support for the development of adequate planning practices and is the source of what planners referred to as "understanding the impact of decisions on delivery" (section 5.2.4).
- Feedback on the progress and conditions of work delivery which may require revisions of the plan (planning changes). This helps reduce uncertainty and unpredictability by supporting the anticipation of problems (section 5.2.6).

The diversity and range of information which is inputted to the planning system is often difficult to manage, as planners expressed during interviews (section 5.2.6). This contributes to uncertainty in decision making processes (Leveson, 2004) and accounts for the underspecified nature of activities in the planning system (Hollnagel, 2009a).

7.1.4. Formal and informal flows of information

As pointed out by Vernon (2001), planning and scheduling activities are often embedded in informal knowledge rather than formal communication and explicit processes. The distribution of decision making amongst several people or teams can enforce some formalisation of information exchanges. Because the planning of engineering work involves negotiations with numerous organisations across the industry, planning decisions require a formalisation and proper documentation, as they often assume the role of a contract between different companies. This can considerably increase the time necessary to reach decisions and disseminate their outcome to all those requiring it to further detail their work scopes. When pressured to solve issues, planners seek informal contacts in order to make a decision, which becomes later formalised according to the process. Planners often alluded to the need to request information from stakeholders or other planning teams. This means that the planning system relies mostly on information pulling, rather than pushing (Hollnagel, 2009a). This creates an informal information flow that runs parallel to the formal and documented decision making. Depending on how trustworthy their source of information may be, planners may build their decisions on an informal basis and seek documented confirmation later. This means that despite standard timescales according to which information should be delivered (information push), system operation relies a great deal on planners chasing information (information pull) (Hollnagel, 2009a). Because planners will tend to look for information when they feel the need for it and where they believe the source to be most reliable, it can be argued that this method of working improves control over decision making. However, this also increases the risk of decisions being made on the grounds of erroneous information, particularly in the case of less experienced planners. As argued by Leveson *et al* (2003), reliable information flows are a fundamental source of control over the system.

7.1.5. Uncertainty and unpredictability

Dealing with uncertainty and unpredictability was recognised as part of the daily activity in planning and as a major obstruction to reliable planning. As pointed out by Leveson (2004), incomplete or inaccurate information are a major source of uncertainty in system operations. Planners pointed out that managing sources of uncertainty is often difficult because information and pressures for changes normally emanate from outside their planning teams or even from beyond the limits of the planning organisation. The cross-organisational scale and the timescale of the planning process inevitably lead to a self-containment of its activities into different stages and with set deadlines. As discussed by Vernon (2001), self-containment may reduce complexity of decision making locally and force coordination and exchange of information between the different planning entities involved. However, in large scale systems such as the planning of rail engineering work, the number of planning units and the diversity of planning steps that must be coordinated clearly contributes to its complexity and uncertainty. This is in line with the arguments presented in section 3.1.6 regarding intractable systems. Operations in the planning system must be seen as being underspecified which means that planners must be provided with means to manage uncertainty, as debated in section 3.4.3.

The broadness of the planning organisation hampers planners' visibility over how decisions made within their own unit, will be carried forward through the process. This considerably reduces whatever feedback planners may obtain regarding the effectiveness of their decisions and creates additional uncertainty and unpredictability.

Information pulled from other sources allows planners to anticipate issues. However, they are aware of the likelihood that such information might change when going through the formal channels of communication. On the other hand, often stakeholders push information through to planning only to keep with the imposed timescales and if necessary, will later seek to change that information. These issues confer a considerable degree of uncertainty to information sources. While these common practices may contribute to the efficiency of decision making processes, if the information used turns out to be unreliable, additional planning changes are generated and the integrity of planning may be compromised.

Despite the scale of the planning organisation and the way it branches out to several geographical structures, the planning process strongly emphasises the need for strict timescales and tight work flows, which is compatible with what Grote *et al* (2009) describe as centralised feed-forward controls that aim to minimise uncertainty. Change Control Process (PL0086) as described in section 5.1.3, aims to reinforce compliance with the planning process and control any deviations deemed necessary. As stated by Grote *et al* (2009), this approach aims to minimise the degrees of freedom of those responsible for delivering the deployed plans. The high incidence of uncontrolled change, as described by planners during the interviews, suggests that such strict and rigid control (by means of the planning process) may be unadjusted to the real demands imposed on planners in terms of balancing the engineering work requirements against the available resources. As discussed in section 3.4.3, this may require additional local control and management of uncertainty (Grote *et al*, 2009).

7.1.6. Planning experience

As pointed out by Hollnagel (2009a), maintaining a high level of safety requires learning from experience. Planning experience was recognised as the means through which trustworthy work relations were developed. It thus becomes a fundamental resource, which supports informal discussion of issues and problem solving. Planners referred to the overall understanding of how the rail industry operates as the means to recognise when and what information is required to support a given decision.

Through experience, planners also develop a geographical knowledge of the railways, which becomes relevant to understand the impact of decisions in terms of what might be the consequences or the arrangements necessary when blocking a particular route with engineering works. Experience and knowledge of the railways support planners when they are confronted with the need to make decisions beyond the strict limits of what would be allowed by the planning process, such as accepting details of work and changes beyond the established deadlines. As discussed by McDonald (2006), professionalism and competence compensate for the rigidity of systems by allowing people to incorporate flexibility in that system.

7.1.7. Reliable work relations

Reliable work contacts are the means through which planners pull information from the wider planning system and work towards an optimised problem solving. When having to deal with issues such as unforeseen delivery conflicts or late changes, planners draw on their work contacts as a bypass of the formal communication and decision making channels.

Depending on the trustworthiness of these contacts, planners try to anticipate issues and mitigate sources of information, which they know often to be unreliable, whilst awaiting formal agreement on the decisions from all parts involved (train operators, engineer suppliers, maintainers, project teams, among others).

By resorting to these methods of working, planners not only increase the level of trust in the decisions they make, but also allow the planning organisation to respond with higher efficiency to numerous pressing issues that often push planning timescales, especially as work approaches its delivery date. These work relations create the proximity between people necessary to respond to issues in a timely manner. Leveson *et al* (2006) consider that rate of information sharing (sharing the news) relies on the number of contacts between people who are at the origin of that information (those who know) and those that may require it (those who don't know). From this perspective, work relations are fundamental to ensure an efficient dissemination of information.

7.1.8. Understanding the impact of decisions on delivery

Overall, planners demonstrated being aware of the fact that planning must above all, support work delivery with reliable information. This became clear by the statements of interviewees regarding the need to understand the impact of their decisions on delivery and their concerns towards the impacts of frequent and late changes.

Planners rely on experience and an overall knowledge of the railways to develop awareness of the potential impacts of their decisions on work delivery. This awareness concerns among others, the issues involved in routing engineering trains and machines in and out of possessions or under which conditions rail vehicles may or may not be run through worksites.

Understanding these issues becomes particularly relevant when having to plan high volumes of work or complex work scopes within diminishing track access opportunities. Throughout the interviews, planners indicated that the more in-depth knowledge they had regarding the requirements and implications of engineering work delivery, the more comfortable they would feel when having to solve safety issues and conflicts within possessions. Within this context and as earlier mentioned, having access to reliable information, both in terms of work to be planned and feedback from work already planned becomes a fundamental source of confidence in decisions by minimising uncertainty. Information is a crucial element in understanding and maintaining awareness of problems and shortcomings within a decision making process and supports the ability to anticipate such problems (Leveson *et al*, 2006).

7.1.9. Development of contingencies

When planning for higher risk delivery scenarios such as complex renewals works or possessions that integrate numerous independent work scopes in order to maximise access opportunities, it becomes crucial to consider in more detail any potential failures and plan for contingencies. For instance, this could mean planning for buffer time to compensate unforeseen issues or having machinery standing-by in case of equipment failures. In this sense, developing contingencies embodies safety criteria into planning as it aims to prevent against delivery failures.

In order to do so, apart from requesting more specific input from the stakeholders involved in that particular work (contractors, project teams or maintenance units), planners rely on their knowledge and understanding of the railways to identify any potential problems and conduct their decision making accordingly. As discussed earlier, feedback is also a fundamental support to the identification and understanding of problems. As argued by Axelsson (2006), weak and diffuse signals must be managed in order to create opportunities for the anticipation of problems. A problem that stays with the one that discovers it and is not disseminated remains an unknown problem and this cannot be dealt with at a wider scope of decision making processes and systems.

7.2. Archival data analysis from a system perspective

Archival data was earlier investigated from three different perspectives:

- Planning data sources provided grounds for an understanding of planning performance based on a comparison of geographical areas (section 5.3).
- Safety data supported the analysis of work delivery incidents, aiming to identify and assess planning related causes (section 6.2).

- Asset and infrastructure data was used to characterise the profile of the infrastructure in each geographical area, aiming to better understand the volume and type of work that different areas of the infrastructure may require (section 6.3).

Keeping in mind that the core function of planning is to support work delivery by producing a reliable plan, this section explores the relations between these three perspectives in order to understand from a system perspective, the extent of the impacts of planning on work delivery. Infrastructure data is also contemplated in this analysis in order to understand the influence that different infrastructure profiles may have on planning. This scope of analysis is illustrated by Figure 7.1.

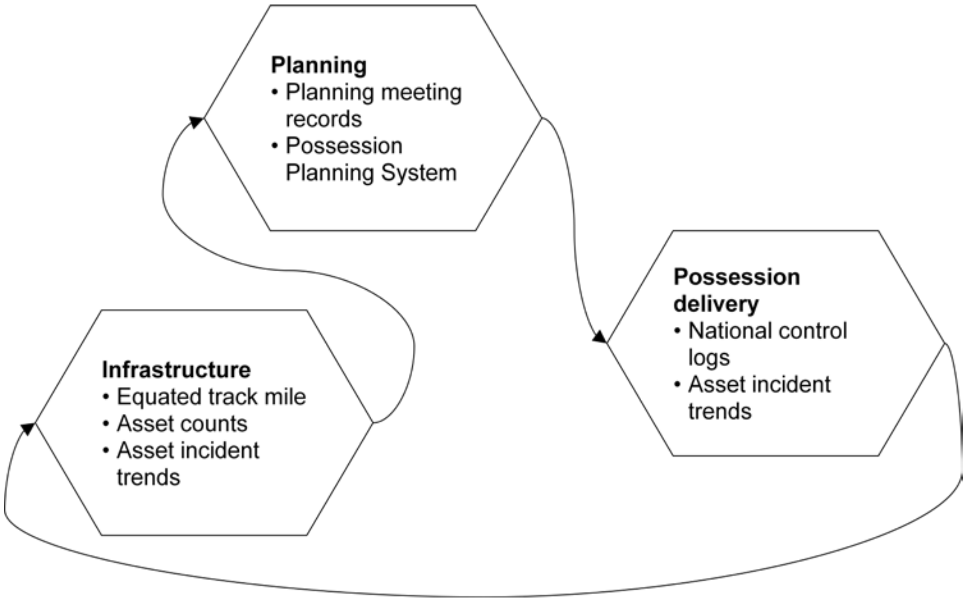


Figure 7.1: Analysis on archival data trends from a systems perspective

The bullet points under each of the three perspectives recall the data sources used. The three perspectives of analysis were depicted as FRAM functional units (section 4.11.2) as in fact each focuses on system components that could be viewed as functions within the scope of a “FRAMing”. This is also in line with the system framework given in Figure 4.1 (section 4.1) and the interactions represented between planning, work delivery and infrastructure. In a simplistic way and from a high system level, these could be explained as follows:

- Planning aggregates the targeted work packs, aiming to match the available resources (including access) and outputs a plan for delivery. Planning mediates the relation between the infrastructure and work delivery, as it balances the requirements of the infrastructure in terms of engineering work against the available resources to deliver it.

- Possession delivery puts this plan into practice and makes access to the infrastructure operational. The infrastructure shapes the service that Network Rail provides to its customers.
- An operational rail infrastructure is the core of the service provided by Network Rail to its customers and thus, indicators on its engineering characteristics and asset performance constitutes a source of feedback in terms of the required engineering interventions.

Exploring these system interactions is expected to contribute to a better understanding of resilience in the planning of engineering work.

Two additional sections discuss archival data aspects relevant for the understanding of resilience in planning. Section 7.2.4 presents a qualitative summary of all the archival data analysed and concludes on different trends exhibit by the geographical areas that supported the comparison of data. The Christmas 2007 possession overruns were earlier discussed in section 6.2.3 as demonstrating a number of behaviours of the engineering system under particularly high business and production pressures. The events presented in section 6.2.3 are recalled in section 7.2.5 to support a discussion on sources of resilience in planning and in the broader engineering system.

7.2.1. Relations between planning and delivery

The planning data analysed revealed a considerable degree of variability, as discussed in section 5.3. This variability was expressed not only by the variation of indicators for each area throughout the three weeks of data analysed, but also by the distinct patterns of each area in terms of volumes of change and duration of planning. As discussed in section 3.1.5, variability in system operations constitutes a major source of uncertainty, which is also consistent with the comments of planners provided during the semi-structured interviews in this regard (sections 5.2.3 and 7.1.5).

Data regarding possession delivery gave way to the identification of different planning related causal factors and the characterisation of their contribution to possession failures. For 27% of the incidents analysed by means of control logs, planning was found to be a main cause (first level of coding). The interpretation of events carried out on the base of the second level of coding found evidence of planning related issues on 73% of the incidents. Worksite planning was identified as the most significant issue affecting delivery. Worksite related issues were recognised in 47% of the incidents occurring within the period of three months, which represents 74% of all planning related issues identified. The analysis of planning meeting minutes and PPS data (section 5.3) showed that worksite planning is the most significant source planning changes, affecting also the volume of change at possession planning level. Because planning changes are at the core of planning variability and its resulting uncertainty, it is likely that planning uncertainty considerably contributes to delivery failures.

As mentioned in section 6.2, it should be taken into account that differences between areas in terms of the incidence of possession failures may be influenced by the volume and type of work planned by each area. In order to verify this, Table 7.1 presents the number possession incidents registered by the asset incident trends database (totals from Table 6.3) against the estimated volume of work planned by each area (based on the estimation of the number of WS from Table 5.6).

Table 7.1: Possession incidents per number of WS planned

	Possession incidents	Estimated volume of work planned in WS	Incidents / volume of work in WS (x100)
Western	46.5	916	5.1
Wessex	68.5	202	33.9
Anglia	65.2	1316	5.0
Kent & Sussex	88.8	525	16.9
Scotland	14.4	1570	0.9
LNW (S)	78.7	1331	5.9
LNW (N)	57.0	3353	1.7
LNE (S)	40.4	267	15.1
LNE (Central)		693	5.8
East Midlands	36.5	512	7.1
LNE (N)	34.9	353	9.9

While Scotland is clearly the area with the lowest rate of incidents per worksite (0.9), Wessex stands out as the one with the highest rate (33.9), with a difference of more than double the second highest rate (Kent & Sussex with 16.9 incidents per 100 WS). Data in Table 7.1 suggests that differences in the rate of incidents per WS are mostly generated by differences between areas regarding the volume of work planned. The variations of the volume of work are considerably higher than those of the number of incidents as can be seen by the standard deviation of both parameters. While possession incidents have a standard deviation of 21.9, the estimated volume of work registered a standard deviation of 907.1.

Figure 7.2 shows the plotting of the number of possession incidents against the estimated volume of work planned, in order to illustrate the differences between areas.

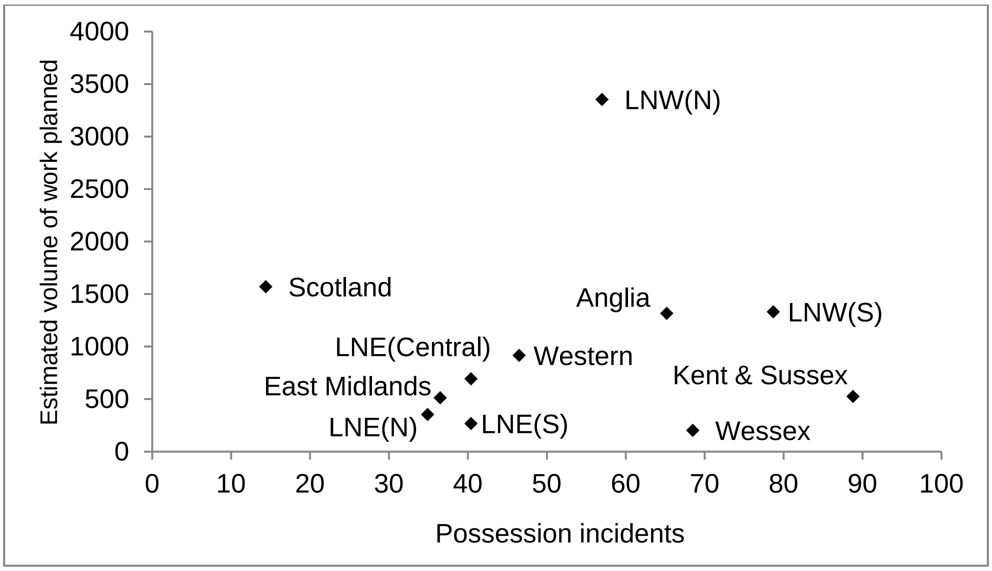


Figure 7.2: Relation between possession incidents and volume of work planned

LNW (N) area shows a clearly different pattern than the remaining areas, mostly due to the volume of work it plans. Above all, Figure 7.2 indicates that the fact that an area plans for (and delivers) a higher volume of work does not necessarily mean that it is also subject to a higher rate of possession incidents.

Regardless of the type of changes and the way these are integrated into planning, an increasing number of changes can impact negatively on the robustness and coherence of any given plan. As planners commented during the interviews (section 5.2.3), the initial plan can be compared to a puzzle in which pieces fit together. As changes are brought in, pieces (work packs in this case) are likely to become less adjusted to each other. Thus, a higher volume of planning changes would likely decrease the quality of planning and increase its contribute as a causal factor in the occurrence of possession failures. In order to investigate this, the incidence of possession failures was plotted against volumes of planning changes. Throughout these comparisons, no areas were identified as having a pattern that outstood from the remaining areas and no other clear trends were visible. As shown in Appendix 5, PossMan is used to manage a considerable number of changes made during the last stages of planning which may not be captured in PPS and thus, not reflected in the data under analysis here. Nevertheless, as shown in Figure 7.3, the number of possession incidents appears to slightly increase with the volume of worksite changes registered in PPS.

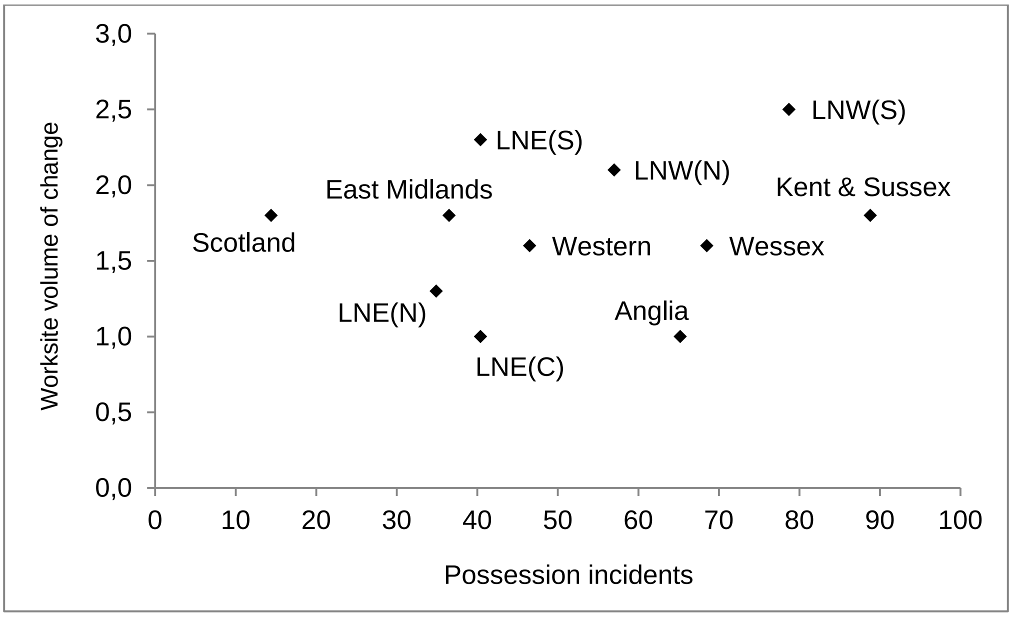


Figure 7.3: Relation between possession incidents and the overall volume of worksite changes

As earlier mentioned, the type of worked planned was also considered as a factor likely to influence this relation. Work on structures such as tunnels involves higher risks and degrees of complexity than work on open plain line. Similarly, major investment projects which must be delivered according to strict schedules and sequences of work is normally subject to higher deliverability risks than isolated maintenance work. Hence, areas with higher concentrations of major projects or structures work would be likely to register higher numbers of possession incidents. Although data does not offer evidence to support this influence of the type of work over the occurrence of possession incidents, the following remarks can be made from the breakdown by categories of the type of work planned shown in Table 5.8 (section 5.3.5):

- There are four areas with 15% or more work under the category of “stations and other structures work”. Two of these areas are locate in southern regions of the country and register some of the highest numbers of possession incidents (Wessex and Kent & Sussex) The other two areas are locate in the north region of the country and register some of the lowest numbers of possession incidents (East Midlands and LNE (N)).
- LNW (S) is the area with the highest percentage of planned work under the categories of “major projects” and “related work” and registers an incidence of possession failures only inferior to Kent & Sussex.
- Wessex was both the area registering the highest number of worksites dedicated to asset inspection and patrolling work (40% as shown in Table 5.8) and the one with the highest number of incidents on the category of “track patrols and related possessions”, as shown in Table 6.3, section 6.2.2 (44.5 incidents).

7.2.2. Relations between infrastructure and planning

Data on asset and infrastructure trends also revealed a strong variability, as clearly illustrated in Figure 6.1 (section 6.3.1). Given that the observed variability extended beyond the periods of the year during which severe weather conditions could account for increased numbers of incidents, it can be assumed that, apart from weather conditions, other factors contribute significantly to this variability. The information available regarding train timetables does not suggest variations in traffic throughout the year, which could justify an increase in asset wear out and therefore, a probable increase on asset incidents.

The ETM numbers together with the asset counts provided a useful understanding of several aspects contributing to the complexity of the infrastructure. From one hand, earlier in section 6.3, Figure 6.2 showed the relation between the infrastructure profile and the incidence of asset failures. Areas with higher ETM tended to register higher numbers of asset incidents. On the other hand, as discussed in section 4.9.1, the asset incidents investigated (apart from the three possession delivery incidents discussed in section 6.2.2) were the ones likely to impose some kind of emergency response from maintenance and therefore, impact on planned work. This section explores the possible impacts of these different trends of the infrastructure on the planning performance of each area. Table 7.2 recalls the data used for this analysis (estimated volume of work planned from Table 5.6 in section 5.3.4 and infrastructure data from section 6.3). Rates of volume of work planned by ETM and incident are also shown to illustrate differences between areas.

Table 7.2: Asset incidents per ETM and per number of WS planned

	Asset incidents (average for periods 4, 6 and 9)	ETM	Estimated volume of work planned (in WS)	Volume of work / ETM	Volume of work / Incidents
Western	405.3	3485	916	0.26	2.26
Wessex	218.7	1606	202	0.13	0.92
Anglia	274.3	1695	1316	0.78	4.80
Kent & Sussex	343.7	1997	525	0.26	1.53
Scotland	349.7	2606	1570	0.60	4.49
LNW (S)	425.7	2789	1331	0.48	3.13
LNW (N)	429.7	2808	3353	1.19	7.80
LNE (S)	300.3	1208	267	0.22	0.89
LNE (Central)		1014	693	0.68	2.31
East Midlands	148.0	1424	512	0.36	3.46
LNE (N)	354.7	2203	353	0.16	1.00

LNE (S) and Central are the areas with higher rates of incidents per ETM, with considerable differences from the remaining areas. Despite having one of the highest numbers of incidents, Western area shows one of the lowest rates of incidents per ETM, as it also has the highest number of ETM with a considerable difference from the remaining areas. Regarding the estimated volume of work planned, the rate of volume of work planned per incident registered by the LNW (N) area shows the clearly different trend of this area in terms of volume of work.

To better illustrate differences between areas, Figure 7.4 shows the plotting of the estimated volume of work planned against both the number of asset incidents and ETM.

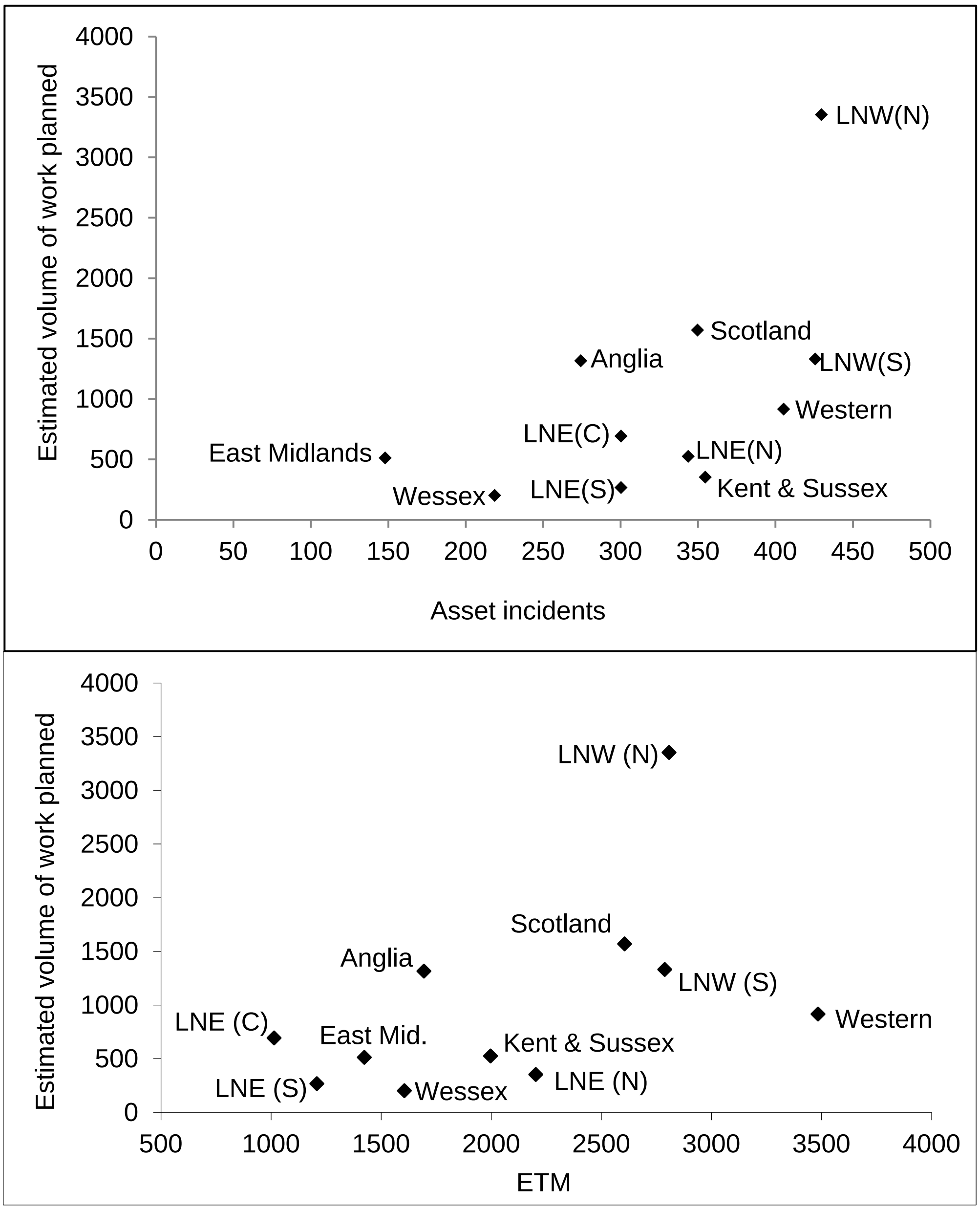
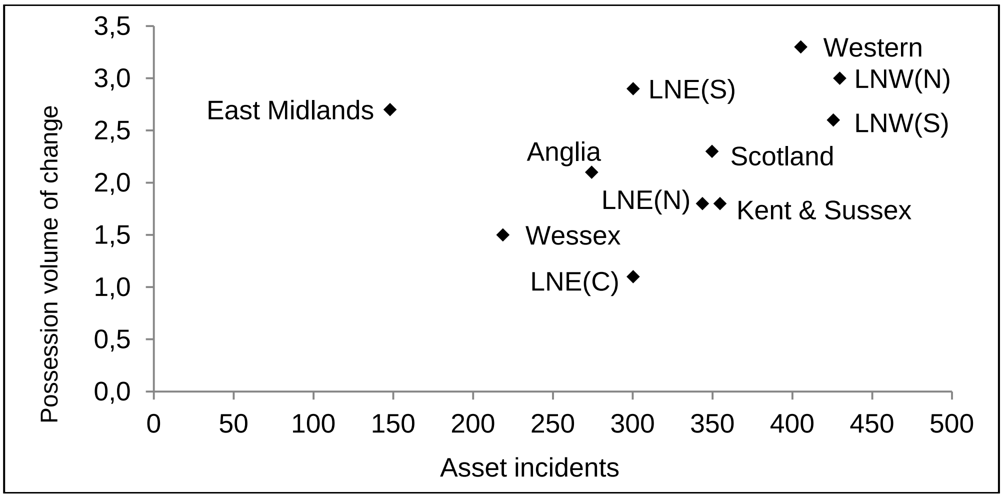


Figure 7.4: Relation between ETM and volume of work planned

Figure 7.4 suggests a slight tendency for areas with higher incidence of asset failures to register higher volumes of work planned. Although it can be assumed that the more incidents one area experiences, the more (emergency) repairing work it will have to undertake, it should be kept in mind that, as mentioned in section 2.3.4, there is a considerable volume of work that is delivered under T2 protection arrangements and thus, does not follow the planning process and protection arrangements of T3 possessions. For instance, work to secure damaged sets of points and regain train operations as quickly as possible, is likely to be carried out under such T2 arrangements.

From one hand, proportionally to other areas, Western appears to plan for less work when compared to its number of ETM. On the other hand, LNW (N) is one of the areas with the highest ETM but the volume of work it plans follows a considerably different pattern. This suggests that planning in the LNW (N) area responds to different demands than in most areas. While having a similar number of ETM, LNW (S) registers a much lower volume of work planned than LNW (N). The considerably lower asset numbers and standard mileage of LNW (S) (section 6.3.2), together with the work involved in the West Coast Main Line Modernisation Programme (Schock, 2010) ongoing in the LNW (N) area, may be the cause of this trend.

The need to carry out emergency repairing work on the infrastructure, like responding to unforeseen delivery needs, was pointed out during the interviews as a cause for frequent planning changes (section 5.2.3). Hence, the occurrence of asset incidents is likely to be reflected in the volume of change registered by each area. This was explored by plotting the asset incidents against the volume of change for both possession and worksite planning (Table 5.6 and Table 5.7), as shown in Figure 7.5.



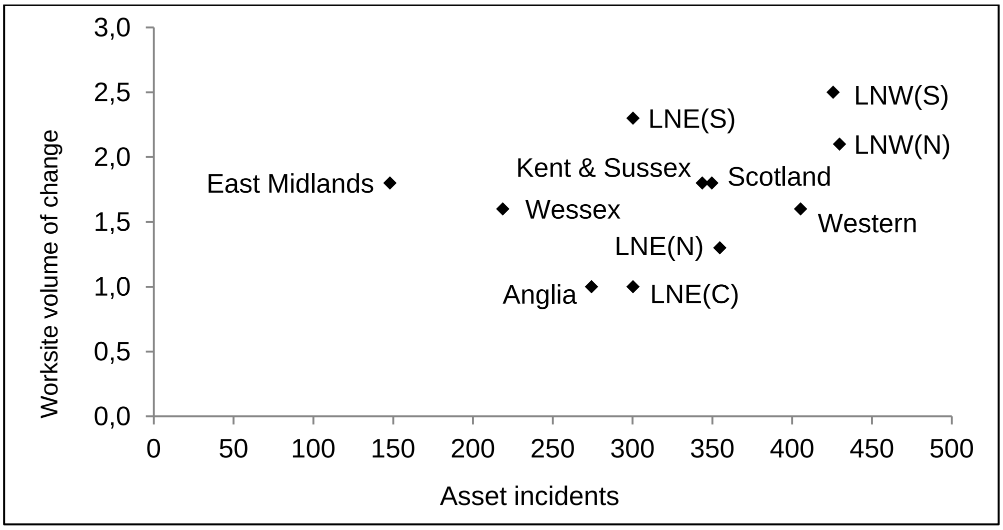


Figure 7.5: Relation between asset incidents and the overall volume of possession and worksite changes

East Midlands clearly stands out for its considerably lower number of incidents. As shown in Figure 6.1 (section 6.3.1), this area exhibits this trend in all periods of the year 2008/2009. In particular regarding possession planning, Figure 7.5 suggests that the volume of change is related to the incidence of asset failures, as areas with higher numbers of incidents also tend to register higher volumes of change. Keeping in mind that planning changes are at the origin of planning variability and uncertainty, from a systems perspective, this would indicate that unforeseen events related to asset performance are a source of variability and uncertainty in planning.

7.2.3. Relations between delivery and infrastructure profile

The analysis of control logs (section 6.2.1) revealed that the damage of assets such as points (points being run-through) and signalling cables, was one of the main causes for possession incidents (32% of the incidents analysed). It was also possible to realise that these incidents often resulted in a possession overrun and in some cases, the need for future interventions to complete repairing work. Hence, areas in which such incidents are more frequent are likely to, not only register higher numbers of possession overruns, but also require more frequent unplanned access to carry out or complete repair work to damaged assets. This could be considered a source of additional pressure on the available access, which is often deemed insufficient to respond to planned cyclic maintenance needs. Within this frame of mind, areas with higher incidence of damage to assets during possession delivery are likely to experience more difficulties in responding to maintenance work demands, which could be reflected in a general poorer asset performance. This is explored in this section by investigating possible relations between the number of possession incidents caused by damage to assets and the number of asset incidents.

The data used for the study of this relation is recalled in Table 7.3. The breakdown by route of the incidents identified during control logs analysis is shown against asset incidents. Given the low amount of data from control logs, which provides little grounds for discussion, Table 7.3 also shows possession overruns from the asset incident trends database (from Table 6.3 section 6.2.2), although this requires contemplating the fact that the overruns registered in this database have other causal factors beyond the damage to assets.

Table 7.3: Possession incidents against asset incidents

<table>
<tr><th></th><th>Possession incidents from control logs (by route groups)</th><th>Possession overrun and related faults (average for periods 4, 6 and 9)</th><th>Asset incidents (average for periods 4, 6 and 9)</th></tr>
<tr><td>Western</td><td>3</td><td>30.0</td><td>405.3</td></tr>
<tr><td>Wessex</td><td>3</td><td>17.3</td><td>218.7</td></tr>
<tr><td>Anglia</td><td>0</td><td>29.3</td><td>274.3</td></tr>
<tr><td>Kent & Sussex</td><td>1</td><td>27.3</td><td>343.7</td></tr>
<tr><td>Scotland</td><td>1</td><td>16.3</td><td>349.7</td></tr>
<tr><td>LNW (S)</td><td rowspan="2">3</td><td>39.7</td><td>425.7</td></tr>
<tr><td>LNW (N)</td><td>29.7</td><td>429.7</td></tr>
<tr><td>LNE (S)</td><td rowspan="4">6</td><td rowspan="2">22.7</td><td rowspan="2">300.3</td></tr>
<tr><td>LNE (Central)</td></tr>
<tr><td>East Midlands</td><td>13.7</td><td>148.0</td></tr>
<tr><td>LNE (N)</td><td>22.7</td><td>354.7</td></tr>
</table>

Overall, areas with higher numbers of possession overruns appear to also register higher numbers of asset incidents. The two areas with higher numbers of possession overruns are also the ones with higher incidence of asset failures (LNW (S) and Western). Conversely East Midlands registers the lowest number of overruns and also the lowest number of asset incidents. Figure 7.6 plots possession overruns against asset failure to illustrate this relation.

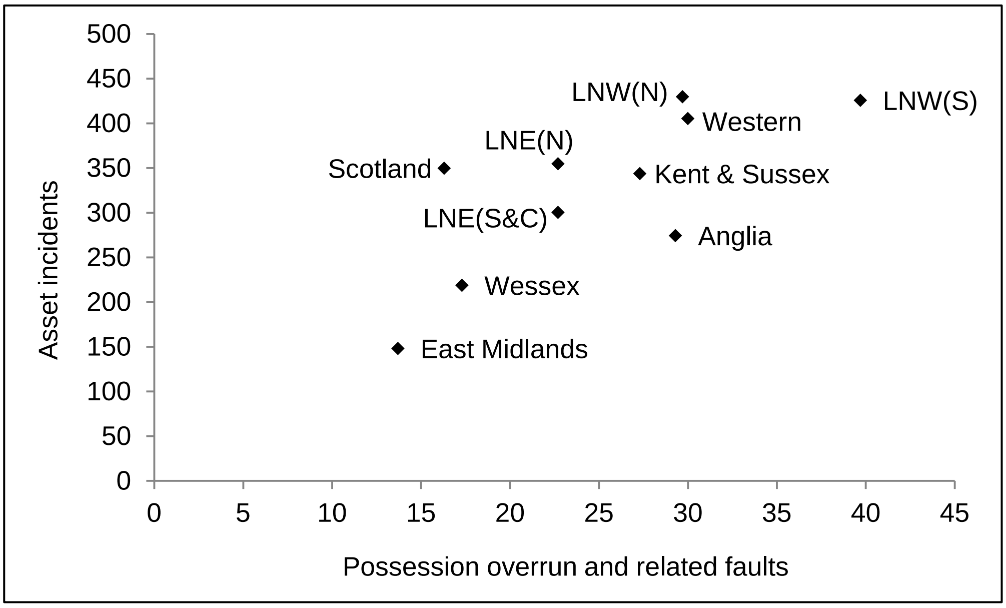


Figure 7.6: Relation between possession overruns and asset incidents

Figure 7.6 suggests a strong relation between the number of possession overruns and the number of asset incidents. A correlation factor of 0.738 was found between these two parameters, which also supports this conclusion. Because the overruns registered by asset incident trends database contemplate other causes than the damage to assets, this suggests that more broadly, areas that performance worse in terms of delivery tend to have poorer asset performance. However, based on the analysis of control logs, damage to assets can be considered one of the main causal factors for the possession overruns illustrated in Figure 7.6.

7.2.4. Area comparison

The main geographical structures used for this analysis were the WON areas. Table 7.4 summarises the main characteristics found for each WON area based on all the quantitative data produced. Whenever no relevant interpretation could be produced from data, the corresponding box in this table was left empty.

Table 7.4: Characterisation of WON areas based on quantitative data analysis

WON	Planning performance	Delivery performance	Infrastructure and asset trend
Western	Highest overall volume of change and longest duration of planning Clearly different trend from other areas	Considerably high number of possession failures but no evidence of planning related causes	One of the highest total number of incidents, and points failures Highest number of ETM One of the highest total number of assets with a considerably Higher number of tunnels
Wessex	Lowest level of planning activity Lowest number of WS per Pos, duration and volume of change Starts and closes planning the soonest	Highest number of patrolling possession incidents	One of the lowest numbers of incidents registered, in particular no TSR caused by condition of track Considerably high number of corner gauge cracking
Anglia	Highest volume of project work but no related work is registered (survey, preparatory or follow-up work)	One of the highest number of incidents, particularly for Pos overruns	Contrary to all the southern areas, Anglia has 12.2 TSR per period caused by track condition, together with the highest infrastructure mishaps and highest number of electrical problems
Kent & Sussex	One of the lowest volumes of change to Pos details and numbers of WS per Pos Shortest WS planning duration		Highest number of weather related incidents One of the highest numbers for track and trackside assets (signals, track circuits, TPWS, IBJ and points op. equip.) Highest number of assets per mile
Scotland	Shortest duration of Pos and WS planning (latest start and closing of planning) One of the highest numbers of Pos published but a below average number of WS per Pos Highest volume of patrolling and inspection work planned	Considerably lower numbers of incidents across all the three categories analysed	One of the highest numbers of weather related incidents and signalling system and power supply failures

LNW (S)	Similar trend to Scotland except for one of the highest numbers of WS per Pos Highest overall WS volume of change	Engineering area with highest number of incidents, particularly for patrolling	Highest total number of incidents motivated mostly by points, OLE and track circuit failures
LNW (N)	Highest level of planning activity Highest volume of change to Pos details Highest number of WS and WS per Pos with considerable differences from other areas	Average numbers of incidents	One of the highest total number of incidents Highest number of signal failures and one of the highest for track circuit failures Highest total number of assets and across most types
LNE (S)	One of the longest durations of Pos and WS planning together with one of the highest overall volumes of change to both Pos and WS, and also on the highest volume of changes to WS details One of the lowest numbers of Pos published On average, only one WS per week for patrolling and inspection work		Highest number of TSR together with one of the highest numbers of track faults (for LNE S & Central) Lowest number of assets
LNE (Central)	Lowest overall volume of change to Pos and WS One of the earliest closing of WS planning		Lowest number ETM and standard miles
East Midlands	Latest closing of WS planning with an averagely duration (tends to plan late in the process) One of the highest volumes of structure work and non-asset related work	Despite a considerable number of patrolling related incidents, registers lowest number of overruns and work left incomplete	Considerably lower numbers for points, signal and track circuit failures and lowest overall number of faults Engineering area with lowest ETM
LNE (N)	Lowest number of Pos published	Lowest number of patrolling incidents	Highest number of TSR, track faults and signalling systems failures and highest number of mishaps related to infrastructural causes

Table 7.4 demonstrates that each area has a different planning performance trend, even when showing similar demands from the infrastructure or similar work delivery requirements. From this perspective, each area seeks to balance their demands and constraints, namely their resource limitations, according to different factors. The following trends were considered relevant as evidence of the different balances that each area is required to manage:

- As shown in Table 6.7 (section 6.3.2), **Western** registers a considerably higher number of tunnels than other areas (409 tunnels against 247 of LNW (N), which has the second highest number). As illustrated in Figure 5.1 (section 5.3.4, Western also stands out in terms of overall volume of change and duration of planning for possessions. Moreover, Western has the highest number of ETM but Figure 7.4 (section 7.2.2) shows it plans for a relatively low volume of work when compared to other areas. Above all, tunnels represent an important limitation and constraint for engineering access. Thus, the infrastructure profile (and the limitations it imposes) may have more severe impacts on planning, rather than the total number of assets or their concentration.

- **Wessex** shows evidence for the lowest level of planning activity, which may indicate fewer constraints in terms of available access in view of the work planned. Wessex also closes their planning considerably sooner than other areas. On average, no changes to possessions are registered after 17.2 weeks before delivery, and for worksites, this average is 24.2 weeks. This area registers the highest number of possession incidents, in particular, patrolling incidents. LNW (S) delivers on average the double of the patrolling and inspection work whilst registering a slightly lower number of incidents in this category. As commented during the interviews, one of the causes for maintenance requesting late changes is the need to comply with their patrolling and inspection requirements. This suggests that either Wessex area is refusing to integrate such changes or they are not being formally registered in PPS. In any case, this appears to produce a significant impact on the delivery, which suggests that the planning output produced by the Wessex area is not responding adequately to the delivery needs.

- According to the asset incident database, **Scotland** registered a considerable lower number of possession incidents than other areas and fewer planning related issues were revealed by control logs. In terms of planning, Figure 5.3 (section 5.3.4) demonstrates that Scotland publishes as many possessions as LNW (N) but only close to half the worksites, which indicates that Scotland tends to plan less worksites per possession. In addition, despite an average volume of change to possessions, Scotland has the shortest duration of planning. This suggests that by planning less complex possessions, Scotland uses a shorter time window for planning and potentially contributes to a more successful delivery. However, a graphical representation of the relation between the number of worksites per possession and the number of possession failures shows no evident trend.

- Contrary to Wessex, the **LNW (N)** area demonstrates the highest level of planning activity, together with the highest volume of work planned and a considerably low number of possession incidents. In terms of possession delivery, although control logs show that at route level, LNW registered the highest number of incidents, asset incident trends indicate that this is mostly due to the high numbers verified in the southern area rather than the northern one. Despite no apparent impact on delivery, LNW (N) registered one of the highest numbers of infrastructure incidents but according to Figure 6.2 (section 6.3.2), this is well within the trend demonstrated by the remaining areas. This suggests that planning output produced by the LNW (N) area might be successfully supporting delivery needs.

Areas such as LNW (N) where more significant access limitations may exist in view of the volume of work to be delivered, also tend to show higher levels of planning activity. Such areas attempt to plan for a maximum of work within each access opportunity, which results in larger possessions. This means that more adjustments will tend to be made to each worksite and possession, as conflicts between items have to be dealt with. When comparing with the performance pattern of Scotland, data suggests that fewer worksites per possession may lead to a more reliable planning, as Scotland also registered lower numbers of possession incidents and fewer planning related issues. Overall, LNW (N) and Scotland show characteristics of a more “positive” planning performance than Wessex, as these two areas appear to better manage planning changes and thus, to better support work delivery.

From a resilience perspective, and taking only into consideration the management of planning changes, the characteristics presented by LNW (N) may be consistent with higher potential for resilience (Hollnagel & Woods, 2006). Despite generating higher volumes of change, this area plans for more work whilst appearing to produce a reliable output for delivery. This could be interpreted as an adequate balance between the need to reject changes that might affect delivery and integrating those that could improve allocation and utilisation of resources.

7.2.5. Resilience indicators from Christmas 2007 overruns

As stated in section 6.2.3, the facts extracted from the report issued by the Office of Rail Regulation (ORR, 2008) have clear implications for the understanding of resilience in planning and the overall engineering system. Recent resilience engineering literature introduced four main capabilities as a support for the measurement of resilience (Hollnagel 2011b). The definitions of these capabilities, as argued throughout section 3.4.6, incorporate many of the resilience concepts also given in the literature. These capabilities were used to support the interpretation of the facts extracted from the ORR report from a resilience perspective. This is in line with the approach proposed by Woods & Branlat (2011) regarding the assessment of resilience through the study of the history of adaptation of a system.

Table 7.5 shows the facts found to be related to each of the four capabilities. For each capability the table is structured as follows:

- The first line recalls the definition of each capability
- Second line introduces the facts which were found to erode that capability.
- The third line of each table introduces the facts which potentially contributed to reinforce that capability.

This approach provides an overview of both “what went wrong” and “what went right”, which is in line with the notion that undesirable outcomes are the “flipside” of success (Hollnagel, 2006). Some of the facts extracted have clearly impacted across more than one or even across all capabilities.

In order to maintain a comprehensive structure of the analysis, each piece of information was singly linked to the capability to which it related more closely.

Table 7.5: Facts from ORR report related to the four main resilience capabilities

<table>
<tr><td colspan="2">Knowing what to do
Ability to address the “actual” and respond to regular or irregular disruptions by adjusting function to existing conditions</td></tr>
<tr><td>Facts eroding capability</td><td>• By endeavouring to avoid a blockade extension, Network Rail came to consider that decision too late (T-3) for a proper formal discussion with stakeholders
• The 12 weeks required by process could never have been met, but decision could have been addressed at least 1 week earlier
• Only after 3 consecutive weekends of lost work Network Rail came to that decision
• Informal working level discussions took place on several occasions but never developed into a formal and precise information
• Inadequate response to a considerable risk of delivery failure identified by the SQRA (Schedule Quantitative Risk Assessment) even before previous weekend possessions were lost
• Management of shift changeovers was inadequate and, other than the correction of the shift change misalignment for the machine controllers, no action appears to have been taken to rectify the problem
• Blockade overran for about 14 hours before a state of operational incident was declared and a “Gold Command” instated</td></tr>
<tr><td>Facts reinforcing capability</td><td>• As Overhead Line Equipment (electrification) staff shortage was detected over the initial 2 days of the blockade, Network Rail re-planned the work to create additional time for the OLE work and sought to obtain additional staff
• As it became clear to the project team that the contractor was not on course for delivery, several planned and real-time contingencies were put in place</td></tr>
<tr><td colspan="2">Knowing what to look for
Ability to address the “critical” by monitoring both the system and the environment for what could become a threat in the immediate time frame</td></tr>
<tr><td>Facts eroding capability</td><td>• No SQRA was undertaken prior to applying for the additional day
• The SQRAs carried out were based on the assumption that weekend works to be delivered throughout November and December would be completed successfully and on time
• In addition to OLE staff shortage, a lack of contractor’s supervision on site had severe impact on its productivity
• The way in which contractors communicated with staff agencies and how they attempted to secure additional OLE staff was unclear
• Reports from contractors on work progress were increasingly inaccurate and undermined the seriousness of shortfalls
• Network Rail engineers were unable to properly monitor the situation as their attention was diverted to other pressing problems
• The fact that train operators were getting informal indications of problems through control centres at an earlier stage demonstrates the existence of indicators which were not being properly monitored</td></tr>
</table>

Facts reinforcing capability	• SQRA recognised that work was sequential and therefore, delays to the early activities would have a knock on effect on the succeeding activities • The readiness-reviews were well structured and identified key risks (i.e. availability of key staff for both the signalling and OLE works) • Information from contractors advised on difficulties in securing the required level of resource
Knowing what to expect Ability to address the "potential" longer term threats, anticipate opportunities for changes in the system and identify sources of disruption and pressure and their consequences for system operations	
Facts eroding capability	• OLE resource shortfalls were already partly responsible for the deferral of work from previous weeks into the blockade • The level of absence verified during this blockade had not been experienced before • Several times the blockade plan was re-configured to deliver an on-time hand back but this continued to rely on remaining OLE staff reporting for duty, supplemented by extra OLE staff from other contractors and Network Rail OLE maintenance staff • Despite resourcing problems Network Rail continued to rely upon the common practice of allowing contractors to self-certify their own work • Network Rail should have done more to test the sensitivity of its assumptions in SQRAs i.e. for the completion of preparatory work and taken appropriate mitigation measures • TOCs complained that it appear to be no one in overall charge or taking an overview • The difficulties from contractors in securing the necessary resources together with the criticality of the work should have driven the provision of a higher level of supervision during the blockade which would have helped Network Rail to predict and to minimise the extent of the over-run
Facts reinforcing capability	• Programme management expertise and its application was deemed as "impressive" and appropriate for the project • An allowance of +20% was considered as a contingency for the duration of works • Network Rail requested from contractors the names of key people rostered for each work to be delivered and checked for double bookings of staff • Network Rail reviewed all national planned OLE work and cancelled lower priority work packages
Knowing what has happened Ability to address the "factual" by learning from experiences of both successes and failures	

Facts eroding capability	• Given the controversies and disruptions already caused by the blockade extension it would be expected that Network Rail management would have devoted its full attention to the delivery of the project • Weaknesses in risk assessment and risk management previously identified in connection with the overrun of the Portsmouth re-signalling project in 2007 were also present in two of the three cases investigated, each in a different part of the country and related to a different type of project • The significant de-scoping of the Annual Integrated Work Plan (AIWP) undertaken in this period is likely to have led to wasteful levels of project development and planning work. Network Rail should work with the industry to review its own planning, looking to improve both predictability and stability • Network Rail contracts should ensure that its suppliers take an appropriate share of the financial consequences of any risk to the projects, and equally share the financial rewards of success
Facts reinforcing capability	• The introduction of "Gold Command" arrangements was successful in recovering train services and communicating with operators and customers. Reviewing how and when such arrangements should be called into effect may contribute to further its effectiveness • Within a period of approximately 2 weeks Network Rail had developed a preliminary investigation and produced actions to be taken as an outcome of that investigation (The actual effectiveness of these actions cannot be demonstrated) • The need to seek an extra day for the possession at a late date, or failure to complete the work on schedule - were not believed to be caused by any significant failure of project or risk management in the weeks beforehand

Facts in Table 7.5 indicate that despite information that work delivery was not going according to plan, Network Rail was **unable to initiate appropriate responses**. There was a clear failure to revise risk assessments and operations as new evidence accumulated (Hale & Heijer, 2006b). The information on emerging problems was not properly conveyed to support corrective actions. Work was lost in three consecutive weekends before measures were taken. Informal discussions at working level had clearly gathered evidence that urgent action was needed, but this never reached higher decision making levels, which demonstrates breakdowns in the feedback information flows and control loops (Leveson, 2004). Because of such communication failures, measures taken as a response to problems (re-planning of work and deployment of contingencies) soon revealed insufficient to recover control. In fact, the possibility that control over the project had been lost appears to have been dismissed, which accounts for the efforts taken by Network Rail to avoid having to declare a failure and request an extension of the blockade. This also suggests that defences were eroded by production pressures (Hale & Heijer, 2006b).

Data shows no indication that SQRA, as a method of monitoring delivery risks, was inappropriate to the task at hand. However, the assessments carried out with this method were based on assumptions and incomplete information, which more than contributing for the lack of visibility over developments at work delivery level (Leveson, 2004), they reinforced shifts towards loss of control (Dekker, 2004). There is ample evidence that staff on the ground was overwhelmed by the numerous minor issues and problems emerging, which made them unavailable to “take a step back” and properly assess to whole picture. Problems like the derailment of an engineering train and the unexpected finding of buried services in area of the Rugby station were mentioned in the ORR report and described as manageable issues with normal capacity. Within this context reports from delivery and communication amongst stakeholders further deteriorated and, despite control centres receiving some information on problems and the indications of potential risks that came out from SQRA (namely the sequential nature of work), project teams **did not know what to look for**.

A global picture of planned work and delivery progress was never developed. As earlier discussed in section 6.4, a fragmented organisational structure is at the origin of equally fragmented information flows which “clouds” the ability of decision makers to reassess a view the “big picture” (Woods, 2006b). Neither the assessments carried out nor the information made available to planning allowed for a national and integrated view on how projects were being planned and later delivered, which led to an incremented overuse and over demand on resources. Thus, project teams and other engineering stakeholders **did not know what to expect**. As stated in the ORR report, on hindsight it was recognised that several aspects of the complexity and scale of these engineering projects had never been experienced before, namely the staff shortages and difficulties in obtaining accurate reports from contractors. Common management and monitoring practices rapidly became inadequate to the complexity of the work and no adjustments were made in time to avoid serious failure (Hollnagel, 2006).

The decision to accept the level of risk estimated by the SQRA appears to have been made on the basis of certain assumptions which might have been reasonably acceptable under normal delivery conditions. However, the real complexity and challenges posed by this project would have made those assumptions unacceptable but, as these were part of normal “way of doing things", they were not given proper consideration (Dekker, 2004).

In terms of **lessons learned**, data from the ORR investigation suggests that some of the failures experienced at Christmas could have been avoided or at least been better managed if previous opportunities for organisational learning had been seized properly (similar weaknesses had been identified in connection to other projects earlier that year). Cook & Woods (2006) present a number of factors which can work as barriers to learning. The great diversity of stakeholders involved in the facts described in Table 7.5 is likely to have generated an equal diversity of views on the causes of the incidents verified, which makes it difficult to produce a clear objective to drive organisational change towards improving and responding to the lessons to be learned (Cook & Woods, 2006). The high exposure to public and political scrutiny, pressured Network Rail to trade-off a more thorough investigation and consequent learning process, with a rapid reaction (approximately 2 weeks) to the events and its consequences (Hollnagel, 2009a).

In line with the business processes described in Chapter 2, the targets for capacity enhancements in the Rugby area had been scoped during Control Period 2 (CP2). In line with the description of the Alaska Airlines accident given by Dekker (2004) and earlier mentioned in section 3.3.5, the Christmas 2007 overruns are the result of decisions made throughout the period of several years which progressively pushed the system across safety boundaries. During the years building up to the final deadline for delivering the capacity necessary for the new timetable of 2008, as planning would come to realise that resources were not sufficient, engineering work was frequently decommissioned and pushed back for later opportunities. This has accumulated a growing volume of work to be delivered during 2007 and in particular, during the blockade of that Christmas.

7.3. Functional Resonance Analysis Method

As stated in section 4.11, FRAM was used to investigate system interactions within the planning organisation and its process flows. This section describes the experimental work developed towards the application of FRAM in engineering planning.

Given the particular interest in better understanding the planning system, the use of FRAM focused mainly on the description of functions. The study of Network Rail documentation and the contacts with planners during interviews supported the identification of functions, as well as some of their aspects, in particular the inputs and outputs. Part of this work was earlier described in chapter 2 (Research context), where the planning system was already described according to three main high level functions (access planning, possession planning and worksite planning). This line of work was then further developed through the cooperation with ongoing projects by the Ergonomics NST at Network Rail and the Rail Human Factors Group at the University of Nottingham. This work is described by Wilson *et al* (2009) and led to the identification of more detailed (lower granularity) functions.

The complexity and extent of the planning process made it unrealistic to aim for the “FRAMing” of the three stages of planning, as described in section 5.1 (long-term, medium-term and short-term). Only short-term planning was considered for this analysis, as earlier work, namely the interview processes, had confirmed this as the most relevant stage. In line with the description given in chapter 2, this corresponds to the last stages of access planning down to delivery.

Table 7.6 shows the initial high level functions considered for this analysis in relation to the lower granularity ones. The organisational units responsible for each of the functions are also shown. From the six FRAM aspects of functions, only the inputs and outputs are shown in Table 7.6. Although further work was developed towards identifying the remaining descriptors for each function, due to time constraints, only inputs and outputs were fully studied, as these were considered sufficient to pursue the stated objectives on exploratory work (section 4.2). The work in progress towards identifying the remaining descriptors is shown in Appendix 9. Following a table which details the extent of the work carried out, a graphical representation of FRAM is given.

Table 7.6: "FRAMing" of the planning system – identification of functions

High level functions	Function	Who	Inputs	Outputs
Access planning	Development of maintenance work plans	Maintenance engineering	Maintenance requirements	Maintenance detailed work plans
	Maximisation of work opportunities for maintenance	Maintenance Delivery Unit	Maintenance detailed Work plans Available resources Available access Outstanding actions	Proposed work
	Development of investments projects (MP&I) work plans	Project team	Investment plans (renewals and enhancements)	MP&I detailed work plans
Allocation of resources	Integration of maintenance and project work	Area Delivery Planning Unit (ADPU)	MP&I detailed work plans	Work approved
			Draft WON Proposed work Haulage and trains plan Outstanding actions	Work in progress
	Issue of WON	NAU on behalf of route directors	Work approved	WON
Possession planning	Development of maintenance work packs	Maintenance Delivery Unit	Proposed work	Maintenance work packs Site specific information
	Development of MP&I delivery details (work packs)	Project team	MP&I detailed work plans	MP&I work packs
			Contractors plans	Site specific information
	Haulage approval	National Delivery Service (NDS)	Work approved Haulage and trains plan	Locked-down haulage and train plan
	Deliverability and risk assessments	Project team	MP&I detailed work plans Available resources	Schedule Quantified Risk Assessment (SQRA)
			Available access Contractors plans	Other risk assessments as required
Worksite planning	Development of Possession Management Packs	ADPU	WON WON supplement	PICOP pack
		Work deliverer	Site specific information	
	Integration of emergency and late changes	ADPU	Maintenance work packs MP&I work packs	WON supplement
	PICOP briefing	ADPU	PICOP pack Site specific information	Work delivery details
Work delivery	Work delivery	Work deliverer	Work delivery details Locked-down haulage and train plan	PICOP report
	T+1 review	Maintenance Delivery Unit	PICOP report	Asset update
			MP&I hand back	Outstanding actions

Functions from Table 7.6 were then used to produce a FRAM graphical representation. The instantiation in Figure 7.7 shows links between functions based on their inputs (left-hand side of the function) and their outputs (right-hand side of the function). A colour coding was used to illustrate different categories of functions based on their role in the planning system. Figure 7.7 should be read as follows:

- Functions shown in green are those providing the main input to the system. This corresponds to the “what”, “where” and “when” of the work to be delivered.
- Functions in yellow are the core planning steps. They process the input fed by green functions, and determine according to rules and procedures, how much and what work is it safe to deliver within each access opportunity.
- Functions in red produce the output of the planning system. They gather the information necessary to support those delivering work.
- Functions in white are work delivery steps and thus, beyond the limits of the planning system. They put into practice the output of planning.
- Continuous line arrows represent the main flow of information towards delivery and dashed lines represent feedback flows.

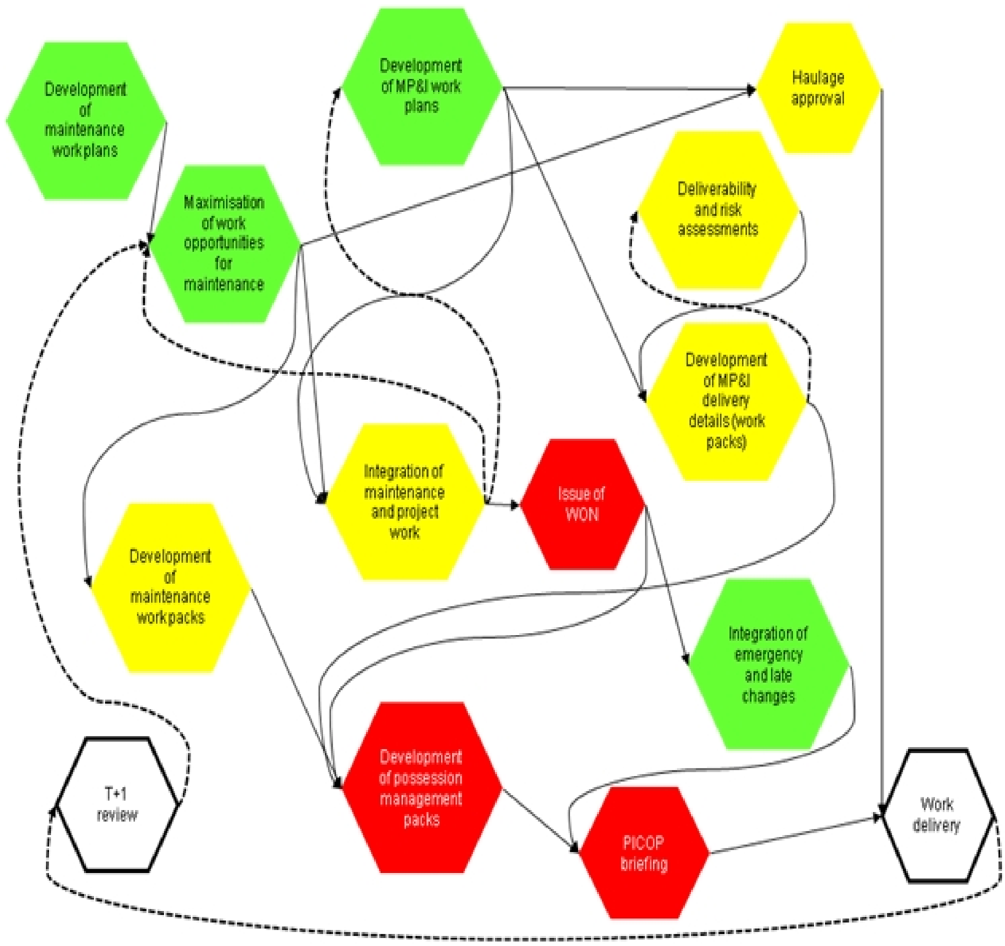


Figure 7.7: “FRAMing” of the planning system - Categories of functions and their interactions

Both Table 7.6 and Figure 7.7 describe what is formally established as the planning system. Overall, Figure 7.7 shows that little flow of information exists between the development and planning of maintenance and investments work. This is consistent with the organisational fragmentation to which planners referred to during semi-structured interviews (section 5.2), in particular regarding the organisational separation of planning between Infrastructure Maintenance and Infrastructure Investments, as described in section 2.3. Information is exchanged to integrate work approved for delivery (connection between maintenance and MP&I green functions with yellow function “Integration of maintenance and projects work”) and beyond that point, each work pack is further detailed separately (remaining yellow functions). Information on work packs is only brought together (formally) later to produce possession management packs.

The planning sequence investigated through planning meeting minutes (section 5.3.2) showed that changes affecting access are made at late stages of the process. Although a function aiming to integrate late changes and emergency needs is formally contemplated (green in Figure 7.7), its links to the remaining functions suggest that little (formal) information on such changes is provided to functions producing details of work (shown in yellow). Keeping in mind the information from the different interview processes (sections 5.1, 5.2 and 6.1) regarding the impact of late changes and the quantitative data gathered on changes (section 5.3), this function and the formal output it produces to the system appear to be insufficient to respond to the considerable volume and frequency of changes submitted.

Several references were also made during the interviews regarding the little feedback information produced by the system. The relatively low number of dashed arrows represented in Figure 7.7 illustrates this. In particular, regarding feedback on delivery, the interviews led to the belief that planning teams only receive feedback when “something has gone wrong on the night”.

Above all, the arguments here presented are consistent with the crucial role played by informal communication, as described by planners during the interviews. The high pace of change and interdependency of planning requires more flexible communication channels, which according to the outcome of interviews, planners develop through informal contacts.

7.4. Questionnaire

This section discusses the application of the questionnaire and the results of its two independent parts. General characteristics of the responding population are given beforehand. Part 1 of the questionnaire focused on the assessment of resilience factors in engineering planning, as described in section 4.10.1. Basic statistics are presented, followed by a description of the principal components analysis approach. Tests were developed to verify the reliability of data as well as its suitability for factoring. The factor extraction and the rotation methods are then discussed, as well as the approach used to interpret the chosen factor solution. Part 2 of the questionnaire provides an assessment of the aspects discussed in section 7.1. Keeping in mind how these aspects were related to resilience concepts and that planners were asked to rate them according to how these affected their performance, the purpose is to better understand the sources of resilience in the planning system.

7.4.1. Characteristics of the population

Despite the fact that several area and territory planning units did not respond to the questionnaire, the sample obtained covers most regions of the country. Figure 7.8 shows the distribution of the 105 respondents by location. For members of territory planning teams the corresponding territory is given and for members of area planning teams the WON area designation was used.

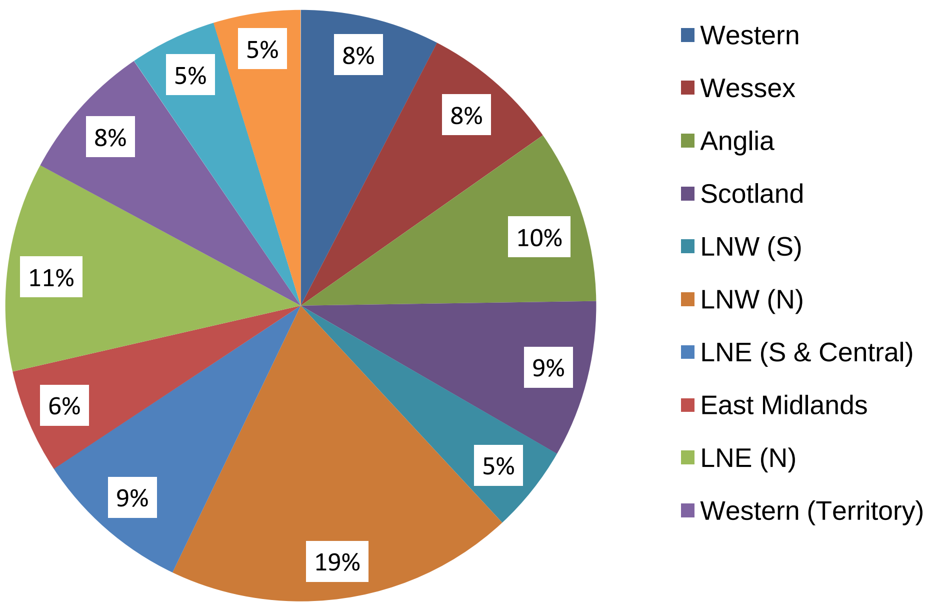


Figure 7.8: Distribution of respondents to the questionnaire by their location

Each location represents approximately between 5 and 10 percent of the sample. Only LNW (N) contributed with a considerably higher number of respondents. 20 questionnaires were completed in this area planning unit, which accounts for 19% of the sample. This can be explained by the fact that, not only this was found to be one of the largest planning teams, but also a particularly strong cooperation was obtained from its members.

The distribution of respondents by level of experience in planning is consistent with the tendency earlier observed in regard to the semi-structured interview process (section 5.2.1), as the majority of planners possesses more than 3 years of planning experience. Figure 7.9 shows the distribution of respondents by level of planning experience.

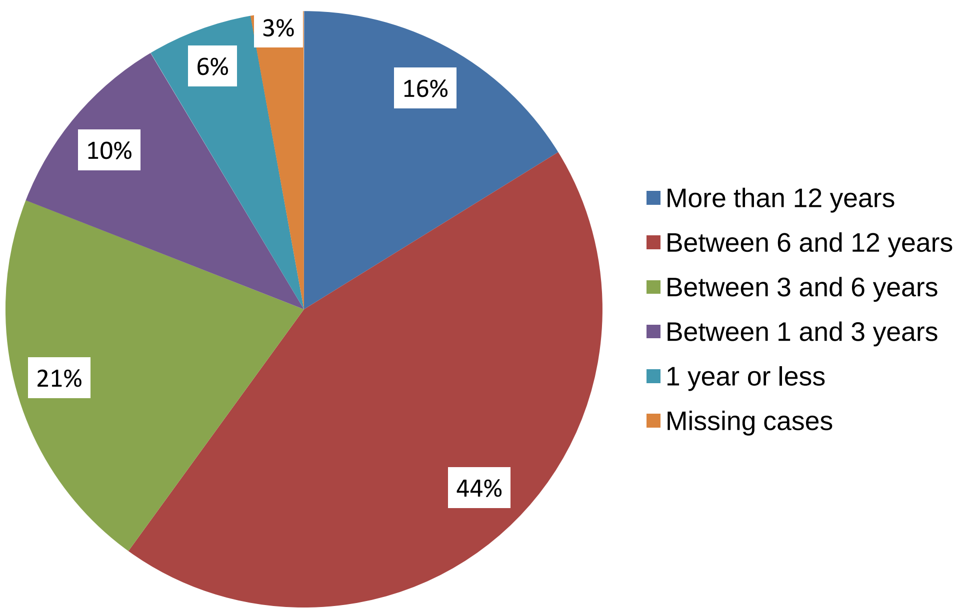


Figure 7.9: Distribution of respondents to the questionnaire by level of experience in planning

While the least experienced respondent was working in planning for a period of about 6 months, the most experienced planner had 34 years of work in planning. Based on the difference between the most experienced and the least experienced planner which responded to the questionnaire, five intervals were created for this distribution, as shown on the legend of Figure 7.9. Planners with more than three years of experience account for 81 percent of the respondents. While the majority of the planners interviewed had more than 10 years of experience, although not shown in Figure 7.9, planners with 10 years or more of planning experience represent approximately 24% of this sample.

7.4.2. Part 1 of the questionnaire

Overall, planners attributed a high score to all 22 statements, demonstrating a general agreement with the issues raised. Figure 7.10 ratings for each statement in terms of percentage of respondents. As in Figure 7.13 (section 7.4.7), absolute numbers of respondents for scores 5 and 6 are labelled on the graphic.

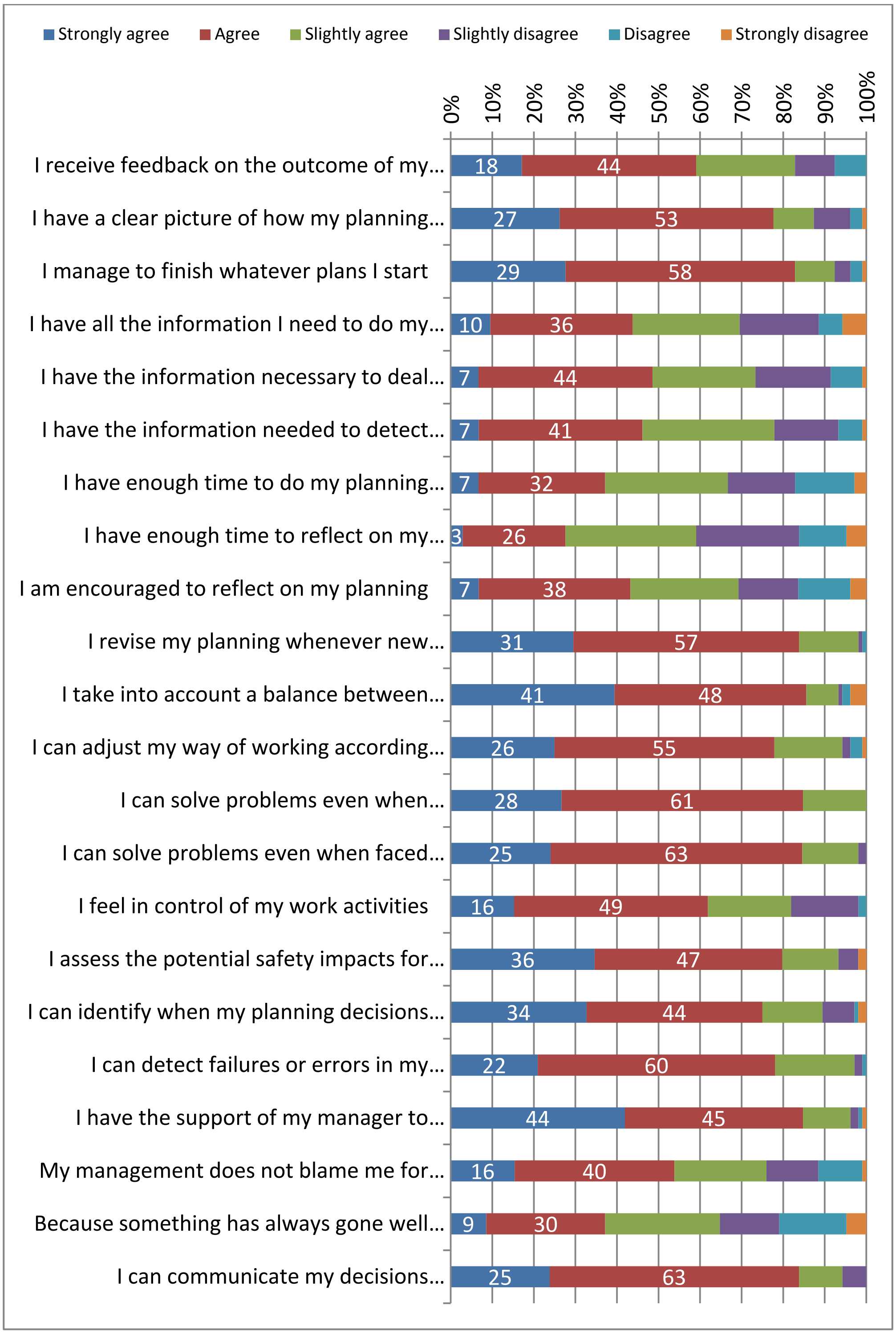


Figure 7.10: Ratings for part 1 of the questionnaire by percentage of respondents

Overall, the data shows a clear shift towards scores 5 (agree) and 6 (strongly agree). The large majority of statements were rated as 5 or 6 by more than 40% of respondents. Statements were rated as “strongly disagree” by considerably lower numbers of respondents. Although not shown in Figure 7.10, “I have all the information I need to do my work” was the statement with the highest number of “strongly disagree” responses (6 respondents).

The statement “having enough time to reflect on my planning” obtained the lowest number of scores 5 and 6 (29 of the 105 respondents for both scores). Although the statement regarding “having enough time to do my planning thoroughly” was rated with scores 5 and 6 by 10 more respondents (39 in total for both scores), both statements were interpreted very similarly, as ratings on both statements were found to be strongly correlated. A correlation of 0.762 was found between these two items for a level of confidence of 0.01 (p=0.711), which constitutes one of the highest inter-item correlations found for this set of data. Most planners might feel that in order to plan thoroughly, they also require time to reflect on it and thus these statements were interpreted in very similar ways.

The statement “being encouraged to reflect on my planning” registered a considerably higher percentage of scores 5 and 6. Although a significant correlation was found between statements “having enough time to reflect” and “being encouraged to reflect” (0.475 significant at the 0.01 level), the different distribution of scorings suggests that planners, despite recognising some encouragement to reflect on their work, feel that they do not always have time to do so.

The highest concentration of scores 5 and 6 were registered on the following statements:

- I manage to finish whatever plans I start (87 respondents)
- I revise my planning whenever new information arises (88 respondents)
- I take into account a balance between safety and efficiency in my planning decisions (89 respondents)
- I can solve problems even when pressured to deliver fast results (89 respondents)
- I can solve problems even when faced with unexpected situations (88 respondents)
- I have the support of my manager to make decisions (89 respondents)
- I can communicate my decisions promptly to those that rely on them (88 respondents)

All the previous statements were rated with either “agree” or “strongly agree” by more than 80% of respondents. When considering the contents of these statements, it appears that they all tend to focus on aspects which planners might take for granted during their normal activities. Finishing their plans, revising them, taking into account safety and efficiency needs, solving problems regardless of constraints, having managerial support and having to communicate promptly, are all aspects that can be considered as everyday requirements of being a planner. These might be aspects of a more constant nature than the remaining ones. Conversely, the rating of other statements such as for instance, having all the information needed, “having enough time” or “receiving feedback”, on which average scores were lower, might have been judged by respondents as aspects that tend to vary in time and therefore are less constant in their daily activities. This could also account for the fact that, as previously mentioned, the statement “I have all the information I need to do my work” registered a higher number of “strongly disagree” responses.

7.4.3. Data suitability for factor analysis

Principal components analysis is based on the study of correlations between items. Thus cases with any missing data had to be excluded from the process. Of the initial 105 cases 7 were excluded on this basis.

Skewness and Kurtosis tests were run to verify the distribution of each variable. Ferguson & Cox (1993) recommend +/- 2 as a cut-off value for both Skewness and Kurtosis. Although Skewness values suggested no need for dismissal of variables, six variables presented Kurtosis values above 2. Ferguson & Cox (1993) further suggest that the possibility of such variables affecting the validity of results is minimal if they represent less than 25% of all variables. On the basis of this heuristic, and with the intent to maintain the largest possible set of data, all variables were taken forward for the factor analysis.

As generally recommended for factor analysis, the correlation matrix showed a substantial number of significant correlations above 0.300. According to Tabachnick & Fidell (2007), the factorability of the data set can be verified by means of the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO). This coefficient provides a ratio for partial correlations. If the value approaches 1 then partial correlations are small. Tabachnick &

Fidell (2007) recommend a KMO above 0.6. The obtained value for this set of data was 0.747 which indicates good potential for factor analysis procedures.

A reliability test was also undertaken using Cronbach's Alpha to verify the internal consistency of data. An Alpha value of 0.856 was found with a value based on standardised items of 0.869.

7.4.4. Principal components analysis

Initial extractions, as recommended by the "Kaiser 1" rule (Ferguson & Cox, 1993), aimed to explore the maximum number of components taking only into account eigenvalues >1. The scree test, although not an exact reference is recommended by Ferguson & Cox (1993) and Tabachnick & Fidell (2007) as a reliable indicator for the most appropriate number of components to be extracted.

Orthogonal rotation using the Varimax method is described by Tabachnick & Fidell (2007) as the most common approach to factor rotation, as it minimises the complexity of the process. The selection of the most appropriate solution took into consideration the concept of "simple structure" described by Kline (1994). A simple structure is defined by the following principles:

- Each of the rotated matrix should contain at least one zero.
- In each factor, the minimum number of zero loadings should be the number of factors in the rotation.
- For every pair of factors there should be variables with zero loadings on one and significant loadings on the other.
- For every pair of factors a large proportion of the loadings should be zero, at least in a matrix with a large number of factors.
- For every pair of factors there should be only a few variables with significant loadings on both factors.

Although it is unlikely that any extracted solution meets simultaneously all these criteria these were considered a useful guidance for the selection of the most suitable combination of components.

Using the Kaiser 1 rule SPSS extracted a six component solution.

However, the aspect of the Scree plot shown in Figure 7.11 appears more agreeable with a four or five component solution.

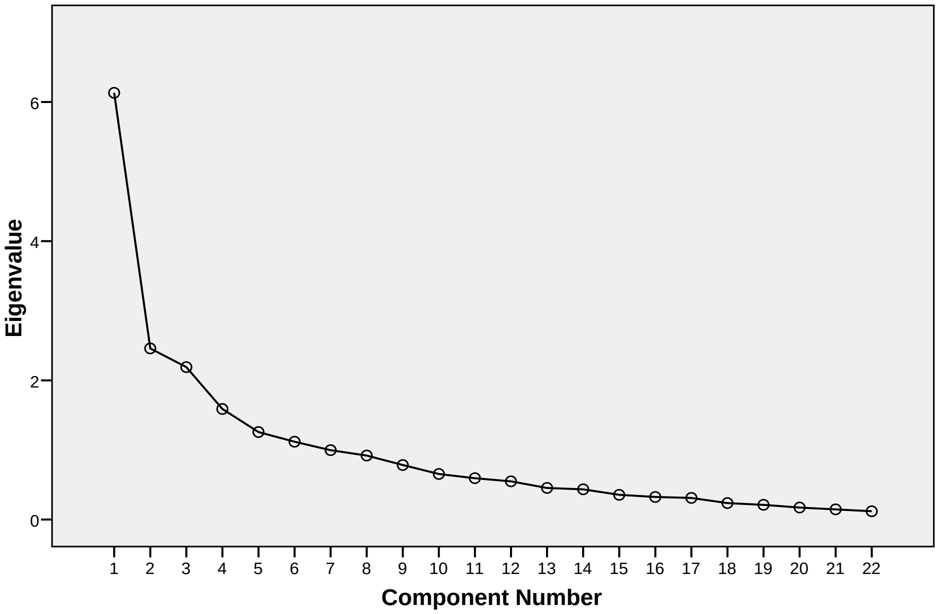


Figure 7.11: Scree Plot

Considering these indicators, solutions for four, five and six components were extracted and rotated. Of all the solutions explored the five components using the Varimax rotation was the one that best fitted the criteria of simple structure. Table 7.7 shows the loading factors for each variable.

Table 7.7: Matrix of extracted components

		Components				
		1	2	3	4	5
1	I receive feedback on the outcome of my planning	-.013	.181	**.573**	.380	.001
2	I have a clear picture of how my planning contributes to the building of an integrated national delivery plan	.114	.071	**.720**	.065	-.107
3	I manage to finish whatever plans I start	.071	**.653**	-.037	.342	-.073
4	I have all the information I need to do my work	.006	**.832**	-.016	.138	.233
5	I have the information necessary to deal with unexpected situations	.234	**.771**	.257	-.044	.167
6	I have the information needed to detect potential planning failures	.084	**.556**	.385	-.050	.360
7	I have enough time to do my planning thoroughly	.193	.306	-.029	-.067	**.825**

8	I have enough time to reflect on my planning	.094	.280	-.038	.215	**.839**
9	I am encouraged to reflect on my planning	-.036	-.095	**.460**	**.433**	**.566**
10	I revise my planning whenever new information arises	**.518**	-.101	.144	.167	.220
11	I take into account a balance between safety and efficiency in my planning decisions	.187	.023	.170	**.671**	.176
12	I can adjust my way of working according to external pressures	.344	.199	**.500**	-.056	.221
13	I can solve problems even when pressured to deliver fast results	**.787**	.141	.058	.247	-.013
14	I can solve problems even when faced with unexpected situations	**.791**	.144	.009	.191	.048
15	I feel in control of my work activities	.426	**.651**	.008	-.113	.338
16	I assess the potential safety impacts for each of my planning decisions	.218	.072	-.149	**.802**	.079
17	I can identify when my planning decisions are pushing the boundaries of safe performance	.284	.115	-.017	**.795**	-.062
18	I can detect failures or errors in my planning before they create problems	**.627**	.170	.122	.401	.169
19	I have the support of my manager to make decisions	.206	-.069	**.665**	.007	.162
20	My management does not blame me for any poor outcome of my planning	-.021	.076	**.715**	-.162	-.059
21	Because something has always gone well before, I feel confident that it will continue to go well in the future	.374	.268	.162	-.234	-.073
22	I can communicate my decisions promptly to those that rely on them	**.458**	.349	.269	.222	.071

Loading factors above 0.400 were considered (shown in bold in Table 7.7) and, where this led to multiple loadings, a minimum difference of 0.200 was imposed (Tabachnick & Fidell 2007). The solution in Table 7.7 converged after 10 iterations and shows one non-loading variable (no loading factor above 0.400 – item 21) and one cross-loading variable (more than one loading factor above 0.400 with difference between them below 0.200 – item 9). Overall, loading coefficients are significantly high, which demonstrates a strong correlation between items and their loading components. The components extracted are shown bellow in Table 7.8.

7.4.5. Interpretation of the extracted components

Ferguson & Cox (1993) suggest two methods for naming the extracted components. Both methods resort to a sample of judges as a way to develop an independent interpretation, which makes their use time consuming and requiring a rather large number of participants.

For this research, an approach was developed based on the Delphi method (Turoff & Linstone 1975). The 25 members of the Ergonomics NST at Network Rail were used as the "discussion group". Team members were asked to name each of the five groups of statements (variables loaded into each of the five components) according to what concept or idea they felt most accurately would describe that group, using as few words as possible. Based on the outcome of these interpretations, a name was proposed by the researcher for each of the extracted components. The interpretations made use whenever adequate, of concepts found in resilience engineering literature.

Following the Delphi approach, team members were then given the opportunity to confirm or dispute the proposed names in the light of their initial interpretations. Each respondent was given a new table showing their own interpretations against the proposed names and asked whether they agree with the given name or still prefer their initial interpretation.

16 members of the Ergonomics National Team responded to the initial step of the Delphi with interpretations for each component. Table 7.8 summarises the expressions and concepts that were most frequently mentioned by the respondents for each of the components.

Table 7.8: Interpretation of the extracted components by members of the Ergonomics NST

Components		Interpretation
1	I revise my planning whenever new information arises	Problem solving Flexibility Adaptability
	I can solve problems even when pressured to deliver fast results	
	I can solve problems even when faced with unexpected situations	
	I can detect failures or errors in my planning before they create problems	
	I can communicate my decisions promptly to those that rely on them	

2	I manage to finish whatever plans I start	Control Information
	I have all the information I need to do my work	
	I have the information necessary to deal with unexpected situations	
	I have the information needed to detect potential planning failures	
	I feel in control of my work activities	
3	I receive feedback on the outcome of my planning	Feedback Organisational support Role clarity Awareness
	I have a clear picture of how my planning contributes to the building of an integrated national delivery plan	
	I can adjust my way of working according to external pressures	
	I have the support of my manager to make decisions	
	My management does not blame me for any poor outcome of my planning	
4	I take into account a balance between safety and efficiency in my planning decisions	Safety Trade-offs
	I assess the potential safety impacts for each of my planning decisions	
	I can identify when my planning decisions are pushing the boundaries of safe performance	
5	I have enough time to do my planning thoroughly	Time available Management
	I have enough time to reflect on my planning	

The interpretation for all five components was considered valid by the majority of respondents. Nevertheless, to improve confidence on the outcome of this process, a clarification was sought whenever challenges were made by respondents.

Comments made by respondents regarding component 3 pointed towards the high number of statements contained in this component and the fact that these (apparently) bring together a more diverse set of issues. The initial interpretations provided by respondents tended to favour sub-groups of statements, according to issues which they felt to be more dominant. This accounted for a lower number of confirmations obtained for this component.

While components 1 and 2 seem to have a higher focus on personal capabilities, components 3, 4 and 5 could be seen as shifting towards a more organisational nature. The fact that the cross-loading item (I am encouraged to reflect on my planning) refers to an organisational cultural aspect and that it loads onto components 3, 4 and 5 supports this assumption. Within this frame of mind, having the organisational support to reflect on ones planning could be an important underlying condition to allow for an adequate performance in regards to the aspects comprised in components 3, 4 and 5.

The non-loading variable (Because something has always gone well before, I feel confident that it will continue to go well in the future) was the one that more explicitly aimed at complacency issues. As shown in Table 7.8, none of the interpretations for the extracted components allude to these issues, which would account for the non-loading of the variable.

Based on the previous feedback, the names shown in Table 7.9 were proposed by the researcher. 12 out of the initial 16 people responded to the second stage of inquiry of the Delphi. Table 7.9 indicates the percentage (of the 12 respondents) of confirmations obtained for each of the proposed names.

Table 7.9: Names proposed for each component and confirmation level

	Component name	Confirmation
1	Adaptability and flexibility	92%
2	Control	92%
3	Awareness and preparedness	67%
4	Trade-offs	92%
5	Time management	100%

The definitions shown in Table 7.10 aim at placing the proposed names within the context of rail engineering planning. Resilience literature, namely concepts from Table 3.3 in section 3.4.1, and the semi-structured interviews with planners described in section 5.2 were used as a background for this process.

Table 7.10: Definitions proposed for components

Component name	Proposed definition
Adaptability and flexibility	Planners are able to restructure their work (the building of a national plan for delivery) in response to pressures and adapt to new arising circumstances through problem solving
Control	People feel they have the means necessary, in particular information, to appropriately control and steer their activities

Awareness and preparedness	The system generates feedback and provides support in such a way that people have a clear view of how they should contribute towards the production of a plan and respond to demands
Trade-offs	Achieving a balance between safety and efficiency through decision making. This can be interpreted in the light of the ETTO principle (Hollnagel 2009)
Time management	Having the time to be thorough when planning decisions require it. Managing a “buffer capacity”

The extracted components emphasize a relation between the issues raised by the questionnaire and resilience engineering constructs, which reinforces the potential use of this approach for the measuring of resilience. To further explore this potential, the extracted components were used to generate corresponding variables in SPSS. As detailed in the next section, a statistical analysis was developed based on these new variables to investigate any possible planning performance trends which these components might reflect.

7.4.6. Analysis of extracted components

Keeping in mind the exploratory scope of this work, the extracted components were integrated into the original SPSS data set as new variables. The purpose was to further understand the constructs produced by the extracted components by comparing the scores obtained by geographical region.

As suggested by Hair *et al* (1998), these new variables were computed in SPSS as an average of the scores of all variables initially loading onto each component. For each case (respondents), the new variables were computed as follows:

$$Vc1 = \frac{V1c1 + V2c1 + \cdots + Vnc1}{n}$$

Where the new variable generated for component 1 is $Vc1$ and $Vnc1$ are the scores for each n variables loading onto component 1. From this, it follows that the new composite variables assume values between 1 and 6. Figure 7.12 shows the average scores on each component by geographical region.

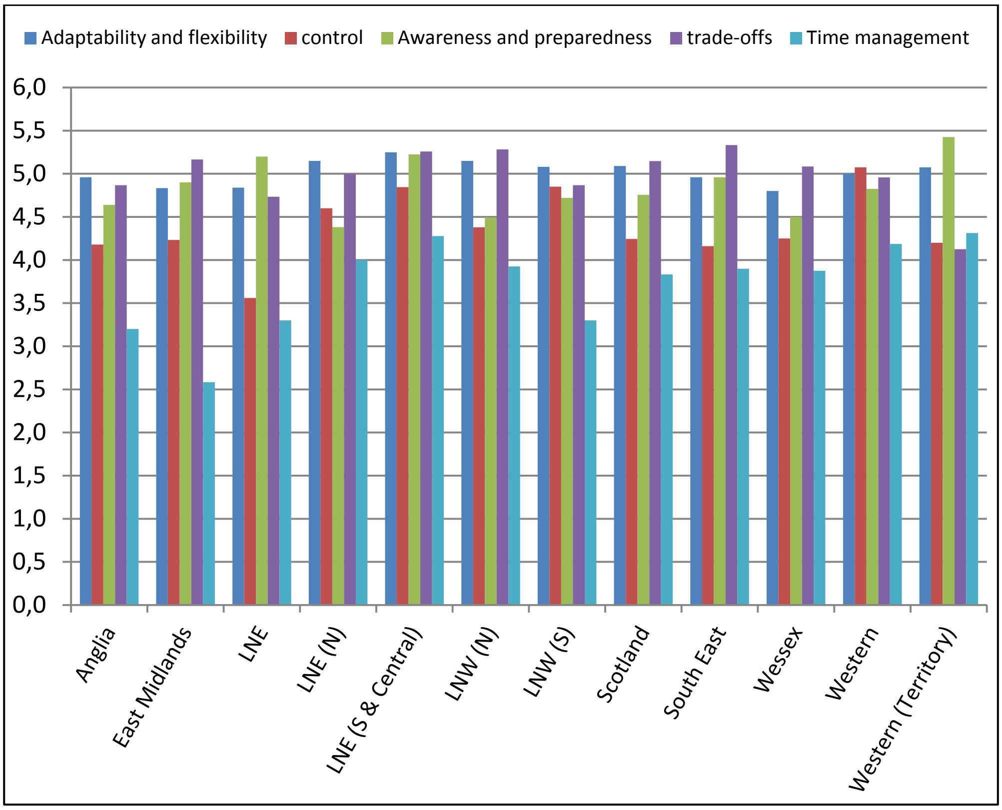


Figure 7.12: Average ratings for extracted components by geographical region

Overall, the component "time management" shows lower scores than the remaining ones in most regions, in particular for East Midlands area. Recalling data for worksite planning (Table 5.7, section 5.3.5), East Midlands was found to be the area which tends to plan worksites the closest to delivery date, despite having an average duration of planning. This could be put forward as a possible cause for a lower rating in the "time management" component.

In order to identify any significant differences between component scores, significance tests were carried out. SPSS was used to perform 2-tailed Mann-Witney tests (Tabachnick & Fidell, 2007) on all components, using geographical regions as the grouping variable. The null hypothesis (H_0) can be given as "there are no significant differences between areas on each of the five components" and the hypothesis to be tested (H_1) corresponds to the existence of significant differences. Table 7.11 shows p-values for "control", "awareness and preparedness" and "time management", as significant differences were identified for these three components. Similar tables were reproduced for components "adaptability and flexibility" and "trade-offs" but, given that no significant differences were found, they are not shown here. These two components are likely to be related to aspects which are less reliant on local capabilities and are dependent on higher level (perhaps nationally) organisational operating conditions. For instance, having the ability to be flexible and adapt at an area level is considerably dependent on the way in which higher levels of the organisation provide enough room for local adjustments or rather they exert pressure for compliance with strict regulations. Grote *et al* (2009) debated these issues in regards to the use of tight and central planning as a way to minimise uncertainty.

Table 7.11: Significance tests for components “control”, “awareness and preparedness” and “time management”

Control											
	Wessex	Anglia	Scotland	LNW (S)	LNW (N)	LNE (S&C)	East Mid	LNE (N)	LNE	Western (territory)	South East
Western	**.001**	**.009**	**.001**	.862	.061	.593	.237	.162	**.010**	**.020**	**.004**
Wessex		.501	.961	.145	.357	.052	.300	.120	.460	.916	.595
Anglia			.537	.152	.520	.108	.512	.303	.324	.823	.420
Scotland				.120	.356	.051	.312	.142	.420	.884	.626
LNW (S)					.367	.937	.279	.464	**.049**	.146	.167
LNW (N)						.225	.951	.531	.108	.413	.338
LNE (S&C)							.405	.616	**.037**	.099	.079
East Mid								.777	.230	.514	.356
LNE (N)									.080	.244	.150
LNE										.335	.525
Western (territory)											1.000
Awareness and preparedness											
	Wessex	Anglia	Scotland	LNW (S)	LNW (N)	LNE (S&C)	East Mid	LNE (N)	LNE	Western (territory)	South East
Western	.205	.654	.922	.769	.311	.100	.514	.257	.210	**.023**	.553
Wessex		.530	.239	.419	.979	**.023**	.216	.900	.065	**.010**	.139
Anglia			.802	.538	.662	.065	.410	.411	.154	**.018**	.419
Scotland				.457	.385	**.028**	.271	.243	.108	**.005**	.443
LNW (S)					.498	.712	.783	.304	.752	.335	.917
LNW (N)						**.037**	.250	.812	.086	**.006**	.253
LNE (S&C)							.321	**.008**	.880	.394	.258
East Mid								.082	.575	.103	.851
LNE (N)									**.039**	**.002**	.119
LNE										.372	.451
Western (territory)											.103

Time management											
	Wessex	Anglia	Scotland	LNW (S)	LNW (N)	LNE (S&C)	East Mid	LNE (N)	LNE	Western (territory)	South East
Western	.556	.105	.591	.412	.717	.770	**.019**	.969	.073	.485	.765
Wessex		.242	.807	.552	.979	.435	**.037**	.910	.134	.275	.821
Anglia			.216	.853	.128	.077	.352	.094	.901	**.042**	.292
Scotland				.494	.444	.326	**.031**	.440	.243	.152	.736
LNW (S)					.299	.202	.357	.351	.670	.083	.459
LNW (N)						.440	**.023**	.874	.245	.429	.944
LNE (S&C)							**.024**	.538	.105	1.000	.588
East Mid								**.010**	.150	**.015**	.097
LNE (N)									**.031**	.245	1.000
LNE										**.043**	.240
Western (territory)											.536

Numbers in bold indicate cases for which the null hypothesis is rejected and therefore, a significant difference between areas exists. For the component "awareness and preparedness" significant differences are mostly concentrated on Western territory. As shown in Figure 7.12, this geographical region registered the highest average score on this component. This could be related to the fact that, as a territory, this geographical structure addresses different planning stages than the remaining ones represented in Table 7.11 (apart from South East territory). For the component "time management", East Midlands area stands out as the region with the most significant differences, which is consistent with previous observations regarding Figure 7.12. From the analysis developed in section 7.2, East Midlands was found to have clear differences from the remaining areas when comparing the number of asset incidents against the volumes of worksite and possession changes. While registering a considerably lower number of asset incidents, this area produced some of the highest volumes of planning changes. Within the scope of this research, it was not possible to further investigate potential relations between such differences and the ones registered in terms of the component "time management", as this would require additional data collection and different methodological approaches.

Although other significant p-values were found, given the high number of tests carried out, it should be taken into account the possibility that these are the result of "statistical chance", rather than representing actual disparities between variables.

7.4.7. Part 2 of the questionnaire

Figure 7.13 shows the ratings given by planners for each of the 10 statements introduced in section 4.10.3. Labels on the graphic are given in absolute values and percentages are indicated on the "yy" axel.

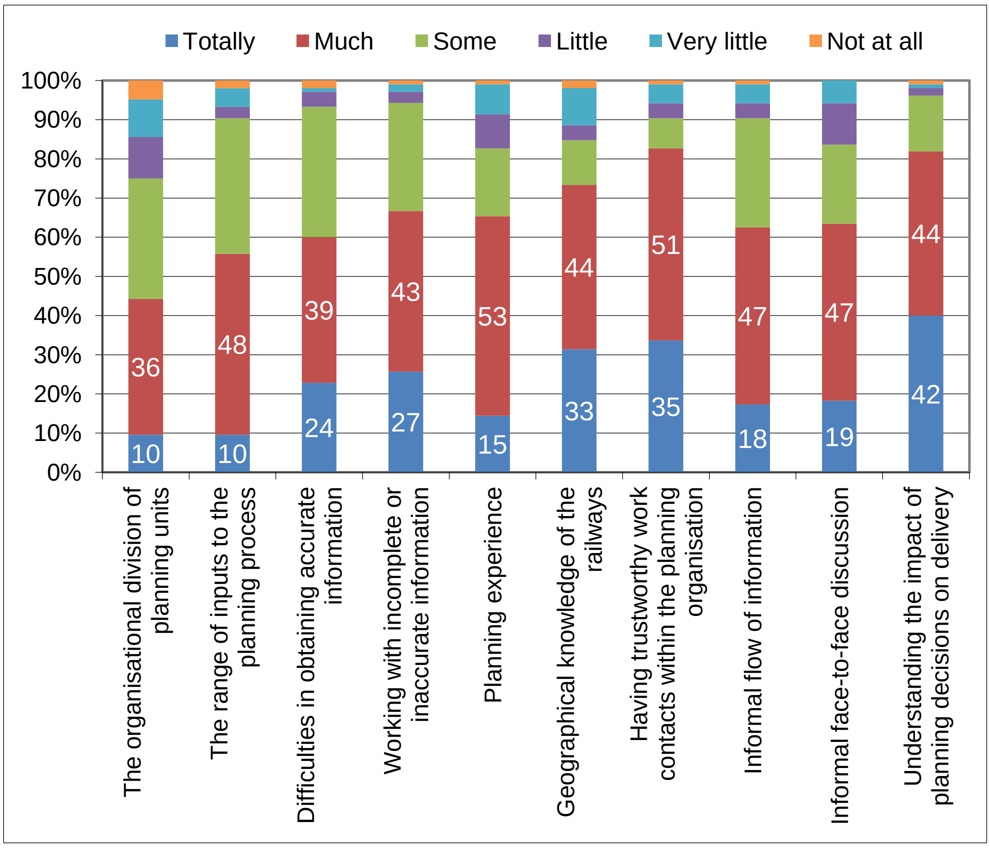


Figure 7.13: Ratings for part 2 of the questionnaire by percentage of respondents

All statements except the one regarding "the organisational division of planning units", were rated with either 5 (Much) or 6 (Totally) by at least 50% of respondents. Keeping in mind that planners were asked to rate statements according to how much they felt the issues influenced their performance, the results obtained demonstrate the relevance of these issues for the performance of planners. Although maintaining the shift towards the higher scores, the aspects regarding "organisational division and "diversity of inputs" only had 10% of respondents attributing a score of 6. As discussed in section 4.10.3, the issues introduced by these statements were described as having a negative impact on planning performance. The relatively lower scores attributed by respondents to these statements can be interpreted as, although recognising their relevance, planners feel that they are able to cope with these issues having serious impacts on their performance.

Statements regarding “understanding the impact of planning decisions” and “having trustworthy contacts” stand out as the most relevant issues with 86% of respondents attributing either a score 5 or 6. This is consistent with the descriptions given during the semi-structured interviews. As earlier discussed in section 5.2, while understanding the impact of decisions on work delivery was considered the fundamental support for decision making in planning, trustworthy contacts were described as the means to acquire information necessary to generate confidence in the decisions made. From discussions in section 7.1, in particular sub-section 7.1.5, reliable information out came as a fundamental resource for reducing uncertainty and unpredictability. Sub-section 7.1.3 discusses the absence of reliable feedback as a hindering factor for decision making and a contributing factor for uncertainty. Planners resort to informal contacts in order to acquire reliable information to support their decisions in terms of better understanding their potential impacts on work delivery and thus attempting to reduce uncertainty.

Only 4 respondents scored these two statements with either 1 (Not at all), 2 (Very little) or 3 (Little). By observing the data tables in SPSS, it was noticed that these 4 planners gave similar scores to the remaining statements.

Figure 7.13 reveals strong similarities between the responses given to each statement. To verify similitude, Pearson correlations are shown in Table 7.12. Levels of significance of 0.05 and of 0.01 were studied, with “p values” of 0.215 and 0.282 respectively. Correlations significant at the 0.01 level are shown in bold numbers and correlations significant at the 0.05 level are underlined.

Table 7.12: Correlations between statements of part 2 of the questionnaire

		2	3	4	5	6	7	8	9	10
		The range of inputs to the planning process	Difficulties in obtaining accurate information	Working with incomplete or inaccurate information	Planning experience	Geographical knowledge of the railways	Having trustworthy work contacts within the planning organisation	Informal flow of information	Informal face-to-face discussion	Understanding the impact of planning decisions on delivery
1	The organisational division of planning units	**.611**	.213	.206	.084	.066	.105	.165	.216	,243
2	The range of inputs to the planning process		.236	.161	.112	.097	.186	.157	.281	,250
3	Difficulties in obtaining accurate information			**.726**	-.026	-.103	.097	.010	.157	.140
4	Working with incomplete or inaccurate information				.065	.134	,230	.109	**.363**	,255
5	Planning experience					**.721**	**.389**	**.335**	**.429**	**.512**
6	Geographical knowledge of the railways						**.482**	**.342**	**.525**	**.521**
7	Having trustworthy work contacts within the planning organisation							**.557**	**.465**	**.686**
8	Informal flow of information								**.603**	**.537**
9	Informal face-to-face discussion									**.635**

Overall, Table 7.12 shows strong correlations, in particular between statements relating to issues impacting more positively on planners' performance (statements 5 to 10). This appears to be consistent with the interdependencies described by planners during the semi-structured interviews. Statements "planning experience" and "understanding the impact of planning decisions" appear as the ones with higher numbers of interdependencies and in particular, the latter shows some of the strongest correlation coefficients.

The issues addressed by the statements assessed in this part of the questionnaire were earlier analysed with regard to resilience concepts (section 7.1), and in particular, the importance of "understanding the impact of planning decisions" to the management of uncertainty was argued in section 7.1.5. Within this scope, the interdependencies demonstrated by correlations in Table 7.12 illustrate some of the mechanism used by planners to manage uncertainty and variability in their daily activities and thus, contribute to system resilience.

The way in which these correlations contribute to the understanding of the sources of resilience in the planning system is later argued as a final research discussion. At this point, based on the information from section 7.1, Table 7.13 clarifies correlations significant at the 0.01 level by providing a brief description. Given that statements regarding "informal flow of information" and "face-to-face communications" were both derived from information issues in section 7.1.4, and that they also originate from the same issues introduced by planners in section 5.2, their correlations are here described together.

Table 7.13: Description of correlations significant at the 0.01 level

<table>
<tr><th>Correlation</th><th>Description</th></tr>
<tr><td>The organisational division of planning units - The range of inputs to the planning process</td><td>The fragmentation of the planning process generates different views on priorities and goals, which contributes to differences in the contents and formats of the information shared throughout the planning system. Overall, this renders planning information subject to a considerable degree of variability (sections 7.1.2 and 7.1.3)</td></tr>
<tr><td>Difficulties in obtaining accurate information - Working with incomplete or inaccurate information</td><td>The imprecision or insufficiency of information forces planners to make decisions based on inaccurate details of work packs (sections 7.1.3 and 7.1.4)</td></tr>
<tr><td>Planning experience - Geographical knowledge of the railways</td><td>Geographical knowledge of the railways is an important element in developing planning experience (section 7.1.6)</td></tr>
<tr><td>Planning experience - Having trustworthy work contacts within the planning organisation</td><td>Knowing who to trust and where to go for reliable information is built through experience in planning (sections 7.1.4 and 7.1.6)</td></tr>
<tr><td>Planning experience - Informal flow of information</td><td rowspan="2">Informal communication and exchange of information is based on the knowledge of people concerning who to trust and of reliable sources of information, and therefore also relies on experience (sections 7.1.4 and 7.1.7)</td></tr>
<tr><td>Planning experience - Informal face-to-face discussion</td></tr>
<tr><td>Planning experience - Understanding the impact of planning decisions on delivery</td><td>Knowledge of the railway is an important element of planning experience because it supports an understanding of how decisions may affect delivery (section 7.1.8)</td></tr>
</table>

Geographical knowledge of the railways - Having trustworthy work contacts within the planning organisation	Having strong and reliable work relations contributes to a better understanding of how the railway operates (section 7.1.6)
Geographical knowledge of the railways - Informal flow of information	Understanding the railway and its operations supports the development of more informal and efficient exchange of information (section 7.1.6)
Geographical knowledge of the railways - Informal face-to-face discussion	
Geographical knowledge of the railways - Understanding the impact of planning decisions on delivery	Understanding the railway and its operations supports the ability to consider possible outcomes of the decisions made (sections 7.1.6 and 7.1.8)
Having trustworthy work contacts within the planning organisation - Informal flow of information	Informal exchange of information is supported by the contacts on which planners feel they can rely on (section 7.1.7)
Having trustworthy work contacts within the planning organisation - Informal face-to-face discussion	
Having trustworthy work contacts within the planning organisation - Understanding the impact of planning decisions on delivery	Information obtained from trustworthy contacts supports the ability to predict possible outcomes of the decisions made (section 7.1.9)
Informal flow of information - Informal face-to-face discussion	Planning meetings are based on face-to-face discussion and are part of the planning decision making processes. This constitutes an important element of information flows within the planning system and reinforces an efficient and timely decision making (sections 7.1.4 and 7.1.7)
Informal flow of information - Understanding the impact of planning decisions on delivery	The informal exchange of information is often the source of reliable information, which planners require to understand how their decision might impact on delivery (section 7.1.8)
Informal face-to-face discussion - Understanding the impact of planning decisions on delivery	

7.5. Chapter conclusions

The information discussed in Section 7.1 illustrates issues with relevance for either the enhancement or erosion of resilience in the planning systems. Two main traits can be identified:

- On the one hand, the organisational and geographical dispersion of the planning system contributes to a higher variability of information inputs, and generates a fragmented information flow. A fragmented organisational structure and information flow were placed at the source of incomplete or inaccurate information which in return, increases uncertainty and unpredictability in planning decision making (Leveson *et al*, 2006). This reflects mainly on the volume of planning changes, as decisions which originate such changes must be frequently reviewed and visibility on their potential outcomes is reduced Leveson *et al* (2003).
- On the other hand, planning experience provides a means for the development of reliable work relations, which support informal exchanges of information. This informal communication provides reliable feedback and supports coping with uncertainty in decision making (Leveson, 2004). Experience also leads to a better knowledge of the railway in general and an understanding of the impacts of planning decisions on delivery by improving awareness on possible scenarios (Woods, 2006b).

In view of the arguments presented by Hollnagel (2009a), the management of planning changes plays a crucial role in achieving and maintaining a balance between efficiency (from production pressures) and thoroughness (through safety requirements). A minimum volume of changes was recognised by planners as necessary to respond to unpredictable engineering needs, which is consistent with the need for proximal adjustments to unpredicted operating conditions (Crawford & Wiers, 2001). However, there was consensus towards the fact that a considerable volume of change brings unnecessary disruption to planning, as this can emanate from issues that planners deemed possible to anticipate. This amounts to distinguish between unpredictable and unpredicted problems. While to deal with unpredictable issues, planning changes are unavoidable, if issues are deemed as unpredicted, it implies that some form of anticipation would have been possible. As discussed in section 7.1.1 and supported by Hale *et al* (2006), changes that can allow to flexibly cope with unpredictable issues should be integrated as efficiently as possible and changes which may disrupt tested and verified planning should be avoided. This demonstrates potential for improvements in the management of planning changes, which can lead to a more adequate coping with uncertainty and therefore, for enhancement of resilience in planning. From this point of view, a better management of planning changes is consistent with more reliable planning and thus, contribute to a more safe and efficient work delivery.

The contents of the investigation report produced by the Office of Rail Regulation (ORR, 2008) provided ample support to the previous arguments. Mainly, production and business pressures led to the planning of volumes of work which clearly exceeded the management and control capabilities of the system and the resources available. The fragmented organisation and communication structures rapidly eroded means to adjust plans and contingencies and the ability to respond and recover from failure.

Woods (2006b) refers to accidents such as the Columbia space shuttle as late indicators of a system that became brittle. A similar perspective could be applied to the chain of events and overall system behaviours exhibit by Network Rail, which led to the Christmas overruns. The work delivery on-going within that period of time throughout the country had been within the scope of planning for more than a year and several years prior to the formal planning, the ambitious renewal schemes that framed such complex engineering work were the scope of high level negotiations with rail industry stakeholders and governance. The following quote of Woods (2006b) summarises this series of events quite clearly:

> *As pressure on acute efficiency and production goals intensifies, first, people working hard to cope with these pressures make decisions that consume or sacrifice tasks related to chronic goals such as safety. As a result, safety margins begin to erode over time – buffering capacity decreases, system rigidity increases, the positioning of system performance relative to boundary conditions becomes more precarious* (pp 315).

At a system level, planning demonstrated inability to produce an adequate overall picture, both at the scale of independent projects and at a national level. Although the problems found during the Rugby project (derailment of train, unforeseen buried services, staff shortages, among others) were considered to be manageable with capacities, their cumulative effect clearly contributed to the inability to properly monitor work and the consequent loss of control. The way in which several major projects on-going simultaneously at national level (Appendix 8) end up by competing against each other for resources, namely experienced Overhead Line Equipment staff, shows that planning was unable to properly integrate a national plan and allocate resources accordingly. The way in which normal (manageable) events combined and generated an operational variability and uncertainty which exceeded the ability of the system to adapt and maintain control over operations is compatible with the principles of functional resonance (Hollnagel, 2004).

The use of FRAM, also offered evidence towards the fragmented information flow and its impacts on the variability and uncertainty of planning. Despite the fact that only the initial steps of analysis were fully developed, useful insight was obtained regarding flows of information and the overall operation of planning by means of the function analysis that was involved in the application of this method. A considerable gap appears to exist between the identified formal exchanges of information and what was described by planners (mainly during interviews) as informal communications.

The variability registered in the analysis of archival data is consistent with the high uncertainty earlier described during the interviews processes. From a resilience perspective, the comparison of data from the different archival sources investigated has indicated potentially relevant couplings between planning, work delivery and the infrastructure. Beyond the evidence gathered from safety data (control logs) regarding the impact of planning on delivery, the analysis of infrastructure profiles against planning data has revealed important characteristics about areas. In particular, areas with higher numbers of asset incidents appear to register higher volumes of planned work and of planning changes. The graphical representations shown in section 7.2.2 highlighted the clear different trend of LNW (N) area, when compared to other areas, in terms of the volume of work planned and East Midlands area in terms of the number of asset incidents. As illustrated in Figure 7.6, higher incidence of asset failures also appears to be related to a higher number of possession incidents.

Regarding data from part 1 of the questionnaire, the high ratings suggest a strong relevance of the issues raised by statements. The principal components analysis has led to the identification of five constructs with potential use as measurable resilience factors. Some significant differences between geographical areas were identified based on the extracted components. In particular, component “time management” tended to register lower average scores across all areas and the East Midlands area showed significant differences from the remaining areas regarding components “control”, “awareness and preparedness” and “time management”.

The results from part 2 of the questionnaire support conclusions from the interviews. The shift towards high scores registered on all statements confirms the relevance of the issues raised. “Understanding the impact of planning decisions” and “having trustworthy contacts” stand out as the issues which planners identified as having the most significant impact on their performance. The strong correlations found between statements are also consistent with the outcome of the interviews as they illustrate the interdependency of issues. Overall, the questionnaire provided a quantified assessment of main planning issues, which contributed to a better understanding of planning activities and their constraints.

8. Discussion

The research developed has contributed mainly to the understanding of planning activities within the context of rail engineering. The adoption of a systems approach added to knowledge on aspects of complexity and its challenges towards achieving and maintaining safety in high performance domains, such as the railways, among others. In particular, the resilience engineering perspective through which this approach was developed also contributed to the knowledge of this yet recent discipline.

This section provides an overview of the research findings and places them in the context of the proposed aims and objectives by referring back to the research questions raised. This discussion is then used to support recommendations for the enhancement of resilience in the planning of rail engineering (objective 6).

8.1. The rail engineering planning system

Objectives	Questions
1) Develop a description of the rail engineering planning system as a complex sociotechnical system 2) Identify the critical human and organisational factors of the rail engineering planning system	• How is the planning process framed within Network Rail's organisational structure and within the rail industry? • What are the boundaries of planning? • What are the main trends of planning performance? • What are the main constraints to planners' decision making? • What are the main resources used by planners to deal with constraints? • How do the planning process and its organisational structure support or hinder decision making processes?

Rail engineering has been the focus of human factors research for some years. Examples can be found in a wide range of fields, such as communications (Murphy, 2002), organisational culture aspects (Farrington-Darby *et al*, 2005) and systems ergonomics (Wilson *et al*, 2007a). In particular, Schock (2010) addressed aspects of rail engineering planning through the identification of functions and activities, and the building of visual scenarios for delivery. In broad terms, this corresponded to what was described in this thesis as the last stages of the planning process, during which work packs are integrated and scheduled within worksites.

One of the foremost contributions of research in this thesis was the thorough description of the planning process and the identification of its boundaries. The focus of this research was a top-to-bottom and across-the-industry investigation of the organisational system that supports the decision making process, ranging from high level business targets down to the definition of the engineering work that is required to achieve those targets. This was early on introduced in section 2.3, and in particular, represented in Figure 2.1, Figure 2.2 and Figure 2.3. The following aspects from the literature were made apparent in the rail engineering planning system:

- Rail engineering planning is a complex sociotechnical system that operates across a great number and diversity of geographical, organisational and temporal boundaries (Carayon, 2006).
- Like many other planning and scheduling activities, rail engineering planning can be fundamentally described as a decision making process that aims to allocate limited resources in view of organisational goals (Pinedo, 2009).
- As a decision making process, planning relies considerably on complete and accurate information (Roland *et al*, 2011) to foresee possible delivery scenarios and allocate resources accordingly.
- Managing the variability and uncertainty inherent to high complexity (Leveson, 2004) constitutes one of the major challenges for planning decision making. These are mainly created by breakdowns in information flows and result in poor visibility of planning scenarios and problems.

The initial familiarisation interview with NAU senior planning manager not only supported this description of the planning system, but also guided the semi-structured interview process. This process highlighted human and organisational factors that provided a better understanding of the problems experienced by planners and their sources. The management of planning changes was the aspect most frequently mentioned by interviewees and on which higher concerns were raised. From the information presented in section 5.2, it becomes clear that much of the discussion developed by planners during interviews, focused on the causes and consequences of the high volume and frequency of planning changes. These are presented in more detail in the next section (Figure 8.1).

As mentioned by the initial interviewee (NAU manager) and described in section 5.1.2, planning at area level (ADPU level) tends to be the point in the system to which much of the pressure and decision making converges. The semi-structured interviews substantiated this point of view, mainly by the following arguments presented by planners:

- Investment projects that have not been able to meet planning targets by providing the required information or by continuously having to change details, are dragged throughout the long-term process. As quarterly plans are passed on to ADPUs, project teams are pressured to finalise their details on work packs. The decisions made by project teams at this point and submitted to ADPUs, often introduce additional changes, which are likely to generate conflicts with other items of work already slotted in to the available access and with critical resources allocated.
- It was recognised by planners that maintenance delivery units tend to operate under significant shortages of resources, in particular of access. Beyond cyclic maintenance work, MDUs also have to respond to emergency work requirements, which under considerable resource pressure, means having to readjust all maintenance work previously planned and redefine priorities. This often implies requesting late changes to ADPUs and generating potential conflicts with work already allocated.

In general, this means that from higher levels, project teams pressure ADPUs with increasing volumes of work that is needed to respond to the business investment targets. From lower levels, maintenance units pressure ADPUs with emerging and unforeseen maintenance needs.

The analysis of planning archival data also contributed to the knowledge of planning in rail engineering. Despite the enforcement of a national planning process under the principle of “one way of doing things”, a great diversity of planning “behaviours” was identified through the quantitative data analysed. Data also suggested that the volume and frequency of change tend to increase as delivery date approaches and showed that a considerable number of these later changes are in fact reversing previous planning decisions. This reinforces the importance of variability and uncertainty in planning and of providing reliable information to improve its management.

8.1.1. Decision making in the planning of rail engineering work

The planning process is a system that aims to provide detailed information organised as an annual plan for the delivery of engineering work. The production of this information is greatly reliant on people and their ability to communicate and relate with others within the planning organisation, not only from within Network Rail, but also from engineering contractors and train operators. Therefore, human factors issues are central for the production of an efficient, reliable and safe plan, and improving on these issues requires an understanding of what supports and what hampers the ability of planners to reach adequate decisions.

Earlier human factors research had explored the central role of decision making in planning activities, mostly in manufacturing industry domains (McCarthy & Wilson, 2001a). The methods developed in the course of this thesis, in particular the interview processes carried out at different stages, added to this knowledge by investigating decision making processes in the planning of rail engineering work and identifying critical human, organisational and system level factors.

Decision making gained additional relevance for the planning of engineering work, as it was found to be at the origin of planning changes. In essence, every decision involves accepting or rejecting work submitted to planning, or any alterations proposed to work already submitted. As discussed in section 7.1.1, because decisions in practice determine how much work is safe to deliver with a given amount of resources available, they represent critical system trade-offs within the principles of ETTOs discussed in section 3.4.4. Figure 8.1 shows a systematic representation of the main findings regarding planning aspects affecting decision making and planning changes.

Figure 8.1: Summary of human, organisational and system level factor indentified in planning

As shown in Figure 8.1, decision making is at the core of every planning activity, both at an individual level and at an organisational and system level. System factors prevailed in the development of this research, as the emphasis of the research scope was set on system aspects emerging from complexity, in particular through the adoption of a resilience engineering perspective on safety and efficiency of planning.

8.1.2. Assessing planning performance

McCarthy & Wilson (2001b) identified the need to monitor performance as one of the crucial areas of research in planning and scheduling. This research also contributed to this end by developing a quantitative approach to the analysis of the planning system. Archival data sources were studied to produce planning performance indicators and subsequently investigate different performance trends based on the comparison of different geographical structures. The analysis of both work delivery and infrastructure and asset data later provided an adequate framework for the interpretation of planning performance. This was based on the principle that planning must be oriented towards providing adequate support for delivery and therefore, it also must encompass the profile of infrastructure for which it is planning.

The fact that planning changes have at their origin a decision making process and that planners described the management of planning changes as the most critical issue for the success of planning (section 5.2.3), performance measurements were based on the numbers and types of changes registered in planning data systems. The concept of “volume of change” was created by the researcher and defined as the amount of changes made per number of items created (section 4.7.2). Based on this concept, planning performance was assessed according to the following parameters:

- The number of items created (possessions and worksites)
- The number and type of changes made
- The volume of change for both each type of change and overall (all types of changes grouped)
- The duration of planning

Apart from basic statistics, the analysis of archival data was based on graphical representations. In general, a higher overall volume of change was found to be consistent with a longer duration of planning (Figure 5.1). Despite this tendency, LNW (N) area was found to have one of the highest volumes of change but a relatively short duration of planning, while planning for the highest number of possessions. Based on these characteristics, LNW (N) was designated as the area with the highest level of planning activity. A higher volume of change to possession details (Table 4.2) was found to be related to a higher density of worksites within possessions (Figure 5.2). LNW (N) was the area registering the highest volume of change (possession details) and the highest number of worksites per possession. In terms of worksite planning, the graphical representations showed that a higher percentage of worksites dedicated to more complex work (structures or major projects work) tend to be related to a higher volume of change.

Further conclusions are drawn from this data in the next section by comparing planning data against delivery and infrastructure data. This provided a better understanding of planning and placed planning performance within the context of its operating environment (work delivery and rail infrastructure).

8.2. System interactions

Objectives	Questions
2) Identify the critical human and organisational factors of the rail engineering planning system. 3) Investigate relations between planning and engineering work delivery and identify the impacts of planning on work delivery. 4) Describe resilience within the planning system and identify means to improve it.	• How do the planning process and its organisational structure support or hinder decision making processes? • What are the main trends in work delivery performance? • What are the different trends in the relations between planning and delivery? • How does variability and uncertainty express itself in the planning system?

As earlier stated, the development of a systems approach to rail engineering planning constitutes one of the main contributions of this research. This was fundamental to support the study of resilience and explore possible means of “engineering” resilience in this particular domain.

Archival data supported the investigation of planning as a system function and its interactions with its operating environment. The main trends of the relations between planning and work delivery were identified, as well as the influences that the profile of the infrastructure for which work is planned and delivered may have on these relations. Overall, the exchange of information between planning and work delivery was described as being poor and fragmented. In line with the concept of a safety control loop described by Leveson *et al* (2003) and presented in section 3.3.6, two main conclusions can be drawn:

- On the up flow of information, planning receives little feedback from delivery, which hinders the visibility of planning over delivery needs and reduces awareness on possible delivery scenarios. As argued by Axelsson (2006), feedback constitutes an important resource for the management of “weak and diffuse signals”.
- On the down flow of information, evidence suggests that planning provides little support to delivery, beyond establishing the “where” and

"when" of the work. The high frequency and volume of changes that often occur at late stages of the planning process and out of its formal control (uncontrolled change), transfers a considerable degree of uncertainty to those managing work delivery (PICOPs and signallers), mainly concerning the "how" of the work (what movements, at what time and on which route, what sequence of work, among other details).

The analysis of safety data have provided evidence of causal factors on possession delivery incidents related to planning. These causes were mainly originated by poor details of worksite planning. Data on the events related to the Christmas 2007 overruns have shown that, among other factors, the fragmented organisational structure and flow of information within the engineering system can lead to serious losses of operational control.

Although not as robust as thorough statistical verification, the graphical representation of relations between the parameters extracted from archival data sources provided enough information to support conclusions on main system interactions. The relations thought to be relevant for the reliability of planning and safety and efficiency of the system as whole were previously debated in section 7.2. These relations are represented in Figure 8.2 and detailed in the following sub-sections.

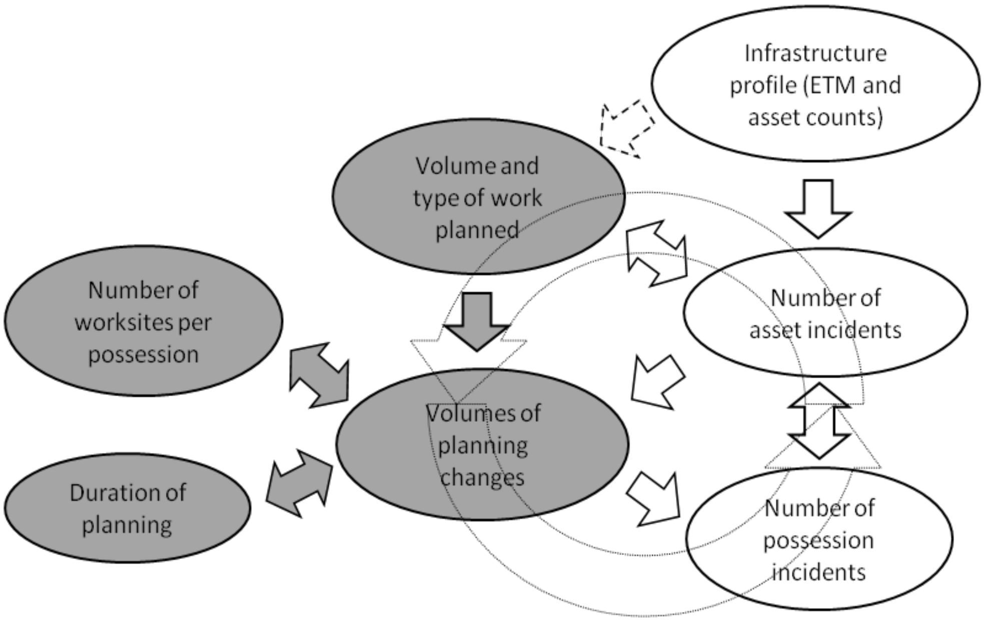


Figure 8.2: Representation of system interactions

The circles with grey filling designate planning parameters, and white filled circles correspond to work delivery and infrastructure parameters. One-way arrows were used only when there was information to suggest which of the related elements was determinant to the proposed relation.

8.2.1. Infrastructure profile and volume and type of work planned

Based on the understanding of planning and the wider engineering system, the profile of the infrastructure, namely Equated Track Miles and numbers of assets, was expected to influence the volume and type of work planned by each area. The data analysed did not support this assumption, which indicates that factors other than engineering characteristics must be taken into account to understand this relation. The information collected during the interview processes in terms of how the management of investment projects impacts on planning, leads to consider the influence of business decisions as a predominant factor in this relation. Because this was not verified through the data sources investigated, the corresponding arrow in Figure 8.2 is shown with a dashed line.

8.2.2. Infrastructure profile and asset incidents

By definition (section 2.4.8) the number of assets and its complexity are some of the main factors included in the calculation of ETM. As argued in section 6.3.2, it follows that areas with higher ETM would be more exposed to asset incidents. Hence, as illustrated in Figure 6.2 (section 6.3.2), areas with more complex infrastructure (higher ETM) tend to register higher numbers of asset incidents.

8.2.3. Volume and type of work planned and volumes of planning changes

The work required to respond to both investments and maintenance needs (volume and type of work planned) constitutes the “raw input” to the planning process. As shown in Figure 5.4, the worksite volume of change is related to the type of work planned by each area. This is consistent with the notion that work for which delivery arrangements tend to be more complex will also tend to involve additional planning work. As discussed in section 5.3.5, work such as major renewals or tunnel work will most likely involve more machinery and perhaps increased risks, when compared to smaller routine maintenance tasks. The planning of worksites dedicated to such complex work will involve a higher number of details and perhaps more complex ones (heavier and more complex machinery involved) on which decisions have to be reached.

8.2.4. Volumes of changes, duration of planning and number of worksites

As debated in section 5.3.4, data suggested relations between volumes of changes in the planning of possessions and both the duration of planning (Figure 5.1) and the concentration of worksites per planned possession (Figure 5.2). Planners may favour an extended duration of planning in order to integrate all changes which they feel necessary. This could be achieved either by starting to plan earlier or by delaying the closing of planning and accepting higher numbers of late changes, as often planners PICOPs and signallers mentioned during interviews. Having higher numbers of worksites integrated into possessions is likely to increase complexity of possession planning as more details have to accounted for, such as having to schedule and coordinate increasing numbers of machine and train movements in and out of worksites and in an out of possession.

8.2.5. Volumes of planning changes and possession incidents

Although it would be expected that areas that plan (and therefore deliver) higher volumes of work would have a higher exposure to possession incidents, data analysed in section 7.2.1 did not lead to this conclusion. Areas appear to manage very differently the equally different volumes and types of work for which they plan. An increased volume of planning changes was also expected to impact on the overall quality of planning by putting at risk its coherence and integrity (section 7.2.1). Figure 7.3 has indicated a slight tendency for areas with higher volumes of worksite changes to also register higher numbers of possession incidents.

8.2.6. Asset incidents, volume of work planned and volume changes

As debated in section 4.9, the categories of asset incidents investigated reflect in some way the need for more or less urgent repair work. Because this constitutes a source of unforeseen work needs, it was expected to be reflected in planning, in terms of either the additional work as a response to the needed repairs, or of the planning changes necessary to slot this extra work in the available access opportunities. As discussed in section 7.2.2, higher numbers of asset incidents seem to be more clearly reflected on the volumes of possession and worksite changes rather than the volume of work planned. The fact that the emergency maintenance needed may be delivered under protection arrangements other than T3 possessions and that a significant amount of late changes (such as those necessary to respond to emergency needs) are likely not to be registered in PPS must be taken into account when examining these relations.

8.2.7. Possession incidents and asset incidents

The analysis of control logs (section 6.2.1) has shown that the damage to assets constitutes one of the main causes of possession failures. Hence, areas with higher incidence of possession failures were expected to also incur higher numbers of asset incidents. Given that the recovery of such incidents frequently resulted in possession overruns, the relation between the occurrence of possession overruns and asset incidents was investigated. As shown in Figure 7.6 (section 7.2.3), A higher number of overruns appears to be strongly related to a higher incidence of asset failures.

8.2.8. A self-reinforcing cycle

The dimmed block arrows in Figure 8.2 illustrate the fact that some aspects of system performance may tend to reinforce each other. This can be summarised as follows:

- An infrastructure characterised by a higher number and density of assets (higher complexity) tends to be exposed to a higher frequency of asset incidents
- A higher number of asset incidents may generate higher volumes of planning work, as a response to the emergency maintenance work needed, which may also impact on the volume of planning changes.
- A higher number and frequency of planning changes may compromise the integrity of the work plan, which may be reflected in a higher number of possession incidents, in particular, through damage to assets and possession overruns.

- A higher incidence of possession failures may result in higher numbers of asset failures, namely through damages caused during possessions.

Planning is at the core of this self-reinforcing cycle, as it mediates demands in terms of volume and type of work to be planned against the availability of resources (including access). The views of planners during interviews and the understanding of the planning system developed throughout this research, suggest that the management of planning changes is one of the most critical aspects in this mediation. Keeping in mind the evidence earlier presented regarding the role of planning in the management of uncertainty, by better managing changes, the planning system contributes to a reduced uncertainty at work delivery and therefore to a more efficient and safe work delivery.

The evidence gathered from the events of the Christmas 2007 overruns shows that over the weeks preceding the Christmas blockade, during which work related to the projects was ongoing, problems were already accumulating. The way in which poor planning impacted on project delivery and poor feedback from delivery hampered the ability of re-planning and deploying adequate contingencies, supports the nature of this self-reinforced cycle.

8.3. Resilience in rail engineering planning

Objectives	Questions
3) Investigate relations between planning and engineering work delivery and identify the impacts of planning on work delivery. 4) Describe resilience within the planning system and identify means to improve it. 5) Contribute to the development of a framework, methods and measures for assessing resilience in planning.	• What are the different trends in the relations between planning and delivery? • How does variability and uncertainty express itself in the planning system? • What are the sources of resilience in planning? • What aspects of planning performance can potentially support the development of resilience indicators? • How can resilience in rail engineering planning be monitored?

The concept of resilience has recently known a widespread application in many different domains (section 3.4). This is with no doubt related to the growing awareness of high complexity and its impacts on many of human activities. There is yet little research dedicated to resilience engineering within the domain of the rail industry and in particular of rail engineering. The focus of this research on the challenges of high complexity for safety and efficiency and the development of broad system approach provided an adequate framework for the study of resilience and of mechanisms to "engineer" resilience in this particular domain. This was apparent by the encouraging way in which the potential contribute of this research to the development of resilience engineering was welcomed by the international workgroups dedicated to the subject (section 4.11).

8.3.1. Functional analysis of planning

The theoretical basis of FRAM and its focus on the modelling of system interactions made it an approach with interest to the objectives of this research. The use of FRAM contributed both to the understanding of the planning system and to the development of FRAM itself through the participation in its annual workshops.

The "FRAMing" of the planning system provided useful insights into the structure of the system, its flows of information and the nature of its interactions. The process leading to the identification of functions added to the information presented in section 2.3 and supported the produce of diagrams of the planning process shown in Figure 2.1, Figure 2.2 and Figure 2.3. The investigation of function descriptors is at the basis of understanding the exchanges of information in planning and the definition of categories of functions, which represent different types of interactions, as detailed in section 7.3. As shown in Appendix 9, the exploratory work carried out with FRAM went beyond what is represented in Figure 7.7 as the inputs and outputs of the planning system. Although this provided useful insights into both the planning system and the development of FRAM as an assessment tool, the identification of all descriptors was not possible within the time available for research. Other possible descriptors beyond the inputs and outputs were identified for some of the functions but could not be verified and thus, were not discussed in the data chapters. The extent of the work developed on FRAM is detailed in Appendix 9.

Overall, the information in Appendix 9 clearly illustrates the complexity of the planning system. The graphical representation shown in this appendix was produced from an application developed by one of the participants at the FRAM workshops and represents all the data from the table also given in this appendix. Each connection between functions represents a shared descriptor. Regarding the development of FRAM, the following remarks can be made, based on the experience of its application to the planning of rail engineering work:

- An extensive and thorough knowledge of the system must be acquired before a full and complete “FRAMing” can be developed. Not only the identification of functions must be based on a profound understanding of the system, but also the identification of all six descriptors cannot be achieved without an in-depth knowledge of system operations. Nevertheless, as demonstrated by the work developed in this research, FRAM can provide useful data, even when all six descriptors are not fully identified.

- As in the use of most analysis tools, the purpose of using FRAM must be clearly stated from start. There can be no unequivocal rules for the definition of functions across all domains in which FRAM can potentially be used. Despite the clear definitions for descriptors provided in section 4.11.2, their identification will often require context specific criteria. Given the recent stages of development and the little amount of work on FRAM documented, having clearly stated objectives becomes a fundamental starting point for the use of this method. The fact that FRAM was used in this research, mainly as a support for exploratory work and with the intent of contributing to its development, raised some difficulties in the definition of clear starting point and objectives for the description of functions and its descriptors.

- FRAM was used in this research to develop a description of the formal planning system. Comparison of the formal process against an informal description can provide important support to the identification of gaps between formal and informal knowledge of system operations (Dekker, 2006). However, the lack of clarity between the formally documented system and the actual system operation may lead misinterpretations of system interactions and their variability.

- Although FRAM can support important system analysis without it, eventually a graphical representation becomes fundamental, in particular to simulate FRAM instantiations. The value of visual scenarios has been amply explored by Schock (2010) in relation to the delivery of rail engineering work. Graphical tools promote comprehensibility, reflection and improved coordination and planning towards the object of representation (system complexity in this case). Schock (2010) quotes a participant in his research approach when saying that visual scenarios provided "an excellent opportunity to reflect on what we do on a daily basis and question some of the routine decisions we make".

- Overall, FRAM must be considered within the scope of a longitudinal analysis of systems. The use of this tool requires an extensive collection of data from different aspects of systems in order to provide adequate support, either in the design or the monitoring of the system. The full potential of FRAM is believed to reside in the accumulation of system data over time, in such a way that the evolution of interactions between functions of the system can be perceived and understood. This can provide a broad perspective of the variability of system operations and the identification of potentially undesired resonance.

8.3.2. Understanding the potential for resilience

The semi-structured interview process provided ample contribution for the understanding of the planning system, not only of its main human and organisational factors, but also of its sources of resilience. In this latter case, the literature background, against which relevant issues from the interviews were discussed, provided useful information on how such issues impact on planners' performance. This discussion was developed in section 7.1 and was then used to support the development of part 2 of the questionnaire, as detailed in section 4.10.3. The high ratings attributed by respondents to statements in this part of the questionnaire confirmed the relevance of the issues emerging from the interviews. Two of these issues were assessed by respondents as having a more significant impact on the performance of planners:

- Having trustworthy work contacts within the planning organisation (issue 7)
- Understanding the impact of planning decisions on delivery (issue 10)

Overall, the 10 statements assessed were found to be significantly correlated, as shown in Table 7.12. The study of these correlations provided further understanding of human and organisational factors that impact on planners' performance and was earlier presented in section 7.4.7. This section interprets the identified correlations within the acquired knowledge of the planning system in order to identify possible sources of resilience.

Figure 8.3 illustrates all correlations significant at 0.01 level between the aspects assessed in part 2 of the questionnaire. Thicker lines between aspects designate stronger correlations (above 0.500).

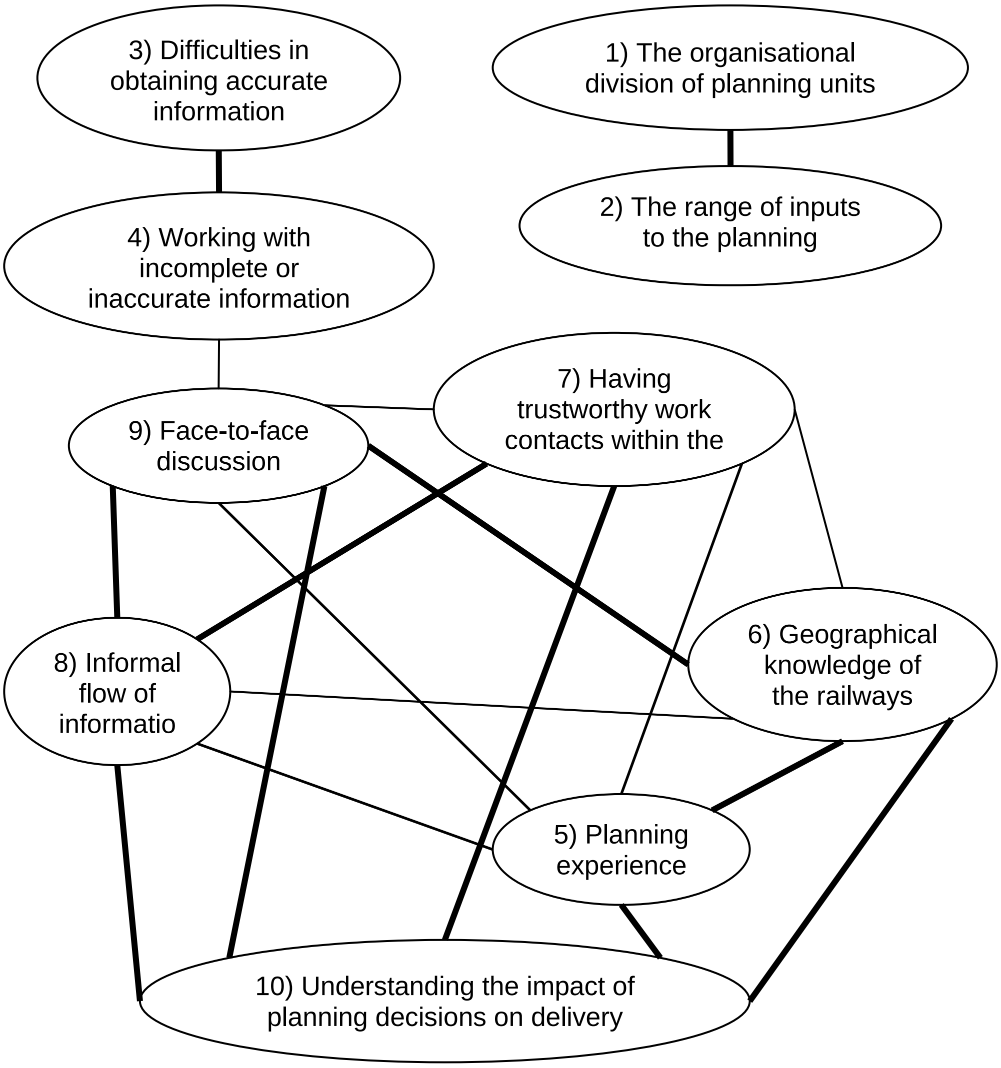


Figure 8.3: Representation of correlations between aspects assessed with part 2 of the questionnaire

Given that all aspects were predominantly rated with high scores (Figure 7.13 in section 7.4.7), all correlations found are positive, which means that for instance, the higher planners consider to be the impact of "having trustworthy work contacts", the higher they also consider to be the impact of "informal flow of information".

Figure 8.3 is consistent with the way in which aspects were initially defined by the fact that aspects impacting negatively on the performance of planners have no correlation with those impacting positively. Only “working with incomplete information has shown a relatively weak correlation significant at the 0.01 level with “face-to-face discussion” (0.363). Face-to-face communication occurs almost exclusively during planning meetings. This correlation might indicate that incomplete or inaccurate information can sometimes impact on the quality of face-to-face communication, as during meetings it is not always possible to chase missing or inaccurate details. This would require extending the planning meeting throughout the day, in order to gather the necessary information to overcome issues.

Within the scope of these two separate traits shown in Figure 8.3, mechanisms towards reinforcement of resilience and those eroding it can be outlined as follows:

- Aspects that tend to reinforce planners’ performance (aspects from 5 to 10) are more interdependent, as they registered a considerably higher number of correlations amongst themselves. Each of the six aspects was found to be correlated to the other five. In particular, as discussed in section 7.4.7, “understanding the impact of planning decisions” shows some of the stronger correlations (all represented in thicker lines in Figure 8.3). In line with the discussion developed in section 7.1.8, the more planners are able to understand how their decisions may impact on delivery, the less uncertain the feel about those decisions. Hence, this understanding is at the core of managing uncertainty in planning. As argued throughout section 7.1, understanding the impact of decisions requires accurate and reliable information (aspects 8 and 9), which planners seek to obtain through informal contacts (aspect 7). The information planners pull from the system is then interpreted in view of their experience and overall knowledge of the railway (aspects 5 and 6), in order to develop an adequate understanding of the work delivery scenarios undergoing planning. **This awareness contributes to resilience, as it facilitates the management of planning changes by supporting decisions regarding which changes should be integrated to improve efficiency of work delivery and which should be refused to prevent undesired delivery (and deliverability) risks**.
- The four aspects impacting negatively on planners’ performance

(aspects 1, 2, 3 and 4) have shown two particularly strong correlations. The "organisational division of planning units" was found to be significantly correlated to the "range of inputs", which is consistent with the arguments presented in section 7.1.3 regarding the broadness of the planning system and its geographical and organisational dispersion. As discussed in sections 7.1.3 and 7.1.5, the range and variability of inputs are also a source of uncertainty in decision making. A second significant correlation was identified between the "difficulties in obtaining accurate information" and "working with incomplete or inaccurate information". It can be easily assumed that the more difficult it becomes to obtain accurate information, the more planners are forced to work with inaccurate information. As argued in section 7.1.5, the inaccuracy of information is also an important uncertainty factor for planners. Poor information, not only generates frequent planning changes, but it also was identified by all planners as the main source of uncertainty and unpredictability regarding the performance of the system as whole. Hollnagel (2011a) placed at the core of achieving and maintaining resilience the ability to cope with the variability and uncertainty inherent to complex operations. **Within this scope, both the variability and range of inputs, and the inaccuracy of information, can be considered a hindering factor to resilience in the planning system, or contributing to its brittleness**.

The interdependencies described between the aspects that impact on the performance of planners provided useful insight into the sources of resilience in planning. While factors that may hinder resilience are fundamentally generated by the complexity of the system, those contributing to resilience are mainly derived from informal strategies of communication used by planners. On the one hand, the organisational fragmentation and the variability and inaccuracy of information, increase the uncertainty which planners have to manage throughout decision making processes. On the other hand, the experience and overall knowledge of the system, and the informal flows of information, aim to cope with uncertainty and better manage planning changes through an improved understanding of decision making problems. From this perspective, the six aspects impacting positively on planners' performance, which were rated highly in part 2 of the questionnaire, are in fact facilitating factors of planners decision making and can therefore, contribute to enhanced potential for resilience.

8.3.3. Measuring resilience

The discussions developed within the scope of the international collaborations around the subject of resilience engineering and FRAM often focused on the need to measure and monitor resilience. The assessment carried out with part 1 of the questionnaire and the subsequent principal components analysis contributed to this end, as shown by the work already published (Ferreira *et al*, 2011).

The extracted components underline a relation between the questionnaire and resilience engineering constructs, hence showing a potential use as measurable factors (Ferreira *et al*, 2011). These components were earlier defined in Table 7.10 and are here recalled:

- Adaptability and flexibility
- Control
- Awareness and preparedness
- Trade-offs
- Time management

Despite this potential, the approach taken here requires further experimentation, in order to respond to two fundamental questions:

- Other statements and issues should be tested as potentially useful contents for the questionnaire. Despite the extensive analysis of resilience definitions and concepts which supported its development, the questionnaire used in this research requires further testing and alternative statements should be investigated in order to better approach aspects of planners' performance which might be relevant for the "emergence" of resilience at system level. As suggested in the previous section, issues more directed at uncertainty in decision making and at means to cope with it, should be explored.
- As Kline (1994) points out, the validity of extracted components and their interpretation should be thoroughly tested. Although the approach taken in this research for the interpretation of extracted components

was founded on demonstrated methods and literature, the methods should be reproduced in different contexts and timings in order to be fully validated.

The design of questions constitutes one of the main challenges of this approach. On the one hand, as basic principle in the design of questionnaires, statements must be designed in such a way that respondents can relate them to their normal every day activities, without which statements can become easily misinterpreted and compromise the validity of the data obtained. On the other hand, for the purpose at hand, it is also fundamental that statements reflect system level aspects with relevance for resilience. Resilience engineering is currently a relatively recent discipline and its concepts are certainly beyond the scope of "common knowledge". Hence, some of these system aspects may regard issues with which respondents might not be familiar with, which can contribute to the misinterpretation of the questions asked. This was explored during the iterative process used to develop statements for this part of the questionnaire. Often statements initially proposed by the researcher, aiming to have a close relation with resilience engineering concepts, had to be reworded to avoid potential sources of misinterpretation identified by the peer reviewers from the ergonomics team.

As discussed in section 3.4.6, the Resilience Analysis Grid proposed by Hollnagel (2011b) relies on the development of questionnaires relevant for each of the four basic resilience capabilities. The questionnaire approach taken in this research for the measurement of resilience can contribute for the development of a RAG in engineering planning. In particular, the use of a principal components analysis method can be proposed as a way to validate the questionnaires that are required to assess the four main capabilities.

8.4. The reorganisation of planning

Throughout the duration of this research, the planning organisation underwent profound transformations. Despite the difficulties that this represented from a methodological point of view, it provided a great diversity of opportunities to follow up on the on-going reorganisation and on some occasions, cooperate with people developing work within the scope of the transformation programme.

An initial report based on the outcome of the interviews was produced, upon the interest shown by planners on learning more about the results and the process itself. This report was primarily disseminated amongst participants in the interview process and was later, on a number of occasions, requested by other members of the planning organisation and by people working at the time in relation to the transformation of planning. Towards the conclusion of research, which coincided with the initial steps of the implementation of the current organisational structure of planning (as in Figure 2.3), there were several opportunities for informal exchanges of information with project managers leading the transformation programme. This contributed to a better understanding of the planning organisation and of the objectives and motives driving the transformation programme. In particular, this was the opportunity for the exchange of data, which similar to the approach taken in this research, members of the project team for the reorganisation of planning were also extracting from PPS. This reinsured the views expressed in this thesis regarding the need to develop means of monitoring and understanding planning performance and the relevance of planning changes towards this end.

8.5. Recommendations

This section produces recommendations to promote safety and efficiency in rail engineering through improved planning, as defined by objective 6. The conclusions of this research come at a time when the transformation programme is concluded or at its final stages. Nevertheless, recommendations in the following sections can be drawn from the work described in this thesis, which can contribute to further improvements of the planning of rail engineering work and some, perhaps useful as well, to the broader engineering system. Recommendations are highlighted in the up-coming sections with bold characters.

8.5.1. Empowerment of planning

The implementation of formal and national processes such as PL0056 and PL0086 was broadly considered by planners as a major contribution to the integrity of planning. Having this formal support, planners were able to impose common mile-stones and deadlines to stakeholders. Despite this improvement, poor information flows and communication breakdowns remain one of the main constraints for planners. Often, the origin of problems and planning conflicts was untraceable and information sources potentially unreliable. All planners expressed their conviction that the creation of an autonomous planning structure could result in significant improvements, as opposed to a disseminated ownership among several functions in and out of the organisation.

The adoption of a structure similar to the model used under the West Coast Main Line Modernisation Programme can help shift away from a system with no specific ownership into which stakeholders input as they can (or as they will), thus transferring their own operational pressures onto planning.

As planners expressed during the interviews, solving planning problems such as access conflicts between work packs or between train routes requires detailed understanding of the work, in order to establish priorities and decide accordingly. Such details are often not provided, incomplete or inaccurate, which renders decision making processes considerably more uncertain. Thus, in order for planners to have control over decision making processes and the effective management of planning priorities and needs, information flows must be considerably improved. Most of the Area Delivery Planning Managers (ADPMs) interviewed recalled having at some point, received instructions from higher management levels requesting that a particular change (frequently accepting additional work) be agreed.

The organisational structure of planning must be provided with the means (and the responsibility) to make "sacrificing decisions" against excessive business production pressures. Planners must be given access to information which allows them to realise when changes to planned work are compromising allocated critical resources and given the responsibility to refuse such changes.

8.5.2. Training and experience in planning

Job experience and knowledge of the railway were frequently mentioned as fundamental assets for the reliability of planning. The organisational transformation appears to have been accompanied by the retirement and reallocation of considerable numbers of experienced planners and by the placement of new people, in some cases, with no experience at all in the rail industry. This may jeopardised the continuity of fundamental work practices and planning expertise, which ceases to be transmitted from senior planners down to junior ones.

A formal and structured form of training and induction into planning can be an important element in the strengthening of planning good practices and a contributor for the robustness of the planning system.

The pursuit of the study on planning archival data and the improvement of performance indicators can provide important support for the identification of planning good practices. The data explored throughout this thesis and the overview of planning performance by areas earlier discussed (section 8.3) demonstrates the potential of this approach.

Good practices should then be disseminated through more formal planning training or, as suggested by Axelsson (2006), through engineering discussion forums.

8.5.3. National robustness versus local flexibility

The scale and complexity of the railway system is entirely compatible with the principles of underspecification and uncertainty. This was shown in the literature to be incompatible with strict and rigid planning processes and centralised control of operations. While local autonomy may be useful to respond to unforeseen issues and adjust planning to emerging work needs, some level of rigidity is necessary to avoid the wasting of resources. **Two conflicting planning needs must be balanced**:

- **Centralised planning is needed to optimise resource allocation at national level**. For instance, some of the crucial resources for renewals work such as engineering wagons and some of the most higher performance and complex track machinery, must be allocated with considerable time before work delivery, so that all the necessary details can be planned, namely, the rostering of the necessary staff, the definition of routes and schedules to enter and exit possession and to and from depots. Late changes to the planning of such resources can compromise, not only formal agreements with TOCs regarding access, but also the efficient utilisation of resources and generate conflicts with other events within possessions or with the route of other train services on open lines.

- **Planning must ensure a certain degree of flexibility in order to respond to emergency maintenance work and other unforeseen issues that can compromise deliverability of work**, such as staff absenteeism, equipment breakdown or extreme weather conditions that can delay work progress. Having access to information in an accurate and timely manner, many of such problems, or the likelihood of issues become problems, can be anticipated and delivery plans adjusted accordingly.

The management of planning changes is at the core of the balance between these two opposing requirements. The key issue is **generating information that can support the understanding of what changes should be accepted as improvements of resource allocation, and up until which point in time and stage of the process these changes should be admitted without compromising robustness and safety of the plan and long-term engineering commitments**. **This information should also support the identification of changes that can be admitted beyond this point, as adjustments to unforeseen issues, and those that should be rejected for safety reasons**. McDonald (2006) approaches these issues while discussing studies on the comparison of aircraft maintenance practices, mainly a traditional top-down planning, with no flexibility for operational feedback and adjustments, against coordinated efforts for planning adjusted to variations of the operational environment.

8.5.4. Cooperation between planning, delivery and operations

The relation between planning and delivery is clearly a crucial one for both the reliability of the plan and the safety and efficiency of work delivery. While a safe and efficient delivery relies on the reliability of the details prepared during planning, feedback from delivery is a fundamental source of engineering expertise and local infrastructure knowledge. **The exclusion of those responsible for managing and overseeing work delivery from the entire planning process represents an obstacle to an efficient exchange of information between planning and delivery.** It cannot be accepted that PICOPs disregard the information that is handed to them during briefings on the day before, because it is likely to change from the day to the night, or stating that they have no knowledge whatsoever of engineering planning, including that it is a complex process which develops throughout a period of approximately 18 months.

PICOPs should be called in to planning meetings to offer advice regarding the admissibility of certain late changes and the potential impacts that these may have on the remaining work planned for a given possession. This has also been described by PICOPs as a more efficient way of learning about the work to be delivered and which they will be managing on the night, as opposed to reading about times and places on PICOP packs on the day before.

Whenever complex movements of machinery and engineering trains are involved, the presence of signallers from local signalling boxes has also been described as good practice, both by planners and signallers who have had such experiences. Similar to PICOPs, signallers also considered that this helps preparing for the signalling work which will be required by possessions with numerous movements.

The fact that PICOPs and signallers have tight and variable work rosters to comply with represents an obstacle to the dissemination of these good practices. In particular, PICOPs are normally working nights and have difficulty in attending meetings during day time. **Improved coordination between planning meeting timings and rosters can be achieved in order to allow this kind of useful expertise to be called into planning meetings whenever necessary**.

Beyond the added value of this cooperation during planning, an efficient communication between PICOPs, signallers and control centres has been described as a useful resource in the mitigation of incidents on the night of work delivery. For instance, if a PICOP foresees a likelihood of a possession overrun, by communicating this to signallers and control centres, arrangements can be made to minimise possible impacts on train services, among other benefits.

Overall, from a resilience perspective, **the cooperation and communication at different levels and stages of the engineering work cycle, between planning, delivery and operations, represents a valuable contribute towards the ability avoid something bad from**

happening, the ability to survive by minimising the impact of incidents and the ability to recover quickly to normal operations.

8.5.5. Resilience in planning and resilience in the engineering system

This thesis investigated planning based on the notion that its purpose is to develop reliable information to support a safe and efficient delivery of engineering work. From this perspective and in line with the arguments presented in section 3.5, planning should be the source of management of uncertainty for work delivery, either by minimising it or by providing means to cope with it (Grote *et al*, 2009). Decision making in planning must manage uncertainty in such a way that it is not transferred down to delivery.

A balance should be achieved between self-contained tasks that can locally reduce complexity of decision making, and the integration and articulation of the whole planning decision making process so as to avoid fragmentation and excessive complexity of the planning system.

Two approaches to the management of uncertainty should be considered complementary towards achieving and maintaining resilience in planning:

- Decisions addressing details of work that should not be submitted to later changes (critical resource allocation, train routes, among others), should be seen as the definition of rigid boundaries according to which the remainder (less critical) details of work should be planned. Such decisions would contribute to minimise uncertainty as they would limit the possibilities for further planning. As a basic example, if a track renewals job is agreed and the necessary train routes are planned, at the scheduled time and path of these trains, no other work is viable. The approach of planning processes so far has been to establish critical resources as soon as possible. Keeping in mind the principles of underspecification and complexity, the sooner these decisions are made, the more likely it is they will have to be submitted to later changes, as new conditions emerge and adjustments have to be made. Within this scope, **attempts should be made to address critical decisions as close as possible to delivery, leaving only the time necessary to plan and schedule less critical work details**.

- Having decided and agreed on the scheduling and allocation of critical work and resources, less critical work such as minor maintenance work, requiring smaller windows of access and few resources, can be slotted in to the plan as close as possible to delivery in order to provide enough flexibility to respond to emergent work needs. **This would be where close cooperation between planning and delivery (MDUs in this case) becomes more relevant, as it can improve the ability to locally (at area or MDU level) cope with uncertainty**.

The timing at which critical planning details should be finalised and barriers raised against any changes to them, may depend on the type of work and the profile of the infrastructure in question. However, it should be kept in mind that **the purpose of imposing a deadline for decision on critical planning details is to achieve a national coherence of the plan, and thus it may not be realistic to have it subjected to any variability**. Regarding less critical work and planning decisions with no impact on previous national agreements on critical work, eventually **deadlines must be established in order to ensure that necessary arrangements for a safe access are made**. However, these are likely to be manageable more flexibly at a local level, and according to local needs.

The arguments previously presented suggest the **adoption of planning rules and procedures that can ensure a dynamic balancing of the need for a plan robust at national level with minimised uncertainty, against a local need for flexibility and means to cope with uncertainty**.

8.6. The research methods

The investigation of planning in rail engineering and the broad system approach documented in this thesis constitute two considerable research novelties. Interview approaches have an extensive tradition in social sciences and in human factors research. As in this particular research, they have often demonstrated their value as approaches to task and job analysis. The study of archival data on such a large scale has proven challenging but with an extensive added research value for both the understanding of the context under investigation and the development of more in-depth quantitative analysis of its performance. The gathering of data on a wider time scale is likely to provide more solid grounds for statistical analysis and further pursue the work initiated in this thesis.

Work that more directly addressed resilience aspects in planning was clearly the area with less background support. The use of a questionnaire approach within this scope has only recently been proposed in literature by Hollnagel (2011b). This method was found to be an efficient means of assessment and monitoring for resilience, without having to resort to complex metrics. The work initiated in this thesis should be further pursued in the sense of “fine-tuning” statements and questionnaire structure, by reproducing the application of the questionnaire within planning. The reproduction of this approach will also provide additional support to further investigate and validate the resilience constructs extracted by means of the principal components analysis method. Factor analysis methods tend to consume a significant part of the restricted time available for research, which may discourage its use. Nevertheless, beyond the assessment of resilience factors carried out, this approach can potentially support the development of a Resilience Analysis Grid (RAG) in planning.

9. Conclusions

The research developed is one of the first few approaches dedicated to the study of planning in rail engineering, both from a human factors and a systems perspective. Up until recent years, the planning of rail engineering work was barely recognised as an organisational function. A detailed description of the planning organisation did not exist within Network Rail or in the wider rail industry. The published work found on the subject provided a relatively small research background on which to ground this study, which constituted one of the first and most significant challenges. From this starting point, the research carried out contributed extensively to the understanding of planning within the domain of rail engineering. This required a broad system analysis, as opposed to the investigation of particular aspects or parts of the planning system. The full time placement at Network Rail's central offices, working in cooperation with the Ergonomics NST, was crucial for the widespread access to data sources and to gather all the conditions necessary for the participative work carried out, which extended at a national level and within many different levels and functions of the organisation.

The exploratory work carried out (as discussed in section 4.2) produced a thorough description of the planning system and its boundaries. Planning was fundamentally described as a decision making process that manages business strategic targets (i.e. investments) against engineering needs (i.e. maintenance) and operational constraints (i.e. access). The main contributions for the knowledge and understanding of rail engineering planning can be summarised as follows:

- Managing planning changes is the single most complex challenge that planners are faced with. Not only does poor information and communication breakdowns at system boundaries increases uncertainty in decision making, but also little organisational and operational autonomy is given to them in terms of control over planning decision processes as whole.
- Informal communication together with job experience and understanding of the rail industry are the most important means of managing uncertainty in planning decision making by contributing to an

increased awareness regarding the potential impacts of decisions on work delivery.

- The analysis of the sequence of planning changes showed that earlier planning decisions are frequently reversed at later stages and that this occurs beyond the deadlines imposed by the planning process, which shows that a considerable part of the planning activity is not developed "to the process". Beyond the fact that this means that planning is partly uncontrolled (at least formally), it demonstrates the need for adjustments which can meet the existing gap between formal and informal procedures.
- Despite the efforts towards a national planning process and "one way of doing things", the archival data investigated showed a considerable diversity of trends in planning performance. From region to region, the rail infrastructure is characterised by different degrees of complexity, and requires different types and volumes of work to respond to, either investment scopes or maintenance standards. Planning was found to respond very differently to such demands, even when faced with similar infrastructure profiles and engineering and business requirements.

It is important to recognise that planning is charged with, and made responsible for, critical business decisions but lacks fundamental organisational aspects to support such complex decision making processes. The planning system must be empowered to make critical planning decisions withstand operational and business pressures. The lack of ownership caused by the fragmentation of the core planning process (both top-down and cross-organisational) hindered planners' ability to maintain control over decision making processes from strategic targets down to work delivery. A considerable amount of planning activity takes place informally and outside the standards and deadlines established by formal processes. The reorganisation of planning has created a national centralised planning unit under NDS, which appears to have contributed towards increased ownership and control over planning decision making processes.

The planning system must also develop local flexibility, in order to adjust planned work as necessary to respond to emerging needs. Despite the increased centralised control of planning, a considerable part of the process remains under the responsibility of engineering areas. The new planning processes (NR/L2/NDS/202 and NR/L3/NDS/302 – section 2.3) also appear to have brought in more flexible principles to the management of planning activities. These two factors could contribute to the local empowerment of planners, necessary to recognise and adequately integrate whatever late changes are needed to respond to unforeseen problems, as opposed to having considerable volumes of uncontrolled changes just hours before work delivery.

The increased ownership and local empowerment of planning must be accompanied by the consolidation of planning expertise and dissemination of good practices. Even with improved information flows in the process, planning experience and knowledge of the railway are fundamental resources to understand how decisions may impact on delivery or realise when further input from planning stakeholders is necessary to solve complex engineering or operations problems.

9.1. Further research

The extent of exploratory work carried out has given an important background to support a more in-depth study of specific planning issues, in particular regarding the relations between the planning system and its operating environment:

- The data sources investigated only allowed for the quantification of planning changes. Beyond the volumes and timings of changes, the analysis of the types of changes submitted to planning and those rejected may improve the understanding of how planning influences delivery and thus, contribute to the understanding of how planning can be improved towards better supporting work delivery.
- Beyond the numbers and types of assets, more detailed knowledge of the characteristics of the infrastructure can also contribute to a better understanding of the constraints and engineering demands that can be imposed on planning. For instance, data regarding the annual tonnage that operates in different areas (volume and type of train traffic operating) or the proportions of non disruptive and disruptive access that each area uses, among others, can contribute to better understand these relations.

Although the sample of data extracted from PPS represented approximately 36% of all the work within the timescale considered (three weeks), this corresponded to only 2.2% of the expected yearly volume of work planned. This suggests that, despite the focus on developing a representative geographic and time base of analysis, a longer-term sample may be required to recognize clearer patterns and assess the magnitude of the variability in planning performance.

Throughout this research, it became apparent that informal communication considerably contributes to decision making processes. Although the time and geographical frame in which such exchanges of communication may occur render this analysis quite challenging from a methodological point of view, this can provide useful insight towards better understanding human and organisational factors in planning. Keeping in mind that a great deal of the informal exchange of information and of uncontrolled planning change tends to occur within the last few days before delivery, further investigation should be considered with a higher focus on engineering area level of planning and its relations with Maintenance Delivery Units.

The pursuit of resilience research in rail engineering can contribute to the monitoring of business pressures on planning and how planning can better cope with such pressures. The reformulation of the questionnaire approach, in view of the findings debated in this thesis and of the most recent resilience engineering literature published, can be the foundation of a robust method of measuring planning resilience and monitoring its sources. Further extending the “FRAMing” of the planning system can also support the identification of critical system interactions in terms of managing uncertainty in decision making. In particular, work towards reproducing the informal planning system, rather than the formal one, constitutes an area of interest for the development of both the knowledge of rail engineering planning and of the discipline of resilience engineering.

9.2. The challenges for the success of railways

Recent events around the UK rail industry suggest that the near future should be faced with particular caution. Within the scope of CP4 and CP5, additional engineering challenges are imposed on Network Rail and its stakeholders in view of further enhancements of the rail infrastructure, whilst further efficiency demands must be met (cost reductions, among other specific objectives). These targets will most certainly increase operational pressures, which already show signs of eroding overall system defences. Only during the year of 2007, two particular occurrences at very different levels of the engineering organisation suggest this:

- The derailment of the Virgin train at Lambrigg on 23, February 2007, which among other causes, was directly related to local resource shortages and the inability to respond to maintenance needs under continuous resource limitations.
- The serious possession overruns occurred in the Christmas period, as detailed in sections 6.2.3 and 7.2.5, were originated by an unprecedented volume and complexity of work planned, and the way in which both planning and management and supervision of work delivery were unable to cope with such demands.

As an interesting fact, the report of the Office of Rail Regulation (ORR, 2008) recommended to Network Rail the development of mutually beneficial contractual relationships with its supply chain and a genuine spirit of partnership in project delivery along the lines adopted by British Airport Administration (BAA) for major projects such as Heathrow Terminal 5. It should be pointed out that just months after the publication of this ORR report, Terminal 5 was inaugurated and rapidly demonstrated serious operational problems, which were traced back to its original scheme and project development.

Overall, these developments bring increasing relevance to the research of resilience, not just in planning, but also in the broader rail engineering system. At the very least, the potential benefits of better “engineering” resilience in the rail system in terms of ensuring a safe and efficient rail transport, makes the challenge of such research an appealing prospect.

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11. Appendices

1. Contents of the Weekly Operating Notice (WON)
2. Equated Track Miles conversion table
3. Sample of table created for the analysis of meeting minutes
4. Sample of tables created for the analysis of PPS data
5. PossMan data
6. Sample of control logs
7. Questionnaire
8. Analysis of possession overruns during the Christmas 2007
9. Work developed with FRAM

1. Contents of the Weekly Operating Notice (WON)

SECTION B - ENGINEERING ARRANGEMENTS.

At or Between	Lines Affected	Remarks

NW1001 NORTON BRIDGE TO PRESTON (FYLDE JN.)

SATURDAY 12 to SUNDAY 13 JULY

Ref. No. P2008/979421 Possession Manager Network Rail

Item	At or Between	Lines Affected	From	To
Item 1	Stafford No.5 SB (SD5) and Crewe South Jn	Down & Up Fast BLOCKED T3	2105 SAT	2200 SAT
	Norton Bridge North Jn and Stone Jn	Down and Up Main BLOCKED T3	2105 SAT	1330 SUN
	Norton Bridge South Jn and Norton Bridge North Jn	Up & Down Recess BLOCKED T3	2105 SAT	1330 SUN
	Stafford Trent Valley No1 Jn and Crewe South Jn	Down & Up Fast BLOCKED T3	2200 SAT	2315 SAT
	Stafford Trent Valley No1 Jn and Stafford No.5 SB (SD5)	Platforms 1 & 3 BLOCKED T3	2200 SAT	2315 SAT
	Stafford Trent Valley No1 Jn and Crewe South Jn	Up Slow BLOCKED T3	2230 SAT	2315 SAT
		All Lines BLOCKED T3	2315 SAT	0815 SUN
	Penkridge and Stafford Trent Valley No1 Jn	All Lines BLOCKED T3	2315 SAT	0815 SUN
	Basford Hall Jn SB and Crewe Sorting Sidings North	Down Fast Independent BLOCKED T3	2315 SAT	0815 SUN
		Down Slow Independent BLOCKED T3	2315 SAT	0815 SUN
		Up Independent BLOCKED T3	2315 SAT	0815 SUN
		Up Through Siding BLOCKED T3	2315 SAT	0815 SUN

Remarks:

Other E&P Work
132m70ch and 134m20ch
W2008/1668013

C15 Drainage Only
154m30ch and 156m50ch
W2008/1951077

Preparatory Work
145m15ch and 147m60ch
W2008/1933839

S&T Work
132m70ch and 134m20ch
W2008/1918577

S&C Maintenance
132m70ch and 134m20ch
W2008/1918582

S&C Maintenance
138m35ch and 139m10ch
W2008/1918623

S&C Maintenance
3m57ch and 3m40ch
W2008/1918646

Structures Examination
25m55ch and 28m35ch
W2008/2072411

S&C Unit Renewal (Maintenance Only)
155m30ch and 156m40ch
W2008/2065896

OHL Work
152m0ch and 153m41ch
W2008/2109677

S&T Work
143m0ch and 144m0ch
W2008/2130487

Structures Work
133m70ch and 134m3ch
W2008/2105710

Survey Work
142m20ch and 142m40ch
W2008/2107519

London North Western (N) WON 16 - 2008/2009 Page B-2

SECTION B - ENGINEERING ARRANGEMENTS.

At or Between	Lines Affected	Remarks

NW1001 NORTON BRIDGE TO PRESTON (FYLDE JN.) - Continued

ITEM 1 CONTINUED

Stafford Trent Valley No1 Jn and Crewe South Jn	Down & Up Fast BLOCKED T3	0815 to 1330 SUN SUN
Stafford Trent Valley No1 Jn and Stafford No.5 SB (SD5)	Platforms 1 & 3 BLOCKED T3	0815 to 1330 SUN SUN

ISOLATION OF ELECTRICAL SECTIONS

21:05 Sat to 13:30 Sun
SW 1, 2, 5 & 6 (Complete)
CW 13, 14, 17 & 18 (Complete)
Stafford Neutral Section to Basford Hall TSC Fast Lines Only Blocked To Electric Traction.

23:15 Sat to 08:15 Sun
SW 3, 4, 7 & 8 (Complete)
CW 15, 16, 19 & 20 (Complete)
Stafford Trent Neutral Section to Basford Hall TSC Slow Lines Only Blocked To Electric Traction.

23:15 Sat to 08:15 Sun
LQ 9 & 10 (Complete)
Gailey TSC to Stafford Queensville Neutral Section Blocked To Electric Traction.

PROTECTION LIMITS

2105 SAT TO 2200 SAT
Down Fast, Down Stone, Up & Down Recess: 68 B pts (SD5) to CE107, NS4333
Up Fast, Up Stone: CE104, NS4332 to SD5:139
2200 SAT TO 2230 SAT AND 0815 SUN TO 1330 SUN
Down Fast, Stafford Platform 3, Down Stone, Up & Down Recess: SD4:84 to CE107, NS4333
Up Fast, Up Stone, Stafford Platform 1: CE104, NS4332 to SD4:215
2230 SAT TO 2315 SAT
Down Fast, Stafford Platform 3, Down Stone, Up & Down Recess: SD4:84 to CE107, NS4333
Up Fast, Up Stone, Stafford Platform 1: CE104, NS4332 to SD4:215
Up Slow: CE102 to SD4:216
2315 SAT TO 0815 SUN
Down Fast, Stafford Platform 3 Down Stone, Up & Down Recess: SD4:84 to CE107, NS4333
Up Fast, Up Stone, Stafford Platform 1: CE104, NS4332 to SD4:215
Down Slow, Down Birmingham, Stafford Platform 6, Up & Down Goods, Down Fast Independent, Down Slow Independent: SD4:87, SD4:203 to CE105, BH29, BH30
Up Slow, Up Independent, Up Through Siding: CE102, BH60, BH62 to SD4:216, SD4:200

TRAFFIC REMARKS

2105 SAT TO 2230 SAT AND 0815 SUN TO 1330 SUN
TRAINS TO TRAVEL OVER SLOW LINES. AT NORTON BRIDGE NO ACCESS TO/FROM STOKE LINES, TRAINS TO BE DIVERTED VIA CREWE AND WILMSLOW.
2230 SAT TO 2315 SAT
DOWN SLOW LINE TO REMAIN OPEN FOR LAST DOWN SERVICES.
2315 SAT TO 0815 SUN
ALL LINE BLOCK PERIOD
2100 SAT TO 1330 SUN
ACCESS TO CREWE CS FROM THE CREWE DIRECTION ONLY.
2200 SAT TO 2230 SAT AND 0815 SUN TO 1330 SUN TRAINS TO BE REPLATFORMED AT STAFFORD.

London North Western (N) WON 16 - 2008/2009

2. Equated Track Miles conversion table

Track Category	Continuous Welded Rail (CWR) Factor	Jointed Track (JTD) Factor	Switches & Crossings (S&C) Factor
035H01	0.494	0.749	1.756
035H03	0.544	0.837	2.007
035H07	0.666	1.055	2.644
035H15	0.837	1.313	3.667
035H30	1.040	1.605	5.458
035N01	0.487	0.737	1.698
035N03	0.505	0.769	1.795
035N07	0.578	0.903	2.162
075H01	0.579	0.869	2.142
075H03	0.674	1.064	3.011
075H07	0.900	1.572	5.076
075H15	1.167	1.957	7.566
075H30	1.519	2.601	12.043
075N01	0.554	0.821	1.969
075N03	0.610	0.942	2.528
075N07	0.714	1.229	3.628
075S01	0.540	0.795	1.834
075S03	0.573	0.861	2.084
075S07	0.635	1.050	2.586
105H01	0.587	0.886	2.258
105H03	0.692	1.171	3.416
105H07	0.944	1.689	5.983
105H15	1.250	2.180	9.418
105H30	1.671	3.051	15.749
105N01	0.574	0.863	2.181
105N03	0.654	1.102	3.204
105N07	0.792	1.432	5.076
105S01	0.548	0.811	1.930
105S03	0.608	1.018	2.895
105S07	0.690	1.175	3.397
125H03	0.776	1.405	5.095
125H07	1.076	2.108	9.824
125H15	1.680	3.428	18.760
125H30	2.172	4.820	35.135

3. Sample of table created for the analysis of meeting minutes

Item (WON)	Created	ADM Input Possession / Worksites	Ref.	T-32 ADM Poss / WS	Ref.	30-04-2007 Changes		T14 Draft Item	T14 Draft Poss / WS	Ref.	13-09-2007 Changes		T14 Item	T14 Poss / WS	Ref.	21-09-2007 Changes		T6 Draft Item	T6 Draft Poss / WS	Ref.	09-11-2007 Changes	
12	28-04-2007	Maintenance (Stafford)	938487					13				1										
						Block location	3				Block location	1				General remarks	1				Block location	2
											New Block	2									New Block	3
						General remarks	1				General remarks	1									General remarks	1
	12-04-2007	URFDO Inspection	1745571																		Cancel WS	1
		Track Maintenance	1745573																		Cancel WS	1
		URFDO Inspection	1745562																			
		S&T work	1745557																			
		OHL Work	1752138																			
														OHL Work	1839128	New WS	1					
17		West Coast South (MP&I)	936143					8														
						Block Time & Date	1															
		Major Projects	1721123																			
18		RuN Project (Rugby)	933787																			
											New isolation	1				Protection	3				New protection	2
											isolation	1									**Protection**	4
											Cancel protection	3									Traffic remarks	1
											New protection	2										
		Major Projects	1750184																			
19		West Coast South (MP&I)	831790																			
																New Block	1				New isolation	1
																Block Time & Date	1					
																Block location	1					
		S&C Maintenance	1418820													Cancel WS	1					
		Structures Work	1652355								Cancel WS	1										
		Major Projects	1708033																			
		S&T Work	1707384																			
		S&T Work	1707448																			
		S&C Renewals	1708718																			
		Major Projects	1708561																			
		Major Projects	1708783																			
		Major Projects	1708804																			
		Major Projects	1709281																			
		Major Projects	1709898																			
		S&C Renewals	1710073																			
		Major Projects	1709968																			
		Structures Work	1709930																			
		Major Projects	1709992								Cancel WS	1										
		Major Projects	1710361								Cancel WS	1										
		Structures Work	1710364								Cancel WS	1										
		Structures Work	1710365								Cancel WS	1										
		Major Projects	1719184								Cancel WS	1										
		S&T Work	1745566																			
		Structures Work	**1754911**																			
									Structures !	1878533	New WS	1										
									OHL Work	1878535	New WS	1										
20		IMM MDU Crewe IQRK T2D	934579																			
		S&T Work	1660956																			
21		IMM MDU Crewe IQRK T2H	934633					24														
		Patrolling	1659794																			
22		Maintenance (Stonebridge)	931588					26														
																					Protection	1
		S&T Work	1752496																			
		Track Maintenance	1752498																Remove Rail Defects		WS details	1
23		Maintenance (Stonebridge)	937178					27														
		S&T Work	1754699			WS details	1															
24		RuN Project (Nuneaton)	933895					19														
						Block Time & Date	2									Block location	3					
		S&C Maintenance	1378299																			
		E&P Work	1667897																			
		E&P Work	1667906																			
		E&P Work	1667921								Cancel WS	1										
		E&P Work	1667924								Cancel WS	1										
									Major Proje	1710360	New WS	1										
														Patrolling	1875610	New WS	1					
														Major Proje	1875946	New WS	1					

Appendices

	T6		19-11-2007			T3 Draft		29-11-2007			T3 / T1 Draft		07-12-2007		Changes beyond T1 (PPS data)		
Item	Poss / WS	Ref.	Changes		Item	Poss / WS	Ref.	Changes		Item	Poss / WS	Ref.	Changes		Date	Changes	
14																	
			General remarks	1				Cancel Block	4				New Block	1	18-12-2007	Block location	2
								General remarks	1						18-12-2007	New Block	4
															18-12-2007	General remarks	1
	S&C Maintenance		General remarks	1													
			General remarks	1													
			General remarks	1													
			General remarks	1													
	Structures !	1899323	New WS	1													
7																	
													Isolation	1			
17																	
			Block location	1				Isolation	1								
								Protection	2								
			General remarks	2													
			Cancel WS	1													
			Cancel WS	1													
			Cancel WS	1													
			Cancel WS	1													
			Cancel WS	1													
			Cancel WS	1													
			Cancel WS	1													
			Cancel WS	1													
	Patrolling	1875765	New WS	1													
	OHL Work	1944300	New WS	1													
										21							
23																	
24																	
18																	
			Cancel WS	1													

4. Sample of tables created for the analysis of PPS data

Anglia		Week 16 (12/07/2008 - 18/07/2008)									
Pos ref.	1069049	WS ref.	2108839	WS ref.	1898530	WS ref.	1899202	WS ref.	1899204	WS ref.	1899325
Item 11	24-06-08	Structures work	06-06-08	Track maintenance	25-03-08	S&T work	10-04-08	S&T work	25-03-08	Litter & Graffity	25-03-08
possession	amended	worksite	amended	worksite	amended	worksite	amended	worksite	amended	worksite	amended
possession	amended	worksite	amended	worksite	amended	worksite	amended	worksite	amended	worksite	amended
possession	amended	worksite	amended	worksite	amended	worksite	amended	worksite	amended	worksite	amended
blocked line	amended	worksite	amended	worksite	amended	worksite	amended	worksite	amended	worksite	amended
blocked line	amended	worksite	amended	worksite	amended	worksite	amended	route	created	worksite	amended
blocked line	amended	worksite	amended	worksite	amended	worksite	amended	route	deleted	worksite	amended
blocked line	amended	worksite	amended	worksite	amended	route	created	route	created	worksite	amended
blocked line	amended	route	created	blocked line	amended	route	deleted	worksite	created	route	created
blocked line	amended	route	deleted	blocked line	amended	route	created	blocked line	created	route	deleted
blocked line	amended	route	deleted	blocked line	amended	worksite	created	blocked line	created	route	created
blocked line	amended	route	created	blocked line	amended	blocked line	created	blocked line	created	blocked line	created
possession	amended	route	created	blocked line	amended	blocked line	created	blocked line	created	blocked line	created
possession	amended	worksite	amended	blocked line	amended	blocked line	created	blocked line	created	blocked line	created
possession	amended	worksite	amended	blocked line	amended	blocked line	created	blocked line	created	blocked line	created
possession	amended	worksite	created	route	created	blocked line	created	blocked line	created	blocked line	created
possession	amended	blocked line	amended	route	deleted	blocked line	created	blocked line	created	blocked line	created
blocked line	amended	blocked line	created	route	created	blocked line	created	blocked line	created	blocked line	created
blocked line	amended	isolation	amended	worksite	created	blocked line	created	blocked line	created	blocked line	created
blocked line	amended	isolation	created	blocked line	amended	blocked line	created	blocked line	created	blocked line	created
blocked line	amended		15-05-08	blocked line	amended	blocked line	created		10-10-07	blocked line	created
blocked line	amended			blocked line	amended	blocked line	created			blocked line	created
blocked line	amended			blocked line	amended		10-10-07			worksite	created
blocked line	amended			blocked line	created						10-10-07

blocked line	amended			blocked line	created						
possession	amended			blocked line	created						
blocked line	amended			blocked line	created						
blocked line	amended			blocked line	created						
blocked line	amended			blocked line	created						
route	created			blocked line	created						
blocked line	amended			blocked line	created						
blocked line	amended			blocked line	created						
blocked line	amended			blocked line	created						
blocked line	amended			blocked line	created						
blocked line	amended				10-10-07						
blocked line	amended										
blocked line	amended										
blocked line	amended										
blocked line	amended										
blocked line	amended										
blocked line	amended										
blocked line	created										
blocked line	created										
blocked line	created										
blocked line	created										
blocked line	created										
blocked line	created										
blocked line	created										
blocked line	created										
possession	amended										
possession	created										
	25-03-08										

5. PossMan data

WEEKLY ENGINEERING NOTICE Page 11 of 72 Bletchley Maintenance Delivery Unit - London North West -

Week: 8 ENGINEERING ARRANGEMENTS BY 214461

Saturday 16 May to Sunday 17 May

Ref. No. **P2009/1015070** **Agreed** **Possession Manager: Network Rail Maintenance (Bletchley)**

WON Item: ***PAF: BY 214461***

MD101 Euston to Madeley
MD105 HANSLOPE JUNCTION TO RUGBY (VIA NORTHAMPTON)

Possession Lines

Milton Keynes North Jn & Hanslope Jn	**Blocked T3**	Down and Up Fast	Sat 20:00 to Sat 23:05
Milton Keynes North Jn & Hillmorton Jn	**Blocked T3**	Down and Up Fast/Main	Sat 23:05 to Sun 08:20
Milton Keynes North Jn & Northampton South Jn	**Blocked T3**	Down and Up Slow/Northampton	Sun 01:40 to Sun 08:20
Milton Keynes North Jn & Hanslope Jn	**Blocked T3**	Down and Up Fast	Sun 08:20 to Sun 12:00

PROTECTION LIMITS

2000 SAT TO 2305 SAT AND 0820 SUN TO 1200 SUN
Down Fast. KR3253 to KR3279
Up Fast: KR3278 to KR3250
2305 SAT TO 0820 SUN
Down Fast/Main: KR3253 to KR3343#
Up Main/Fast: KR3354# to KR3250
0140 SUN TO 0820 SUN
Down Slow/Northampton: KR5255 to RY1402B pts
Up Northampton/Slow: RY1402A pts to KR5252

ISOLATION OF ELECTRICAL SECTIONS

AC: 2000 SAT TO 2305 SAT & 0820 SUN TO 1200 SUN
VD 1(c) VD 2(b)

2305 SAT TO 0820 SUN
VD 1 & 2 complete
PA 3 & 4 complete
PA-AF 3 & 4 complete
PN 3 & 4 complete
PN-AF 3 & 4 complete

0140 SUN TO 0820 SUN
VD 3 & 4 complete
PA 1(r,t) PA 2(a,b)
PA-AF 1(c,d) PA-AF 2(a,b,c)

GENERAL REMARKS

RotR section 7 Register possession.
Axle counter area Category 1 engineering works.
2000 SAT TO 1200 SUN
RUG71 & RUG77
2305 SAT TO 0820 SUN
RUG72,73,74,75
RUG78,79,80,81
0140 SUN TO 0820 SUN
RUG83 & PART SECTIONS RUG87
Engineering exam required before handback.

TRAFFIC REMARKS

2000 SAT TO 0140 SUN AND 0820 SUN TO 1200 SUN
TRAINS TO TRAVEL OVER SLOW LINES.

2305 SAT TO 0140 SUN
TRAINS TO TRAVEL VIA NORTHAMPTON.

0140SUN TO 0820 SUN
NBS ALL LINE BLOCK.

POSSESSION MANAGEMENT

PICOP:

Note: The above information is correct at the time of issue. Make no changes to these arrangements without agreement of Network Rail Planning. questions on planning procedures. PossMan or this WEN contact your local planning department.

Work undertaken outside worksites is RED ZONE WOR

06 April 2009 08:24 Week 8 PossMan WEN/IPN report by: Graham Mcl

Appendices

Week: 8 ENGINEERING ARRANGEMENTS BY 2

C 056m20ch - 056m70ch **Patrolling** W2009/2347755 BY1017185 AGD Sun 01 40 to Sun 08 2

Level 1 S&C Inspection
Plant: Hand Trolley
Access: Hanslope 1130
Shift: 01:40 Sun to ~~08:50~~ Sun

MUST ~~PASS~~ C2
TAMPER 02

S&C Inspection
Weekly Level 1 S&C Inspection of Hanslope Jn. Track to be kept clear for Inspections
All Lines
Trolley in use
Access at Hanslope
0140 Sun to 0820 Sun
No Iso

All Lines WO:. NRM (BLETCHI

D 058m00ch - 063m00ch **S&T Work** W2009/2253780 BY888728 AGD Sat 23 05 to Sun 09 0

Axle Counter Mtce
Plant: None
Access: Various
Shift: 20:00 Sat to 07:30 Sun
Axle Counter Mtce/Signal LOCs Mtce
Wheels Free Reqd
Access - Various
~~No Iso~~
~~TSR required~~

COSS 1020
S&C F
ABOVE
6220

Down & Up Main WO NRM (BLETCHI

d 059m00ch - 061m00ch **S&T Work** W2009/2253816 BY887869 AGD Sun 01 40 to Sun 08 2

Axle Counter Mtce
Plant: None
Access: Various
Shift: 01:40 to 06:50 Sun
Axle Counter Mtce/Signal LOCs Mtce
Wheels Free Reqd
Access - Various
No Iso
TSR required

Down & Up Northampton Slow WO:. NRM (BLETCHI

E 061m32ch - 064m60ch **Preparatory Work** W2009/2414671 BY1112562 AGD Sat 23 55 to Mon 05 C

Prep. 63m 1758y - 64m 1180y. U/N.
Snagging. 63m 0000y - 63m 1522y. U/N.
1x R/R, access Hunsbury Hill
Trolleys.
~~TSR required~~
NO ISO

0140 - 0750 SUN

NORTON/AMPWO:. PPSData

F 062m20ch - 065m00ch **OHL Work** W2009/2254066 BY887852 AGD Sat 23 05 to Sun 09 0

Wire Runs
Plant: 1 x SRS
Access: Blisworth
Shift: 23:05 Sat to 07:30 Sun
OHL Mtce
Wire Runs W87. W88. defects E02 Mtce
SRS Access/Egress Blisworth
G62/36.37 to G64/66.67
TSR required

Down & Up Main WO:. NRM (BLETCHI

6. Sample of control logs

01-12-08

(LNW) WON 36 (IM) item 18 Hanslope Junction - Kilsby Tunnel Down and Up Main lines blocked 0700 (Sat) – 0530 (Mon) overran until 0753 due to no tamper being booked for the work.

03-12-08

(Sc) At 0327 (Wed) it was reported that WON 36, Item 389 (NDS) Scotland East possession, Up & Down lines Markinch – Ladybank Junction, 0105 (Wed) – 0450 (Wed), was likely to overrun. Stressing issues were stated as the cause. The Up line was handed back at 0524 (Wed), and the possession of the Down line was shortened at the same time. An estimate of 0700 was given for handing the Down line back, but at 0657, it was reported that the fishplates supplied were of the wrong type. Down trains were diverted via Stirling and Perth. Fishplates of the correct type were located in Edinburgh, and were en route to site at 0741. NWR from 0912 after the plates were installed and the possession handed back.

05-01-2009

(A) WON 41 item 1, (II) Liverpool Street to Shenfield, Up & Down Main and Up & Down Electric lines blocked 0140 (Sun) to 0400 (Mon) overran until 0457 (Mon) on the Electric lines and until 0548 (Mon) on the Main lines due to shortage of staff due to illness amongst the signal testing teams, Fast clipper machine failure and difficulties encountered by tampers at the Balfour Beatty track renewals site in the Manor Park area. The tamping marks had been obscured by snow and when the snow was brushed away this also erased the marks, with the plans having to be consulted to determine the tamping requirements. This delayed OLE staff, who were following the tamper, from completing their gauging and testing work before the OLE isolations could be given up.

19-01-2009

(WX) At 0302 (Mon) the Engineering Supervisor working within (IM) possession WON 43, Item 52, Portcreek Junction - Havant, Up Main/Brighton line blocked, 2335 (Sun) – 0420 (Mon), reported that the Stoneblower machine had dislodged the railhead equipment for ‘VHF’ & ‘HFY’ axle counters, together with having damaged a length of associated cable, on the Up Main line at Bedhampton. It was confirmed that the markers for the damaged cable had apparently been washed away. The possession was handed back 18 mins. late at 0438 (Mon), and repairs & rectification were undertaken under T2X protection, with NWR at 0630.

09-02-09

(LNW) Engineers Infrastructure Investment possession Kingmoor Junction – Cove L.C. (WON 46, item 183, All lines blocked 0430 Sat – 0030 Mon) overran on the Down Main line until 0148 and on Up Main line until 0328. At 1730 (Sat) Babcock Rail reported that the Babcock Rail S&C renewals site at Mossband was running three hours late, due to difficulty in shunting ballast trains during the track renewal and ballast removal. This time was not recovered and installation of the S&C track panels commenced at 0845 (Sun). However, moving and installation of the new S&C panels proceeded much slower than planned, with the last of the track panels not being installed until 1845 (Sun), 10 hours late. By 1630 (Sun) it had been reported that the possession would overrun on the Up Main and Up Goods line until 0230 (Mon), but would be given up on time on the Down Main line and arrangements were put in place to institute Single Line Working. Ballast unloading was completed at 2036 (Sun) and tamping completed at 2330 (Sun), seven hours late. Difficulty in completing the handover of the Form 'C' Permit to Work prevented the traction current on the Down Main line from being re-energised until 0131 (Mon).

29-03-09

(LNW) At 0700, it was reported that possession planning issues had been discovered at Manchester Piccadilly. LNW(N) WON 01, Item 267 (Infrastructure Maintenance) shows various lines blocked, Slade Lane Junction – Manchester Piccadilly, 2130 (Sat) – (0700) Sun. However, in the Protection Limits section of the WON, the Up & Down Fast lines were shown as being blocked 0130 (Sun) – 0800 (Sun). The staff working in the possession were working to the latter times. However, with LNW(N) WON 01, Item 273 (Infrastructure Maintenance), various lines blocked including All lines Ordsall Lane Junction - Manchester Piccadilly and Up & Down Slow Longsight South – Manchester Piccadilly, 0700 – 0800, there was no route out of Manchester Piccadilly. Item 267 was handed back at 0716, and Item 273 was taken between 0724 and 0828.

31-03-09

(A) Anglia WON 1, Item 10 (Various lines blocked T3, London Liverpool Street – Bethnal Green / Stratford Central Junction West / Maryland East Junction, 2215 – 0545). The possession of the Down & Up Suburban lines, London Liverpool Street – Bethnal Green West Junction, was booked from 2215 to 0125. However, for this to take place, staff required the Up & Down Electric and Main lines blocked under T12 conditions to access the Suburban lines. These lines were subsequently blocked for 10 minutes, and the possession of the Suburban lines was taken at 2312. In addition, no schedule provision was made for trains requiring to call at Bethnal Green station ,which only has platforms on the Suburban lines. The WON states the possession manager as Network Rail Maintenance (Romford).

7. Questionnaire

Questionnaire for the assessment of planning decision making processes and problem solving

This questionnaire looks at how people make decisions related to planning and the areas that affect them.

Thank you for your cooperation!

Route		Territory / Area	
Title		Years of planning experience	

Section 1: Generic assessment						
Mark how much you disagree or agree with the following statements	1 - Strongly disagree	2 - Disagree	3 - Slightly disagree	4 - Slightly agree	5 - Agree	6 - Strongly agree
I receive feedback on the outcome of my planning						
I have a clear picture of how my planning contributes to the building of an integrated national delivery plan						
I manage to finish whatever plans I start						
I have all the information I need to do my work						
I have the information necessary to deal with unexpected situations						
I have the information needed to detect potential planning failures						
I have enough time to do my planning thoroughly						
I have enough time to reflect on my planning						
I am encouraged to reflect on my planning						
I revise my planning whenever new information arises						
I take into account a balance between safety and efficiency in my planning decisions						
I can adjust my way of working according to external pressures						
I can solve problems even when pressured to deliver fast results						
I can solve problems even when faced with unexpected situations						
I feel in control of my work activities						
I assess the potential safety impacts for each of my planning decisions						
I can identify when my planning decisions are pushing the boundaries of safe performance						

I can detect failures or errors in my planning before they create problems						
I have the support of my manager to make decisions						
My management does not blame me for any poor outcome of my planning						
Because something has always gone well before, I feel confident that it will continue to go well in the future						
I can communicate my decisions promptly to those that rely on them						
Section 2: Assessment of specific issues previously identified as impacting on planning						
Mark how you feel the following factors influence your performance as a planner	1 - Not at all	2 - Very little	3 - Little	4 - Some	5 - Much	6 - Totally
The organisational division of planning units (NDS, NAU, II, IM…)						
The range of inputs (formats, type of information and timings) to the planning process						
Difficulties in obtaining accurate information						
Working with incomplete or inaccurate information						
Planning experience						
Geographical knowledge of the railways						
Having trustworthy work contacts within the planning organisation						
Informal flow of information by means of phone calls, e-mails						
Informal face-to-face discussion of issues						
Understanding the impact of planning decisions on delivery						

8. Analysis of possession overruns in the Christmas 2007

List of work being delivered at national level during the period of Christmas 2007

Location	Scope of work	Work description
Edinburgh Waverley	Enhancements	Mound tunnel track lowering and installation of fixed conductor; Waverley bridge jack and girder modifications
Glasgow	S&T	Gantry erection (part of resignalling scheme)
Shields junction	Track	S&C renewals
Clyde viaduct	Enhancements	Track renewals
Annan	Enhancements	Gretna doubling project
Preston	E&P	Points heating
Farnworth tunnel	Track	Reballast, Resleeper, Rerail
Manchester	Track	S&C renewals
Sandbach	WCRM	Data load and testing of new signalling system -
Derby station	Estates	Reconstruction project - Removal of old works footbridge
Shugborough viaduct	Civils	Waterproofing
Trent Valley	WCRM	Four tracking - plain line and bridge works
Rugby-Nuneaton	WCRM	Remodelling and line speed improvements
Leamington	S&T	Enabling works (Signalling renewals)
Milton Keynes	WCRM	Remodelling and line speed improvements
Swindon	Track	S&C Renewals
Radlett Junction	E&P	Head span wire renewals
Airport Junction	Track	Great Western route performance improvement (S&C renewals)
Bethnal Green	Track	S&C renewals
Liverpool Street	Enhancements	Bridge 19 Demolition
	E&P	Contact & cantenary wire renewal, removal of 6 portals and installation of 3 six track portals
Shenfield Junction	Track	S&C renewals
Stratford	Enhancements	Extension of western underpass & demolition of signal box

Holloway – Finsbury Park	E&P	Contact & cantenary wire renewal
Stevenage	Track	S&C upgrading
Sundon & Sandridge	E&P	Neutral section renewals
Westoning	E&P	Head span wire renewals
Wrawby Junction	Track	S&C renewals
Hull Docks	Enhancements	Infrastructure refurbishment
Wakefield (Kirkgate)	S&T	Signalling interlocking renewal
Dewsbury	Civils	Under-bridge replacement
Keighley	Civils	Under-bridge replacement
Newcastle	Track	King Edward Bridge longitudinal timber replacement

Information extracted from control logs regarding events on other projects

Control log date	Location	WON / Item	Event description
22-12-07	Camden Junction - Willesden North Junction	39/8	Possession overran
24-12-07 (Mon)	Slade Lane Junction - Manchester Piccadilly	39/40 & 114	Possession causes severe line congestion and delays with the agreed train plan exceeding the line capacity at Ardwick Junction
27-12-07 (Thu)	Liverpool Street – Gidea Park	39/1	Possession overran due to the wrong crews being booked and unable to operate the tampers
27-12-07	Hessle Rd Junction - Hull Docks	39/119 & 124	Possession overran due to late installation of rails on the swing bridge, with further delays awaiting base plates to secure the rails to the bridge beams. Further delays were caused by the failure of a tamping machine

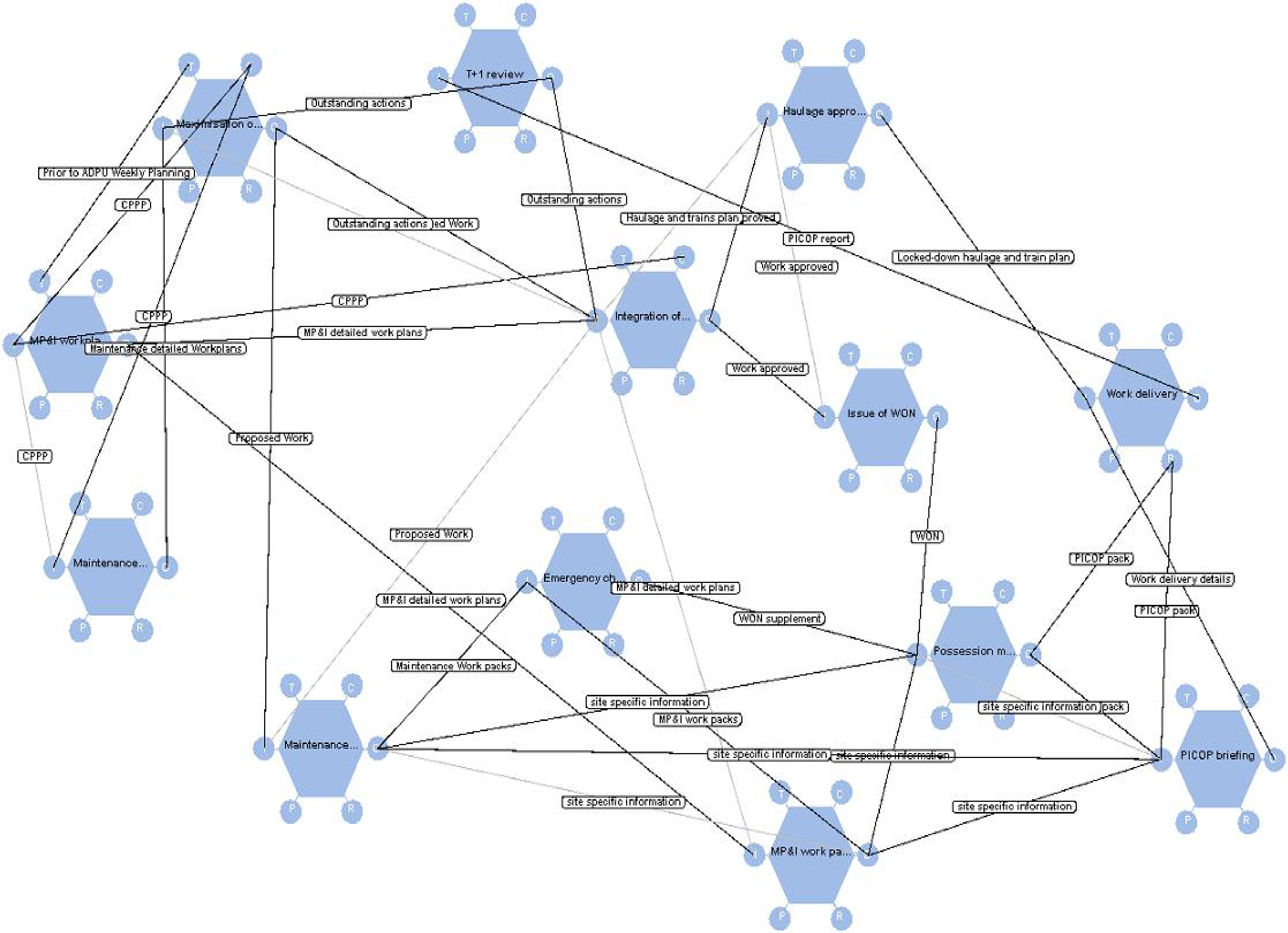
			07:00 (Wed): track renewals was running three hours late, with tamping work programmed to start at 09:00 (Wed) now expected to start at 12:00 (Wed), and work on installing rails across the Hull River Swing bridge still not completed 18:00 (Wed): tamping operations had not yet started, estimating that the Hull Docks Branch would not reopen until 15:00 (Thu) 00:21 (Thu): tamping operations on the Up Main line were completed 04:20 (Thu): tamping operations on the Down line were completed 05:00 (Thu): work on the Swing Bridge had been completed but the Up & Down Main lines would overrun until 06:15, the point work at Hessle Road would be secured with detection available in the normal position only, and the Hull Docks Branch would remain blocked until 12:00 Friday
27-12-07	St. Pancras - Cricklewood	39/23	Possession overran due to delays in work and planning error 19:40 (Tue): digging associated with the renewals work at Carlton Road Junction was 4 hours late 05:30 (Wed): Kirow cranes were taking much longer than planned to install track panels, with the work now 6 hours behind 05:00 (Thu): confirmed that the possession would overrun until 08:00 07:20 (Thu): track bonding associated with the OLE had not been completed, estimating an overrun on the Fast lines until 09:00
28-12-07 (Fri)	Hessle Rd Junction - Hull Docks	39/119 & 124	All signalling work completed but the Hull Docks branch was short of ballast, which required further unloading before tamping could commence. Estimated that the work would be completed by 06:00 (Sat)
29-12-07 (Sat)	Hessle Rd Junction - Hull Docks	39/119 & 124	00:55 (Sat): ballast was delivered to site by road and unloaded 02:48 (Sat): tamping operations were completed 05:13 (Sat): Up & Down Main lines reopened without restriction 06:40 (Sat): Hull Docks lines reopened with 10 mph ESR due to a shortage of shoulder ballast
29-12-07	Shields Junction - Glasgow		Delays to trains due to congestions. Delays exacerbated due to possession
02-01-08	London	40/1	Possession overran

	Liverpool Street – Bethnal Green		18:00 (Tue): due to a shortage of OLE staff the possession would overrun until 05:00 (Wed) 01:40 (Wed): OLE work would be completed by 02:30 on the Main and Suburban lines, and OLE work would be completed by 04:00 03:00 (Wed): completion estimate was revised to 07:00 05:00 (Wed): Area E&P Engineer reported that, having walked through and examined the OLE, the previously given estimates were not accurate, there was no likelihood of the Electric lines being returned during the day and that the Main and Suburban lines were not likely to be returned before 12:00 14:00 (Wed): OLE work affecting the Main lines Would be completed by 15:30, but that OLE restoration on Electric lines would continue to at least 09:00 Thu 03/01
03-01-08	Liverpool Street – Bethnal Green	40/1	Possession continued to overrun on the Electric lines: NWR at 06:35

9. Work developed with FRAM

Function	Who	Inputs	Outputs	Preconditions	Time	Resources	Controls
Development of maintenance work plans	Maintenance engineering	CPPP	Maintenance detailed work plans	TOC agreement to access	T-16 weeks	PPS	Rules of the Route (RotR)
Maximisation of work opportunities for maintenance	Maintenance Delivery Unit	Maintenance detailed Work plans	Proposed work		Prior to ADPU Weekly Planning	PPS	Confirmed Period Possession Plan (CPPP)
		Available resources				PossMan	
		Available access				Ellipse	
		Outstanding actions					
Development of MP&I work plans	Project team	CPPP	MP&I detailed work plans	TOC agreement to access	Prior to ADPU Weekly Planning	PPS	RotR
Integration of maintenance and project work	Area Delivery Planning Unit (ADPU)	MP&I detailed work plans	Work approved		T-14 weeks	PPS	CPPP
		Draft WON	Work in progress		T-6 weeks	PossMan	
		Proposed work			T-3 weeks		
		Haulage and trains plan			T-10 days		
		Outstanding actions					
Haulage approval	National Delivery Service - NDS	Work approved	Locked-down haulage and train plan		T-4 weeks	NROL	Integrations/confirmation of haulage
		Haulage and trains plan				PPS	
Issue of WON	Network Access Unit on behalf of route directors - NAU	Work approved	WON	TOC agreement to access	T-7 days	PPS	
Development of maintenance work packs	Maintenance Delivery Unit	Proposed work	Maintenance work packs			PPS	
			Site specific information			PossMan	
Development of MP&I delivery details (work packs)	Project team	MP&I detailed work plans	MP&I work packs			PPS	
		Contractors plans	Site specific information			PossMan	

Deliverability and risk assessments	Project team	MP&I detailed work plans Available resources Available access Contractors plans	Schedule Quantified Risk Assessment (SQRA) Other risk assessments as required				
Development of Possession Management Packs	ADPU Work deliverer	WON WON supplement Site specific information	PICOP pack	Pos and WS approved for delivery	T-7 days	PPS PossMan	RIMINI
Integration of emergency and late changes	ADPU	Maintenance work packs MP&I work packs	WON supplement			PPS PossMan	Approval by line manager
PICOP briefing	ADPU	PICOP pack Site specific information	Work delivery details		T-3 days	PossMan	
Work delivery	Work deliverer	Work delivery details Locked-down haulage and train plan	PICOP report			PICOP pack	
T+1 review	Maintenance Delivery Unit	PICOP report MP&I hand back	Asset update Outstanding actions		T+1 weeks	Ellipse	


T+1 review
Haulage appro...
Maximisation o...
Outstanding actions
Prior to ADPU Weekly Planning
CPPP
Outstanding actions
Haulage and trains plan proved
PICOP report
Work approved
Locked-down haulage and train plan
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Integration of...
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Proposed Work
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