A study of the GB rail socio-technical system: developing guidance for implementing sustained improvements in safety and performance

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Key words: socio-technical systems, organisational learning, systems-thinking, systems analysis methods, and resilience engineering

Abstract

The rail industry in Great Britain has faced unprecedented demand for its services in the past decade, whilst addressing technological transformation, and with multiple objectives in relation to safety and performance. Sociotechnical systems theory seems to offer solutions for these challenges, but there has been little research on how rail organisations can establish processes and build resilience during periods of significant change that are complementary with this type of theoretical approach. This thesis describes the studies undertaken between late 2014 and December 2020 to evaluate the GB rail socio-technical system and reflects on the impact of change on frontline staff, going on to describe organisational learning and the systems approach to safety-driven design.

Two national change programmes (Business Critical Rules (BCR), and Planning and Delivering Safe Work (PDSW)) affecting the frontline rail engineering workforce have been used as contexts to frame consultations within this study.

Five studies were conducted and are described in Chapters 5 to 9.

A total of twenty-eight interviews were undertaken as part of Studies 1 and 2 (Chapters 5 and 6), with senior executives and managers in the railway industry, to investigate how they, as senior business leaders, describe the management of change in a complex rail socio-technical system. These interviews were designed to explore the perceptions of industry personnel in policy setting and senior management roles and what they see as barriers to change within a dynamic, fast moving, industry. This included exploring both the 'work as imagined' in the corporate strategy and company procedures, as well as their understanding of 'work as done', including some interviews specifically addressing the roll out of the two national change programmes.

An employee survey, using a questionnaire, was sent out to a select group of frontline staff as part of Study 3 (Chapter 7). There were 1355 responses to this survey, helping to understand the perceptions of the changes at the 'sharp end'. A longitudinal (observational) study was also undertaken (over 6 years), and this Study 5 (Chapter 9) tracked the change programmes as they progressed and the effects of changes as they have occurred, including delivery of safety and performance targets during the coronavirus pandemic.

In order to provide recommendations to aid the industry in forward planning, Study 4 (Chapter 8) considered two different techniques / analysis methods, and whether they are suitable for prospective analysis. Both STAMP (the Systems Theoretic Accident Modelling and Process model) and the bow-tie analysis technique (used by Network Rail) were evaluated to determine their suitability as prospective tools for industry to use to support future interventions in change programmes.

The results of the five studies, when combined, identify what should be considered when designing change in a complex industry, and how a socio-technical system framework or model might go on to be applied in practice, whilst calling for greater user-centred input.

It is also clear from the research, particularly Study 2 (Chapter 6), that a systemic approach is required, considering social and technical aspects concurrently, as change programmes are implemented (among other workstreams and competing priorities).

The thesis outputs are recommendations that help guide the implementation of sustained improvements in safety and performance in GB rail and culminate in a series of steps guiding managers and programme teams on how they might design, implement, and embed change.

The thesis concludes by reflecting on the contribution that this work makes to the bodies of knowledge in socio-technical system theory, resilience engineering, and human factors / ergonomics (HFE).

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I am enormously grateful to everyone mentioned for helping to make this possible.

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Glossary of terms

Bow Tie Analysis	A Bow Tie is a diagram that visualises the risk you are dealing with in just one, easy to understand picture. The diagram is shaped like a bow-tie, creating a clear differentiation between proactive and reactive risk management
Business Critical Rules (BCR)	Network Rail's standards regime – across a range of disciplines – that provides simple, clear accountabilities for individuals working for Network Rail, and outlining what all staff need to do to run a safe and efficient railway. They are being designed from risk-based principles - understanding the things that can go wrong and what must be done to prevent them
Controller of Site Safety (COSS) / Individual Working Along (IWA)	This role is responsible for protecting their own safety and the safety of others in the work group from the risk of being struck by trains, and verifies that the planned Safe System of Work is appropriate and can be implemented as planned
Managing Successful Programmes (MSP)	Managing Successful Programmes (MSP®) (2020) represents good practice in the delivery of transformational change through the application of programme management. MSP was developed by the UK Government in 1999 and is used both within the public and private sectors
Managing Successful Programmes for Network Rail (MSP4NR)	See MSP above. Used by Network Rail for its business change programmes
Means of Control (MOC)	Means of Control are the tasks / activities put in place by Network Rail to mitigate against risk events happening. Supporting documentation contains a process flow chart for the control event, identifies who is carrying out the activities in that control, provides supporting tables and guidance including frequencies, safe tolerances and critical limits, and the means of assurance.
Office of Rail and Road (ORR)	Network Rail is regulated by the Office of Rail and Road (ORR) for its stewardship of the rail infrastructure
Organisational Learning (OL)	How an organisation is capable of creating, acquiring, and transferring knowledge, and able to learn from and react to events.
Person in Charge of work (PIC)	See COSS/IWA above. The PIC role is the alternative title used instead of COSS/IWA following revisions to the Network Rail Standard '019'

Planner	This is role is responsible for planning the work and the Safe Systems of Work in accordance with the priorities set by the Responsible Manager
Planning and Delivering Safe Work (PDSW)	PDSW is a wholesale reform of how infrastructure work is planned and delivered safely and, ultimately, it makes clear who is responsible
Planning for Work (P4W)	P4W is the name for the re-titled PDSW, with a renewed focus on track worker safety and a much greater focus on frontline communications and briefings
Protection	Ways of making sure that a railway line is protected, this includes keeping signals at danger, placing detonators on the line, using a track circuit operating clip and showing a hand danger signal
Rail Accident Investigation Branch (RAIB)	The Rail Accident Investigation Branch is a British government agency that independently investigates rail accidents in the United Kingdom and the Channel Tunnel
Rail Safety and Standards Board (RSSB)	RSSB supports the GB rail industry to address issues of common concern, providing information and guidance for all aspects of railway operations, including standards, wellbeing, sustainability, infrastructure and rolling stock asset integrity, customer satisfaction, performance, and safety
Responsible Manager	This role is accountable for the preparation of Safe Systems of Work, how the work is to be prioritised, planned, and delivered, which is then delegated to the planner
Safe Systems of Work	Arrangements to make sure a workgroup who are to walk or work on or near the railway line is not put in danger by passing trains or movements, this includes arrangements for entry to and exit from the railway, walking on or near the line, walking to or from a site of work, setting up and withdrawing protection or warning arrangements, and carrying out work
Safe Systems of Work Pack	A pack of information, used by the Controller of Site Safety (COSS) / Individual Working Alone (IWA), or Person in Charge of work (PIC), that provides details of the safe system of work and the work to be carried out
Socio Technical System (STS)	A socio technical system (STS) is a way of describing or depicting complex interactions between human, social and organisational factors as well as technical factors in organisational systems

List of Publications

Nolan-McSweeney, M., Lowe, E., Weatherill, W., Ryan, B., and Hutchings, J. (2008). “Comparison of Different Types of Reports in the Investigation of Signals Passed at Danger (SPADs).” Contemporary Ergonomics 2008: Proceedings of the International Conference on Contemporary Ergonomics (CE2008), 1-3 April 2008, Nottingham, UK.

Nolan-McSweeney, M. (2016). “The Transformation Journey.” The Ergonomist No. 556 November - December 2016.

Nolan-McSweeney, M., Ryan. B., Cobb, S. (2017). “The Challenges and Strategies for an Effective Organisational Structure in a Complex Rail Socio-Technical System.” Human Factors Rail Conference, 6-9 November 2017, London, UK.

Nolan-McSweeney, M., Ryan. B., Cobb, S. (2018). “Getting the right culture to make safety systems work in a complex rail industry.” The International Ergonomics Association Conference, Florence, August 2018.

Nolan-McSweeney, M., Ryan. B., Cobb, S. (2019). “Engineering the right change culture in a complex (GB) rail industry.” The Applied Human Factors and Ergonomics Conference, Washington DC, 24-28 July 2019.

There is also a paper – currently in draft form, and based on Study 1 – entitled “Using interviews with rail industry leaders and decision makers to identify perceptions of and barriers to organisational change” and it is hoped this will appear in a future Safety Science journal.

1. Introduction

As the former Head of Corporate Assurance and Accident Investigation and more recently an Executive Director in Network Rail with long experience in different roles, I know only too well that improving railway safety and performance [service][1] – and continuously doing so – is expected by the public, regulators, maintainers, and operators. Decades of incident and accident reporting and investigation, the scrutiny of operational performance, and the imperatives to continuously improve are never far from the top of the rail industry's agenda, albeit in differing guises – whether politically motivated (e.g. 'the northern hub'), driven by recent external events (such as the coronavirus pandemic), or a catastrophic accident (e.g. a workforce fatality).

Safety is an emergent property that comes when all elements in the system are working effectively; emergent outcomes are not 'additive' nor analysable into separate parts, and consequently not predictable from knowledge about such parts (Leveson, 2004). It seems, in a growing number of cases, it is difficult to explain what happens as a result of known processes or developments, and so trying to make sure things go right, rather than preventing them from going wrong (Safety II (Hollnagel, 2014)) is perhaps one way of taking this safety management principle forward; considering human factors in a way that supports system flexibility and resilience rather than a problem to be fixed.

Understanding why incidents and accidents occur, and reviewing performance-affecting and major asset failures, has existed in various forms over many years in GB rail. Major accidents have often driven interest in system safety and highlight the dangers associated with safety-critical industries (Cooter and Luckin, 1997; Saleh *et al*., 2010). For rail, the demands to improve safety and performance are usually made following accidents which involve a high number of casualties (e.g. Clapham, 1988; Hatfield, 2000; Potters Bar, 2002)[2], or incidents involving significant environmental damage (e.g. Stonehaven [Scotland], 2020; Llangennech [Wales], 2020)[3], and/or workforce fatalities (e.g. Margam, 2019 (RAIB, 2020)). Stakeholders (e.g. governments, regulators, management teams, employees, Unions and the general public), expect such incidents and accidents to be prevented, limiting reputational damage, whilst meeting regulatory standards etc.

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[1] The terms safety and performance are often inter-changed with 'safety and service' and/or 'performance [service]'. For the purposes of this thesis the terms safety and performance will be used, with performance meaning operational performance and service excellence.

[2] Chronology of major rail accidents: http://news.bbc.co.uk/1/hi/uk/465475.stm

[3] Rail Accident Investigation Branch investigations and digests: https://www.gov.uk/government/organisations/rail-accident-investigation-branch

As Underwood and Waterson (2013) found, and others before them have also identified (e.g. Hollnagel *et al*., 2008), being able to prevent incidents and accidents requires an understanding of why a certain combination of events, conditions and actions led to specific outcomes, i.e. incident / accident analysis, and then applying the knowledge of causation to the data collected during an investigation in order to understand what happened and why.

As an employee (now retired) of Network Rail, and the author of this thesis, I am aware that systems analysis methods play an important role in the investigation process, providing a structured means of applying accident causation theory. Various researchers (e.g. Leveson, 2001; Rasmussen, 1997) have been recommending the use of systemic accident analysis techniques for two decades or more.

However, these tools are not widely adopted by the practitioner community (Underwood and Waterson, 2013), and from my own research and knowledge of the rail industry and its approaches, it is true to say that practitioners are applying more traditional accident causation techniques during their investigations and producing ineffective recommendations – certainly ones that are not necessarily truly systemic. The reasons for this are explored in the studies described in the thesis. Part of this can be explained through the study of two national change programmes that help frame the research and demonstrate the complexity of a rail sector, where change is constant, but also very difficult to implement at scale across a dynamic system of systems.

Wilson *et al* (2007) so eloquently describe the rail industry as:

> *"…….a purposeful system that is open to influences from, and in turn influence, the environment, technical, social, economic, demographic, political, legal etc.); the people within it must collaborate to make it work properly."*

It is within this context that Network Rail operates and develops the GB rail infrastructure, to run a safe, reliable, and efficient railway, whilst regulated by the Office of Rail and Road (ORR). Network Rail is funded through a mix of direct grants from Westminster, and Scottish and Welsh Governments, besides charges levied on train operators that use the network, and income from commercial property estate. Network Rail finds itself challenged with delivering a number of ambitious programmes to achieve the envisaged improvements, whilst reducing the level of public subsidies received[4].

Rail demand has more than doubled since rail privatisation in 1994/95; in 20 years rail journeys increased by 89% to reach a record 1.8 billion journeys in 2018/19 but declined to 1.7 billion in 2019/20. The coronavirus pandemic undoubtedly impacted on journeys during 2020/21, but rail use has still increased faster than any other mode of transport[5].

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[4] In September 2020 rail franchising was 'scrapped' by the Department for Transport and replaced with a model which means the taxpayer is currently liable for the losses on the railways https://www.gov.uk/government/speeches/rail-update-emergency-recovery-measures-agreements

[5] For further information see: Office of Rail and Road: Passenger rail usage statistics: https://dataportal.orr.gov.uk/statistics/usage/passenger-rail-usage/

Rail also remains one of the safest transport modes, with 0.2 fatalities per billion passenger miles in 2019/20[6]. In stark contrast, there were 1460 road-related fatalities per billion vehicle miles recorded in 2020[7].

Network Rail, operating within the overall GB rail socio-technical system, is considered a critical element of the STS, seeking to deliver an efficient, reliable, and safe railway. Similarly, organisational learning – and from this sustained improvements – is considered necessary such that it can be the driving force for the productivity, performance, and safety of the whole railway.

Bringing all the various elements together to affect change at scale is the challenge, and a key question is whether using a systemic approach can lead to a more mature learning organisation, and a railway that is sustainable? Do national change programmes influence key decision making; and are there trade-offs?

Other related questions seek to establish what it actually means in practice to use an STS systemic approach – and what resilience means in the rail sector, i.e. whether the rail system can adjust its functioning during perturbations, and sustain required operations under expected and changing conditions (Leveson, 2001, Rasmussen, 1997)? For example, does Safety I predominate, i.e. accidents are the organisation's primary focus point and they try to prevent bad things from occurring? Are there signs of Safety II in the safety management systems of Network Rail, where the emphasis is more on ensuring as much as possible goes right, and going beyond prevention and into promoting robust safety management over simple risk assessment (Hollnagel, 2014)?

1.1 Background

There are various traditions and concepts within the fields of safety, human factors, and ergonomics (HFE) that support the design, planning and management of human interactions and safety within complex systems such as rail (Wilson *et al*, 2007). Beyond safety and HFE, there are other areas within the management sciences that also deal with similar concerns, where the emphasis is on organisational factors, including employee behaviour, motivations, decision-making and autonomy.

The focus of this research is how a complex sector, such as rail, can design systems and processes during periods of significant change that allow for sustained improvements whilst still able to support human and system performance, and remain resilient to unanticipated events.

-Department for Transport: Transport Statistics Great Britain: https://www.gov.uk/government/collections/transport-statistics-great-britain

[6] Office of Rail and Road: Rail Safety: https://dataportal.orr.gov.uk/statistics/health-and-safety/rail-safety/

[7] -Department for Transport: National Statistics: Reported road casualties, Great Britain, annual report: 2020 https://www.gov.uk/government/statistics/reported-road-casualties-great-britain-annual-report-2020/reported-road-casualties-great-britain-annual-report-2020

Being able to apply an appropriate model when implementing change – including decentralisation of the organisation – that can jointly optimise the social and technical aspects of the structure – would be valuable to Network Rail (and others), particularly if the outcome affords sustainable improvement in safety and performance.

Sociotechnical systems theory (STS) and resilience engineering (RE) are two approaches that have been described within the literature and show how organisations – nuclear, healthcare, military etc. – can develop an emerging perspective on safety in complex adaptive systems that emphasise how outcomes develop from the complexity of the given environment (Leveson, 2004). There are compelling arguments about how these approaches help organisations in the type of decision-making and associated activities that can occur across the levels of the system (government bodies, regulators, the organisation, management, staff and the work (processes)), interacting to shape behaviour, safety, incidents and accidents (Rasmussen, 1997) and the trade-offs and adjustments that are needed to manage uncertainties in this type of complex and high risk system (Hollnagel, 2012; Wilson *et al*, 2009; Grote, 2015).

Similar to the experience and insights gained from the multi-disciplinary research of Rasmussen, Hollnagel and others, railways also operate within a complex landscape which includes national, international organisations and devolved government bodies, regulators, train and freight operators, suppliers, trade unions, trade associations, and safety and passenger bodies. Successful operations require sustained improvements in safety and performance, and depend on managing social and technical interactions effectively, both internally, and across the wider rail industry.

Whilst railways are generally reported to be safer than other forms of public transport, there is still room for improvement, particularly within workforce safety. Sadly, four railway workers lost their lives in 2019/20 which further emphasised the high-risk environment in which many railway staff are required to work (ORR, 2020).

The ORR issued two Improvement Notices on Network Rail in July 2019 which are designed to eliminate planned work taking place on railway lines that are open to traffic where the only protection is a lookout – hence a [track worker] safety task force being established to attend to these matters which is described in later chapters.

Railways have faced increasing passenger numbers (Network Rail, 2019) at a time of ageing infrastructure and technological transformation to meet the huge increase in demand, and multiple objectives in relation to safety and performance. That said, there has been a decline in passenger volumes due to Covid-19 during 2020/2021, with some train services operating at 72% of normal levels, and passenger numbers on some services below 10% of capacity[8].

[8] Office of Rail and Road: Passenger rail usage statistics: https://dataportal.orr.gov.uk/statistics/usage/passenger-rail-usage/

There have been some considerable developments as regards railway research, and in particular in the field of human factors and ergonomics (Wilson and Norris 2005). However, Wilson *et al* (2009) also found that less has been published on the joint issues of safety and performance, more often instead focusing on safety risk, and prediction and analysis of human error.

Rasmussen and Svedung (2000), based on experience gained from multi-disciplinary research, including rail, developed a model of the socio-technical system (STS) in risk management that reflects social and organisational levels in a dynamic, fast moving, society using a hierarchical control structure. They focused on gaining an understanding of three main areas: (1) the decision-makers and actors involved; (2) the part of the work-space under their control, and (3) the structure of the distributed control system (i.e. the communication channels through which the decision-makers cooperate). They indicated that there may be gaps in the way decisions are made based on the available information, and control of safety in the system should be considered.

The work described by Wilson *et al* (2007) in the area of socio-technical systems also sheds some light on human factors at the heart of successful rail engineering (Wilson, Farrington-Darby *et al*. 2007). However, there is little research on how an organisation that faces an array of challenges in a complex and changing rail industry within Great Britain can develop a STS framework or model that can be applied in practice, particularly one that can complement established processes.

Hollnagel (2012) defines 'resilience' as *"the intrinsic ability of an STS 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".* How this can be achieved and the ability to effectively trade-off such issues of safety, costs and productivity are questions posed previously (Wilson *et al*. 2009) but have yet to be comprehensively answered. Also of note here is the potential gap between the 'work as imagined' in the corporate strategy and company procedures that senior staff may be more familiar with, and the 'work as done' by the frontline staff, to ensure the resilience of the system (Hollnagel *et al*. 2006).

New technology and the pace of change also make it much harder to analyse incidents and accidents. Leveson (2004) posits that the most effective models must go beyond assigning blame and instead help engineers [and operators] to learn as much as possible about all the factors involved, including those related to social and organisational structures.

Within a number of contexts and domains (e.g. safety culture, Zohar and Luria (2005); patient safety, Karsh and Brown (2010)), it has been demonstrated that certain phenomena (e.g. safety violations) can occur because of the influence of several levels within the system (e.g. group and individual behaviour).

Studying one system level in isolation runs the risk of designing interventions (i.e. improvements) which only apply to one system level and therefore likely to be ineffective. However, adopting multi-level analysis and examining causation across and between system levels is needed if complex systems, such as rail, are to be more resilient (Hollnagel *et al* 2006).

Whilst Network Rail's safety leadership has broadened, to meet demand and balance conflicting goals in a complex and dynamic industry, its staff must constantly make decisions, requiring an understanding and continuous dialogue about how the system works (e.g. prioritising train paths, for example a train operator ahead of a late running freight operator). Organisational learning is linked to this and remains a relatively unexplored area in GB rail, which justifies the focus of objectives on the development of descriptive and exploratory work.

Gudela Grote concluded in her work that when uncertainties are managed well, a basic prerequisite for good risk management is established; and she argues for *"….the importance of making deliberate operational and strategic choices between reducing, maintaining, and increasing uncertainty in order to establish a balance between stability and flexibility in high-risk systems while also matching control and accountability for the actors involved"* (Grote 2015).

This research looks at current systems analysis methods and basic systems theory concepts, reviewing approaches to designing for safety, risk assessment techniques, and approaches to organisational learning. It considers the extent to which traditional models don't appear to be able to evaluate the potential for risk migration, i.e. where risk transfers from one area to another, or comprehensively identify accident scenarios involving humans and organisations. The research goes on to describe the development of a framework that supports organisational learning and a systems approach to safety-driven design, which identifies prospective analysis tools to support future interventions in change programmes. Adopting a systemic approach, considering social and technical aspects concurrently to achieve joint optimisation, could help produce the desired outcomes of improved rail safety and performance, and a more mature learning organisation and sustainable railway.

1.2 Aim and objectives

Britain's railways are currently the safest they have ever been (ORR, 2020). The progress of the last decade has been built on a shared commitment by industry leaders, managers, workers, trade unions, government, and regulators to improve risk management. It is, however, acknowledged that there is still room for improvement, from a position where safety and performance still falls short of Network Rail's ambitions, particularly workforce safety.

The challenges Network Rail faces include responding to Covid-19 in terms of passenger demand (previously forecast to double in the next 25 years), and the cessation of rail franchising. There are also the demands previous rapid growth has placed on an ageing infrastructure and ever busier stations, whilst addressing technological transformation, and multiple objectives in relation to safety and performance.

Transforming a company, the size and scale of Network Rail, is a huge undertaking, especially when coupled with changing how it operates (Network Rail, 2019). The company has been pushing decentralisation further, making its 14 business routes more responsive to local needs and cutting through red tape and bureaucracy.

The routes are responsible for operations, maintenance, and minor renewals, including the day-to-day delivery of train performance and the relationship with their local train operating companies.

Phase two of Network Rail's decentralisation programme started in November 2019; this new structure is designed to set the organisation up for deeper devolution with less control through the centre, and greater autonomy at the Route level.

The overall aim of this Doctoral Thesis is, therefore, to evaluate the GB rail socio technical system and to develop guidance that supports implementation of sustained improvements in safety and performance.

The research objectives were:

1. To develop a description of the GB rail socio-technical system, including consideration of the multiple objectives in relation to safety and performance.
2. To investigate the extent to which a systems approach is applied within rail industry processes and practices.
3. To investigate the perceptions of senior business leaders, managers and frontline staff on policy and processes intended to improve workforce safety and performance.
4. To apply systems analysis tools (e.g. STPA, bow ties) and determine their suitability as prospective tools for industry to use to support future interventions in change programmes

Recommendations are made following on from data analysis, outcomes, and conclusions, and culminate in a series of steps guiding managers and programme teams on how they might design, implement, and embed change.

1.3 Structure of the thesis

Chapter 2 provides an overview of the railway context in which the research was conducted. The descriptions presented regarding various Network Rail national change programmes (section 2.3) were derived from initial familiarisation work by the author and continued as part of a longitudinal (observational) study (Chapter 9).

Chapter 3 provides a review of the literature. Research methods, philosophy and the reasons for selecting methods / research approaches are described in Chapter 4.

Chapter 5 reports on senior management interviews used to identify important components of the GB rail socio-technical system, and how STS theory can be applied in support of sustained safety and performance improvements.

Chapter 6 reports on further interviews undertaken to understand the inter-connectedness of human actions, decisions, and technological factors as part of an overall 'systems approach' to change, viewed through the 'lens' of two Network Rail national change programmes.

Chapter 7 is a build on studies from Chapters 5 and 6, and reports on survey work and a questionnaire developed to gather the perceptions of frontline staff on the two Network Rail change programmes intended to improve workforce safety.

Chapter 8 goes on to report on the evaluation of systems analysis tools (i.e. STPA with bow ties) to identify their suitability for prospective analysis. Chapter 9 brings together the overall research through a longitudinal (observational) study, used to inform the development of a framework that supports organisational learning and a systems approach to safety-driven design.

Chapter 10 summarises the research findings and goes on to discuss their relevance and importance to the fields of socio-technical system theory, resilience engineering, organisational learning, and the role of human factors. Recommendations are made that help guide the implementation of sustained improvements in safety and performance in GB rail.

Chapter 11 draws final conclusions, acknowledging the contribution of this research to safety science, and wider research opportunities and future work are also identified.

2. Research context

This research was conducted by the author, an employee of Network Rail (now retired), who in a previous role was the Head of Corporate Assurance and Accident Investigation, and more recently was the Transformation Director for the Wales and Western Region, overseeing both the strategic command and response to the coronavirus pandemic, but also the organisational (and operational) changes – and cultural challenges – to deliver a set of strategic ambitions out to the year 2035.

The research focus was set on the GB rail socio-technical system, with particular interest on organisational learning and a systems approach to safety-driven design.

Although organisational learning constitutes the focus of this research, a basic understanding of the rail industry was considered necessary to support and interpret the investigation results. The following provides a broad description of the main organisational areas and functions that impact on safety, and broad issues that impact on performance.

2.1 The rail industry in Great Britain (GB)

The GB Rail Industry has a wide diversity of infrastructure, equipment types and ages, complexity of interfaces, and different traffic types, besides a range of stakeholders, and employees with varying degrees of knowledge, skills and experience. Such diversity, particularly in a safety critical industry, has required rules and requirements to be laid down, but there remains the ever-present challenge of delivering safe performance amid the co-existence of old equipment with new technologies, an ageing workforce, and increasing technological change to meet the shifting demands for rail travel.

In October 2002, Network Rail took over the running of Britain's rail infrastructure with a mandate from the Government to improve the safety, reliability, and efficiency of the railway. When it took responsibility for the rail network on 28 October 2002 the immediate priorities were clear: restoring public confidence in the safety of the railway, reducing the number of late trains – at the time almost a quarter were late – and bringing costs under control.[9]

The activities and performance of Network Rail are bounded by the Network Licence granted by the Secretary of State for Transport (as per the Railways Act 1993) and monitored by the Office of Rail and Road (ORR). The licence sets the standards and terms for service that Network Rail is required to provide to train operators.

[9] The priorities are published and updated on Network Rail's website http://www.networkrail.co.uk/

Every year one billion journeys are made on Britain's railway and over 100 million tonnes of freight are transported around the country. A million more trains run every year than a few years ago, but the popularity of rail means that, at peak times, there is no space for more trains on busy parts of the network[10].

The coronavirus resulted in several shutdown periods, providing opportunities to bring forward maintenance and renewals, but it has also meant Network Rail scaling back or delaying other work. Going forward, they will re-plan this work in conjunction with stakeholders, in addition to making structural changes likely to emerge from Government policy[11].

Of course, Network Rail's stakeholders are many and varied, including the Department for Transport, Transport for Wales, and Transport for Scotland, the Office of Rail and Road (both as the economic and safety Regulator), the Treasury, passenger (train) and freight operating companies, the Rail Safety and Standards Board (RSSB), the Rail Accident Investigation Branch (RAIB), passengers, contractors, Unions, lineside neighbours, local communities, and employees.

The structure of the rail industry is complex, and the industry model changed in the mid-1990s from one of public ownership to a model where freight operating companies (FOCs) compete for freight contracts, and passenger services are largely specified by the Government and delivered by train operating companies (TOCs). First Railtrack, and then Network Rail, have managed the rail infrastructure, with the Office of Rail and Road (ORR) regulating both bodies in turn. These activities are supported by an extensive supply chain (Oxera, 2015).

The decision to re-classify Network Rail as a central government body in the UK national accounts and public sector finances led to a new relationship in 2014 where Network Rail Limited became an arm's-length body of the Department for Transport (DfT). Pre-classification, Network Rail had the flexibility to raise more debt independent of Government that allowed for additional funding to be made available if, for example, a project's efficient cost had increased[12]. The decision to reclassify Network Rail was a statistical one and was not due to any changes in the circumstances or performance of Network Rail (DfT 2014).

2.2 Network Rail's organisational structure

Network Rail's core obligation is *"to secure the effective and efficient operation, maintenance, renewal, and enhancement of its network to satisfy the reasonable requirements of persons providing services to railways and funders"* (Network Rail, 2019).

[10] Office of Rail and Road: Passenger rail usage statistics: https://dataportal.orr.gov.uk/statistics/usage/passenger-rail-usage/

[11] Office of Rail and Road: Network Rail's delivery during the coronavirus pandemic: https://www.orr.gov.uk/search-news/network-rail-mid-year-report-december-2020

[12] Part of the evidence given by the then CEO of Network Rail, Mark Carne, to the Public Accounts Committee in October 2014 as part of the Committee's 'Network Rail:2014-2019 investment inquiry'.

As the mainline railway's infrastructure owner, Network Rail operates, maintains, and develops Britain's rail tracks, signalling, bridges, tunnels, level crossings, viaducts, and a number of key stations.

The organisation employs over 40,000 staff and has begun a change programme to decentralise much of its business, and there are 5 Regions with 14 Routes which are at the heart of the way Network Rail operates in a matrix structure, with National Functions (e.g. Human Resources, Finance, Route Services, the Technical Authority etc.) discharging their responsibilities as service providers and/or policy setters, primarily there to facilitate lateral learning, and identify national improvements that span the network.

The Routes are the main geographical locations, each led by Route Directors, whose accountabilities are for safety and operational performance, delivery, and sustained improvements of current performance, bounded by national functional strategies and policies.

Within the Routes there are delivery units that oversee the management and maintenance of assets within a defined section of the network; activities include the scheduling of patrolling, inspection and repair work, submissions for planning of more significant works / renewals, and requirements and sponsorship of infrastructure delivery (e.g. upgrades).

To deliver its obligations, Network Rail has policies and strategies embedded in the business that demonstrate the organisation's commitment to health, safety and wellbeing including employees, contractors, passengers, and members of the public who may be impacted by its undertaking. However, the organisation operates in a changing political, economic, and social environment, and is committed to evolving as a business at a rapid pace (Network Rail, 2020).

Network Rail has implemented a safety vision entitled 'Everyone Home Safe Every Day' together with supporting commitments that provide a common thread for all its interventions and communications around safety, addressing risks recorded in the company risk register. The safety vision is signed by the Chief Executive (CEO) and seeks to establish the corporate attitude to safety and provides a formal statement on the approach to effective safety, health, and wellbeing management, including the prevention of injury and ill health. The essence of the safety vision and Network Rail's Health & Safety Management arrangements are set out in a formally published document (Network Rail, 2018), and describe how risk is managed through a regime of legal compliance, clear strategies, and a set of business objectives that will deliver a reduction in accident rates, provide sustained improvements opportunities, harness technology for the future railway, reduce the risk of long term potential health and safety hazards, and improve business performance through optimised safety, wellbeing, and productivity.

2.3 Network Rail's national change programmes

Network Rail has developed an ambitious 'Home Safe Plan'[13] that is kept under regular review. This comprises a series of ongoing projects which target reduction of risk in key safety areas. These range from workforce safety issues such as manual handling and trackside working, to significant programmes set out to tackle emerging risk issues such as fatigue management.

Many of Network Rail's national change programmes have a focus on workforce safety aimed at improving how work is planned and undertaken, removing potential for error, increasing understanding of the way tasks are to be executed, and making it easier to share best practice through standardisation.

Improving how Network Rail operates is part of a planned journey to being a safer, higher performance railway of the future that puts passengers and freight users first. However, this is against a backdrop of data reporting that shows workforce safety performance not being where it should be, a network that is almost full, actually full, or already has an excess of demand over capacity in many places, and on occasion being too slow to apply technologies to the future railway (Network Rail, 2020).

2.3.1 Simplification of the Standards regime

Back in 2013 Network Rail identified 844 standards as part of 9664 controlled documents, 4200 distinct competences across 2881 job titles, 620,000 individually held competences, and 165,000 hours per year being taken up by managers on the front-line supporting assessment of competence. This was in addition to the 222,000 risks within Network Rail's Risk Management database, and the 3314 Temporary Non-Compliances (TNCs) raised in relation to Standards (Network Rail, 2013).

A view that the Standards regime is too complex and cumbersome to be truly effective appears to be a widely held belief and resulted in a 'moratorium' on Standards' publications so that a thorough review could be undertaken (Nichols, 2013(a)).

The Standards regime has evolved over many years and been developed in such a way to mitigate, as opposed to eliminate, risk. Many Standards have been built up over time – informed by historical data – and a number are reported to be out of date; affecting their credibility amongst those using the documents (Nichols, 2013(b)).

Addressing the two reports from Nichols, and their concerns that the Standards regime is not necessarily delivering the best risk control in the most effective manner, Network Rail developed several risk-related programmes that they are seeking to embed into the organisation, including business critical rules.

[13] Network Rail 'Home Safe Plan' https://www.networkrail.co.uk/who-we-are/our-approach-to-safety/home-safe-plan/.

2.3.2 Business Critical Rules (BCRs)

The Business Critical Rules (BCR) programme was initiated in 2012. This programme's aim is to fundamentally reform the Standards regime – across a range of disciplines – and to provide simple, clear accountabilities for individuals working for Network Rail; outlining what all staff need to do to run a safe and efficient railway.

Network Rail stated that the Rules *"will provide a framework to encourage local decision making by staff who can rely on a supportive culture and on a set of documentation which clearly summarises mandatory controls and tolerances" (Network Rail, 2013).*

Network Rail initially consulted with around 40 other organisations introducing management systems (including safety management, quality management, and Sarbanes-Oxley related (financial) systems) in the oil and gas, aeronautical, mining, and fast-moving consumer group (FMCG)[14] sectors. The Office of Rail and Road then commissioned The Nichols Group to provide an independent report, as the ORR were seeking to *"understand the scale and deliverability of safety and efficiency benefits that Network Rail can achieve by implementing the proposals to simplify its existing Standards regime"*. At the heart of each approach, from the comparator studies[15], it was found that there was a sophisticated and systematic understanding of risk. From this Nichols identified best practice that includes using risk to prioritise and shape decisions, with clear and easy to use supporting information, and role-based training (linked to risk and accountability).

What also became apparent from the consultations and interviews with other organisations is that, without improving the control framework for managing risk, Network Rail's ability to deliver its committed safety, performance and efficiency targets was significantly compromised.

Using the findings from the comparator study (see Table 2.1), Network Rail determined it would need to replace the existing Standards framework with a simpler, risk-based BCR framework. This new framework would be underpinned by the Bow Tie methodology of risk management that improves the understanding of threats and how these are controlled.

[14] Examples of FMCG sectors include Nestle, Kraft, Unilever etc.

[15] The comparator study by Network Rail subsequently included further structured interviews by Nichols of representatives from the Ministry of Defence, Royal Dutch Shell, National Grid and several other organisations who asked to remain anonymous. Meetings were held and interviews undertaken which are referred to in the Standards Efficiency Study final report (Nichols 2013(a)).

Table 2.1 – Summary of the Network Rail and Nichols Comparator Studies (2013(a))

Topic	Key Finding
Developing Standards	• Set standards for those areas where risk is highest • Prioritise risk based on probability (and impact) • Understand barriers (and their strengths) to prevent/ mitigate risks • Rules at global level express the minimum requirement (local rules specify further detail) • Rules become more specific as you move down into the organisation (generic at global, specific at functional / entity level) • Risks are split into different categories to avoid comparing a commercial versus a safety risk • Standards/ requirements are aligned with corporate objectives
Implementing Standards	• Visible leadership buy-in is vital • Implementing new standards or requirements should be accompanied by a rigorous management of change process • Engagement and education are key: Why we do it, what it means • Key standards (e.g. Risk) require dedicated, sustained effort • Distinguish between “big-bang” versus gradual implementation / change approaches
Supporting Systems	• Competencies are key: need the right training & skill assessment to ensure people are competent for the role • Establish audit & assurance processes to provide assurance that rules are being followed and to flag up future areas for improvement • Set up structures and forums that bring together the right people to encourage knowledge sharing and collaborative learning • Lessons learned are fed back into the organisation (informing risk assessments and activity planning) • Ensure contractor competency and understanding • In-house standards are built on/ supplement industry standards
Changing Behaviours	• Clearly define accountabilities and responsibilities • Ensure leadership commitment – leaders must walk the walk • Consult & co-create with peers and users when developing standards • Clearly express the “Why”: Common cause for change and context • Build understanding of risks and how they’re controlled to drive compliance • Safety culture is embedded when safety is a standing item on the board agenda
Measuring Success	• Criteria for success must be clearly defined and KPIs aligned to this • Gap assessments should be conducted to understand current performance and set appropriate improvement targets • Beware of conflicting priorities, e.g. safety versus commercial targets • Audit and assurance processes incorporate measure of management system performance • Just culture encourages honest discussion of compliance

The Business-Critical Rules (BCRs) framework that Network Rail has developed over the past 8 years has sought to provide a clear line of sight from its risks to how they control them. An extensive development programme, delivering a thorough understanding of risk across the railway, has been undertaken. Systematic analysis by Network Rail will see them ultimately define a set of around 100 BCRs, developed at a category level[16] and at asset system and/or management function level.

There were seven steps defined at the start of the Business-Critical Rules programme using the Network Rail corporate risk register as the basis for creating the output documents including a suite of products[17] that the business wants to use to help it manage its risks (safety, financial and reputational risks) including the use of bow-tie risk assessments and 'means of control' documents.

It is intended that the BCRs will simplify the existing standards framework and, through 'Bow Tie' risk analysis, will provide an easy way of illustrating risk assessment results. The 'Life Saving Rules' were the first 11 rules to be introduced under the BCR programme (since reduced to 10 after a period of review), and they articulate what needs to be done to maintain a safe and efficient railway (Network Rail, 2014).

Like the 'Life Saving Rules' all other BCRs are intended to be succinct and relevant and are to be widely consulted before publication. Compliance with the BCRs will also be supported by changes to competence arrangements and better provision of information.

Network Rail has previously committed to embed the following changes:

- Simplified capability frameworks designed around the risk of each individual role;
- Role-based manuals which summarise accountability and expectations placed on role-holders;
- Specifications which provide suppliers with a clearer vision of what is needed, and foster innovation;
- Guidance material which enables staff to easily obtain assistance when needed.

Through creating the new system, the intention is to address the following issues:

- Excessive, un-prioritised, workload;
- Conflicting information between documents;
- A historic focus on writing, not implementing, Standards; and
- Unmanageable competence arrangements.

[16] There are seven categories: Network Operation and Performance, Stakeholder Focus, Asset Management, Asset System Specific, Leadership, Workforce, and Control.

[17] Network Rail set out to develop circa. 100 rules as part of the Business-Critical Rules programme. The rules form the control framework and are grouped into seven categories; these cover technical regulations and core cultural requirements for managing the business (such as expectations of leadership).

The implementation of the BCRs will allow Network Rail to formally state its expectations of anyone seeking to manage out / mitigate risk and foster high performance on the railway; the process is simplifying the way Network Rail operates, and one of the main benefits are expected to come from the cultural change *“which will allow front-line leaders to be more aware of risks and controls, and to enable them to make decisions, when competent, and will encourage the frontline workforce to think more about the task*” (Network Rail, 2013).

Lloyd’s Register Rail were appointed in 2014 to consider the compliance of the BCR programme with the process requirements of the Common Safety Method on Risk Evaluation and Assessment (CSM RA), along with a judgement on the effectiveness of the risk assessment process. Their findings are contained in a detailed report[18] where they acknowledge that, at the programme level, BCR is not itself making changes; these will occur as the BCR process is applied at the asset / functional level. They go on to recommend that updates to specifications are essential and timely to ensure that risk assessments are themselves robust and compliant as the BCR documentation is ‘rolled out’ over a period of several years. Hence the justification for the longitudinal study and the ability to observe changes (and variability) over 5+ years, for which a detailed timeline is provided in Study 5 (Chapter 9), outlining key moments in the various phases of the change programme.

2.3.2.1 Bow Tie risk assessment model

The origins of the Bow Tie method are found in a simplified fusion of fault and event tree methodologies (CAA, 2015) – see also Chapter 3 where the theory and literature behind the bow tie risk assessment model is provided.

Network Rail elected to use the Bow Tie approach following its comparator study in 2013, which found their use to be recognised in numerous other industries, including defence, medical, financial and the aviation industry, primarily as a risk evaluation method that can be used to analyse and demonstrate causal relationships in high-risk scenarios. The bow ties also graphically portray how risks are being managed such that resource can be focused in the most efficient way (CAA, 2015).

The Bow Tie is a tool that Network Rail uses to support the analysis, communication, and consultation of the risk management process (Network Rail, 2017). Bow Ties for the BCR programme have been built to address the business risks recorded in Network Rail’s corporate risk register, and to cover the three focus areas of safety, financial performance, and reputational impact. They do not generally make specific mention of human factors (see paragraph 2.5); any relevant human factors / ergonomics matters tend to be part of the detail included in the causes (or threats) in the bow tie, and/or part of the mitigation, rather than stand-alone elements. Neither do the bow ties address every possible threat or barrier, only those risks already known / quantified.

[18] Lloyd’s Register Rail “Business Critical Rules Programme, Safety Assessment Report for Network Rail”, issue 1, 20 February 2015

2.3.2.2 Means of Control

Whilst the Business-Critical Rules framework explains 'what to do', the Means of Control (MOC) documentation describes 'how to do it' (Network Rail, 2014; 2017).

Expert railway engineers have been involved in the development of the Bow Ties for the BCR programme, and the Bow Tie analyses show diagrammatically the 'means of control' for which an individual is accountable, and who is responsible for each element of the process. NB: a MOC is derived from either one or many combined bow-tie controls.

Means of Control are the tasks / activities put in place to mitigate against the top risk event happening. Network Rail believe a key benefit of BCRs is *"….the ability to make changes to the MOC, enabling those responsible and accountable for managing risks to make decisions appropriate to their area of the business"* (Network Rail, 2015(a)).

MOC documentation contains a process flow chart for the control event, identifies who is carrying out the activities in that control, provides supporting tables and guidance including frequencies, tolerances and limits, and a means of assurance.

The Means of Control for which individuals will be accountable are baseline requirements which can be changed through risk assessment to enable the development of local MOCs that – whilst requiring a review by the local Route Steering Group for BCR – will allow for the appropriate controls to be selected and applied commensurate with the risk to be actively managed (and whether that be related to safety, performance, cost or a shortened asset life).

The Rules are clearly designed to provide the technical and cultural requirements for everyone that works for Network Rail. The reason for introducing these is to move the organisation away from controlling risk which is centrally driven and complicated with often unclear responsibilities and accountabilities; with the intention of giving employees much more flexibility in the way they work. Training is to be provided for those required to undertake risk assessment and control activities, and chapter 7 describes the research investigating the impact, in practice, of adopting a more autonomous approach on frontline staff behaviour.

Role Based Manuals will eventually replace the previously issued suite of Standards and enable those issued with the documentation to work within the new BCR framework which directly maps risks to roles (and capabilities required to undertake the role) – providing employees with a single reference document containing everything they need to do their job, e.g. as a Section Manager (Track), Track Maintenance Engineer, Route Asset Manager etc. A longitudinal (observational) study – see Chapter 9 – enables a greater understanding of the extent to which this reference documentation is made available and used in real-world settings.

2.3.3 Planning and Delivering Safe Work (PDSW)

Network Rail has been seeking to change the way it manages safety on its worksites to enable better planning, improved risk assessment, safer delivery, and right-time hand back of work. The Planning & Delivering Safe Work (PDSW) programme was established in 2014 and was formed from two former Network Rail 10-Point Safety Plan elements, 'Control of Work' and 'Roles & Responsibilities', which were to address the less than satisfactory workforce safety performance (Network Rail, 2014(a)).

The PDSW programme has been designed to deliver a change in the way Network Rail and its supply chain approach the management and planning of work to reduce harm to their employees. The aim was to have one person accountable for managing task, site and operational safety risk, and that person will have been involved in the planning of the work (Network Rail, 2015(b)).

The Planning and Delivering Safe Work programme was specifically developed to create a series of changes to radically improve the way railway work sites are managed and risks controlled. The project team worked with front-line teams from across Network Rail's business to develop, test and evaluate the proposed improvements ahead of a national roll out.

It was reported that too many Network Rail and contractor staff are injured, sometimes fatally, whilst working on Network Rail's infrastructure (Network Rail, 2014(a)), and feedback from those on the frontline, and analysis of previous incidents and accidents, highlighted to Network Rail the need to:

- Improve planning and risk assessment processes and be clearer about safety leadership on site;
- Provide greater clarity about the arrangements in place to manage both the operational railway and task risks.

The PDSW programme's primary focus has been on developing a system for planning and delivering safe work, through a series of key steps:

- Electronic permitting (ePermit) technology, to replace voluminous (and generic) safe system of work packs, that produce paperwork that fully describes the plan, alongside track schematics to visualise all activity on the particular infrastructure.
- A single national control of work process (a system called Proscient), to plan, risk assess, deliver and hand back all work carried out on the given piece of infrastructure.
- A Single Accountable Person, accountable for safe delivery of work within a worksite, ensuring that risks associated with both work site and task are appropriately managed.

The new permit system was designed to contain an electronic 'map', providing better understanding of the worksite and task environment, and a risk assessment system to assist with task risk assessment.

Network Rail has actively sought to adopt systems which have been well proven in other industries who have better workforce safety performance than the UK rail sector, and they designed a national training package that directly involved over 20,000 delegates such that this much larger group than was initially envisaged are able to use processes and systems more effectively than they've ever been able to do before.

Network Rail Standard '019' (along with supporting briefing materials)[19], regarding the safety of people at work on or near the line, was originally created to control the risks to rail colleagues from train movements. However, lots of other risks can cause injuries to track workers, such as site and task risks, and this meant that Network Rail was not adequately identifying all the risks. The initial PDSW programme work sought to revise Standard '019' and introduce the 3 key steps (outlined above) to improve safety, particularly for those trackside, but there was insufficient funding or planning for how the technologies would be implemented, embedded or sustained. As a result, the programme was paused on several occasions during 2015 and 2016 as both funding and IT solutions were sought.

A number of possible options were socialised with a wide stakeholder group, including business routes, project teams, the supply chain and trade unions, and the programme was re-launched, including a further revised Standard '019', for compliance in July 2017. Unfortunately, the programme ran into financial and commercial difficulties with the chosen technology system and once again PDSW was paused in September 2018 to allow for a revised concept to be presented to the Network Rail Executive ready for another 'launch' in the summer of 2019.

Sadly, two track workers were struck and fatally injured by a passenger train at Margam East Junction on the South Wales mainline in July 2019 (RAIB, 2020), and Network Rail then made it clear they only wanted their workforce to go on track when essential, and a [track worker] safety task force was established with £253m committed to support the programme to work smarter and safer within the funding control period (CP6) 2019-2024.

The PDSW programme was renamed the Planning 4 Delivery (P4D) programme in late 2019, and subsumed as part of the safety task force. The P4D programme had a clear remit –looking to introduce new technology (note, the previous unsuccessful system (Proscient) was decommissioned in 2016) that will simplify how work on or near the line is planned and delivered – and a new timeline was published (Network Rail, 2019).

The P4D programme will progress from a discovery phase established in May 2020 through to the roll out of new technology, better information systems and skills for frontline staff, and to deliver and embed these solutions out to 2024. A new programme team is in place, and oversight is via the safety task force reporting directly to the CEO of Network Rail.

[19] https://safety.networkrail.co.uk/safety/planning-and-delivering-safe-work/standard-019-briefing-materials/

Lessons learned from the response to Covid-19 by both Network Rail, and the wider industry, will also be used to inform future thinking around planning timetables for the year 2021 and beyond, and the effects on track access for the frontline, as these issues remain and have not gone away during the pandemic. That said, it is acknowledged by the ORR that the delivery of four emergency timetables in very short order and in continuing to deliver efficiencies in a challenging environment, was a notable achievement[20]. Network Rail has certainly benefited from the process that required rapid decision making and changing working practices to support the wider sector during Covid-19, and this has enabled the reintroduction of services, and preparations for the return to steady state. There has also been a retained focus on delivering planned maintenance and renewals work, and the pace of change required during the pandemic is to be used to guide and remind teams how they might also use a similar approach to prioritise and accelerate other changes related to the work of the safety task force (Network Rail, 2021).

The longitudinal (observational) work has allowed for repeated reviews of progress with PDSW (and P4W) roll out, and the variability introduced by the covid response and the introduction of the [track worker] safety task force. Chapter 9 further reflects on the circumstances that the rail industry was faced with during the pandemic, what changes were made, and how successful these were.

2.4 Organisational Learning

Organisations depend on systematic approaches to gain the ability for systematic learning (Dekker, 2015). Such approaches can be found in the organisational learning (OL) discipline (Crossan, Lane, & White, 1999; Schneider, von Hunnius, & Basili, 2002). In the case of Network Rail, and the rail industry more broadly, there are numerous opportunities for them to learn – whether from reflections on the consequences of incidents and accidents, individual and organisational behaviour, organisational environments and decision making, or through performance and service metrics.

Despite its relevance for performance, organisations still struggle to implement OL (Garvin, Edmondson, & Gino, 2008; Taylor, Templeton, & Baker, 2010) due to its highly conceptual nature with little practical guidance (Garvin *et al*., 2008; Reich, 2007; Taylor *et al*., 2010), as well as confusion about the OL concept (Wu & Chen, 2014).

The rail sector uses safety and performance data to measure, monitor and report on its collective ability to deliver a safe, reliable railway. But notwithstanding this scrutiny, incidents and accidents keep occurring that seem preventable and that have similar systemic causes (Salmon *et al,* 2012). Too often, as identified from Rail Accident Investigation Branch (RAIB) reports, and internal rail industry reports that the researcher has been party to in former roles, the sector fails to learn (sufficiently) from the past and/or makes inadequate changes in response to events (ORR, 2020).

[20] https://www.orr.gov.uk/search-news/network-rail-mid-year-report-december-2020

Examining the assumptions and paradigms that underpin organisational learning from a risk management and safety-driven design perspective may help identify the problem as to why OL is so difficult in a real-world context, particularly cross-industry such as rail, where there can be different political motivations, commercial sensitivities, and imperatives at play.

Alternatives based on systems thinking are explored (e.g. Bow-Ties and STAMP) as part of Chapter 8 to see if particular models or tools can help with prospective analysis, and later on in the thesis guidance is developed offering a stepped approach to change implementation, such that it can be effective and sustainable.

2.5 Human Factors in Railways

Human factors and ergonomics are often inter-changeable terms used in the context of ergonomics (Wilson, Farrington-Darby *et al*. 2007). In the rail industry human factors has traditionally focused on ensuring that employees have safe and easy-to-use equipment and a place in which they can work efficiently. However, things have changed in the past couple of decades and there is now a broader focus because of several interconnected trends (RSSB, 2008):

- Technical systems are becoming more wide-reaching and complex, making it necessary to consider their effect on the larger work group (and indeed the total organisation);
- Work is placing increasing demands on people's knowledge; and
- Rail organisations regard employees – as well as new and emerging technologies – as valuable investments.

In 2003 – following the Ladbroke Grove Rail Accident in 1999 when many reports were published, and 100s of recommendations were made – human factors really started to emerge as a 'force for good' in the railway industry and it was recognised that human factors could support the design of railway systems to optimise performance. Subsequently, integrating human factors activities at the start of projects was seen to be able to reduce the need for re-design once systems became operational, reduced the potential for staff turnover, and could help increase productivity. However, attending to all human factors would require a whole industry approach and the timely application of human factors knowledge and techniques has not yet become a feature of many programmes; this is despite the fact that the application of human factors knowledge can significantly reduce the likelihood of an accident or incident and any subsequent loss to property, or human life (RSSB 2012).

Investigations into a number of track worker fatalities and accidents over the last 20 years (Ruscombe, 2007[21]; Newark North Gate, 2014[22]; Margam, 2019[23] etc.) have highlighted more often than not that those involved do not behave unsafely because they do not know what to do, but because there has been a human factors related issue; for example, assumptions are made, there is miscommunication, someone has made a decision without properly thinking through the consequences, or there has been a failure to challenge something that is unsafe.

As a result of rail related incidents and accidents, a number of recommendations have been made by both the Rail Accident Investigation Branch (RAIB) and the Office of Rail & Road (ORR) for the rail industry to assess and develop the Non-Technical Skills of those individuals undertaking particular duties, e.g. Controller of Site Safety (COSS).

It would seem from report findings that there is a general lack of understanding of what these non-technical skills are, beyond those published by RSSB[24], and what they mean in practice in the domain of signallers and train drivers; to-date it has primarily been the operations function of Network Rail and train and freight operators who have been the main adopters.

Research funded by the Rail Accident Investigation Branch (RAIB) and published in April 2020, sought to understand the factors affecting safety behaviours of Controllers of Site Safety (COSSs). The final report points to a wide range of systemic factors *"which cut across individual, group, organisational, and external levels of analysis and in combination contribute to accident and incidents involving trackworkers*" (Loughborough University, 2020). This report, along with a specific class investigation by the RAIB on trackworkers outside possessions (RAIB, 2017), suggest the factors affecting safe behaviours are many and varied.

It is evident that there have been advances in the priorities of human factors in many sectors going back twenty years or more, but perhaps nowhere has this been clearer than in infrastructure such as transport, utilities, and construction.

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[21] Track worker fatality at Ruscombe Junction, 29 April 2007:
https://assets.publishing.service.gov.uk/media/547c9034ed915d4c0d000197/R042008_080228_Ruscombe.pdf

[22] Fatal accident involving a track worker near Newark North Gate station, 22 January 2014:
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/405864/150216_R012015_Newark_North_Gate.pdf

[23] Track workers struck by a train at Margam, Neath Port Talbot, 3 July 2019:
https://assets.publishing.service.gov.uk/media/5fabd9c9e90e075c4965171e/R112020_201112_Margam.pdf

[24] RSSB: Understanding Human Factors - Non-Technical Skills for Rail
https://www.rssb.co.uk/en/safety-and-health/improving-safety-health-and-wellbeing/understanding-human-factors/non-technical-skills

However, the greatest proportion of new human factors ideas (understanding, analyses, designs, standards, and implementation) has been credited to the rail industry (ORR, 2014), including:

- A system engineering orientation and advances in theory and methods to understand social and socio-technical systems;
- Concern with complex multi-person, spatially and functionally distributed systems;
- A shift from concern with physical work and life to the cognitive and social; and
- Understanding of context and setting, including government, regulatory, and societal influences.

It is on this basis that human performance particularly is considered in the context of the Business-Critical Rules programme and its associated elements of Bow Ties and Means of Control, the PDSW programme, and the rail industry's Covid-19 response. Learnings from incidents and accidents, and the coronavirus pandemic recovery by the rail sector, present an opportunity to shine a light on the many positive responses, but there is also the potential to highlight where there may be gaps in things like systems thinking, or human and organisational factors and the application of HFE theory in real-world contexts.

2.6 Research context summary

The ORR annual report on health and safety 2019/20 stressed that safety across Britain's railways had improved over the previous 12 months but more needed to be done to improve on a number of fronts. Network Rail, for its part, had already recognised similar issues, and embarked on a range of national change programmes which are at different stages of implementation (two of which are used as contexts to frame consultations within this study) (Network Rail, 2019).

Whilst there are clear parallels, and Network Rail and the Regulator having comparable objectives, there is also the challenge of:

- whether there may be conflicts and contradictions in their intended outcomes;
- a lack of a clear strategy and detail regarding their implementation;
- building operational capability (e.g. should training be re-framed around role rather than task-based competence, and what behavioural competences are necessary to enable greater autonomy and localised risk-based decision-making? How does organisational learning work in practice?).

The following critical success factors were identified in the Nichols Group summary report (Nichols, 2013(b)), typifying 'comparator' organisations' experience(s):

- Focusing on the effective management of change;
- Educating the whole company in the importance of the systems, and regularly reviewing the effectiveness of the systems;
- Have teams that 'own' the respective programmes, and who can provide guidance post-implementation when the system(s) move to 'Business as usual'.

Given the significance of the changes being brought about and the pace of change being sought within the rail sector, it is important that this research is undertaken to help guide the implementation of sustained improvements in both safety and performance for GB railways.

The Williams-Shapps 'Plan for Rail (DfT, 2021)'[25], as a reform package and White Paper, seeks to create a new structure for rail that would facilitate the opportunities for efficiencies identified by previous reviews conducted by Sir Roy McNulty (2011)[26] and Richard Brown (2013)[27]. Socio-technical system and resilience engineering theories seem to offer solutions to the challenges, and the research goes on to identify ways in which joint optimisation of the social and technical aspects might be achieved through recommendations and guidelines that deliver sustainable change in Network Rail, but also the wider sector.

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[25] DfT, Great British Railways 'The Williams-Shapps Plan for Rail', dated May 2021
Great British Railways (publishing.service.gov.uk)

[26] Independent report: A study chaired by Sir Roy McNulty, commissioned by the Secretary of State for Transport.
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/4204/realising-the-potential-of-gb-rail.pdf

[27] Independent report: The Brown review of the rail franchising programme.
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/49453/cm-8526.pdf

3. Literature Review

The overall aim of this research is to evaluate the GB rail socio technical system and to develop guidance that supports implementation of sustained improvements in safety and performance. The focus is, therefore, on understanding the complexities of the GB rail sector, and how it designs systems and processes during periods of significant change, that continue to support human performance and are resilient to unanticipated events.

This chapter explores the key fields of knowledge that support the research carried out. It reflects the situation and developments relevant to the investigations, put forward in the introduction, related to the socio-technical systems of GB Rail. This has supported the further study of the extent to which the systems approach is applied with rail industry processes and practices; understanding if managers have applied systems thinking and how this can affect work they prescribe and oversee. The impact of these change initiatives on employee perceptions has also been considered. The part rules, procedures, standardisation, and compliance play in organisations is also addressed.

Further on in the chapter, literature is introduced that contributed to the investigation of organisational learning and a systems approach to safety-driven design, and related systems analysis methods, and perforce resilience engineering.

The review provides a structured overview of the available literature in these specific areas and identifies the related research gaps.

3.1 Socio-Technical Systems (STS)

3.1.1 Systems theory

This section provides a brief description of systems theory (general and socio-technical) and how such approaches have evolved over the past half century or more.

von Bertalanffy (1968) was seen as the founder of 'general systems theory' (GST), based on his earlier work as a biologist. His premise was that complex systems share common organisational principles, and he wrote that *"a system is a complex of interacting elements….that they are open to and interact with their environments."* He posited that the system provides the framework for structuring the parts and relationships into an organised whole, thus leading to the common adage *"the whole is greater than the sum of its parts."* His work was intended to be applicable in the broadest sense, as opposed to one domain of knowledge. His field of work is related to among other things, systems thinking and systems engineering, and has some parallels with the work of Trist *et al* (1951; 1960), also seeking to emphasise the importance of adopting a systemic viewpoint.

The term 'socio-technical system' (STS) had earlier emerged in the 1950s. Trist, as part of the Tavistock Institute of Human Relations in England, postulated that systems have technical and human/social aspects, and it is the interconnections that affect system performance (Trist, 1981).

Trist and his fellow researchers (Trist and Bamforth, 1951; Emery and Trist, 1960) observed how mechanisation in the coal sector had broken up tightly knit teams which resulted in decreased productivity and labour discord, thus joint optimisation (i.e. systems encompassing both humans and technologies) became the goal of socio-technical design. The idea of developing semi-autonomous groups, with more flexibility, was explored, serving both the human element and technical efficiency.

Since the 1950s and 60s, socio-technical systems theory (STS) has evolved, supporting work system changes, and optimising safety and productivity (Hackman and Oldham, 1976). There was recognition in Hackman's and Oldham's work of the contribution that socio-technical systems theory had in developing the notion of the "autonomous work group," and shared decision-making (Herbst, 1962; Gulowsen, 1972). However, Hackman's and Oldham's belief was that a limitation of the approach was that it did not offer a way of understanding and evaluating the work system before and after change.

Albert Cherns, in papers published in 1976 and later in 1987, set out some of the important principles of the socio-technical system approach, with nine principles taking the form of a set of guidelines to help design work systems (Waterson, 2015). Clegg (2000) went on to update Chern's list, expanding the original nine principles to nineteen principles across three groups (meta-principles (philosophy / vision), content principles (e.g. task allocations), and process principles (e.g. expertise and skills)). He recognised that many organisations lack an integrated approach to change, and he developed principles to be used alongside other methods and tools such as accident analysis and investigation.

Certainly, the term 'systems thinking' often appears in the literature referenced above when discussing complex socio-technical systems, and the term 'systems approach' is also routinely used in relation to this as part of socio-technical thinking and practice (Arnold and Wade, 2015). Various definitions have emerged since 1987 when Barry Richmond first coined the term 'systems thinking', after which he wrote about the importance of learning in new ways as interdependency increases, and the need to deal with complexity and system dynamics (Richmond, 1994). Other 'systems thinking' definitions focus on the elements of which systems thinking is *made*, but as Arnold and Wade found (2015) these tend to then neglect to say what the systems thinking *actually is*, and what it *does*. They helpfully offer a 'systemigram' to bring their own thoughts on system thinking to life (see Figure 3.1), synthesised through their review of other work in this area too (e.g. Senge, 1990; Sweeney and Sterman, 2000; Sterman, 2003). As can be seen, the common elements include interconnections, understanding dynamic behaviour, and seeing systems as a whole.

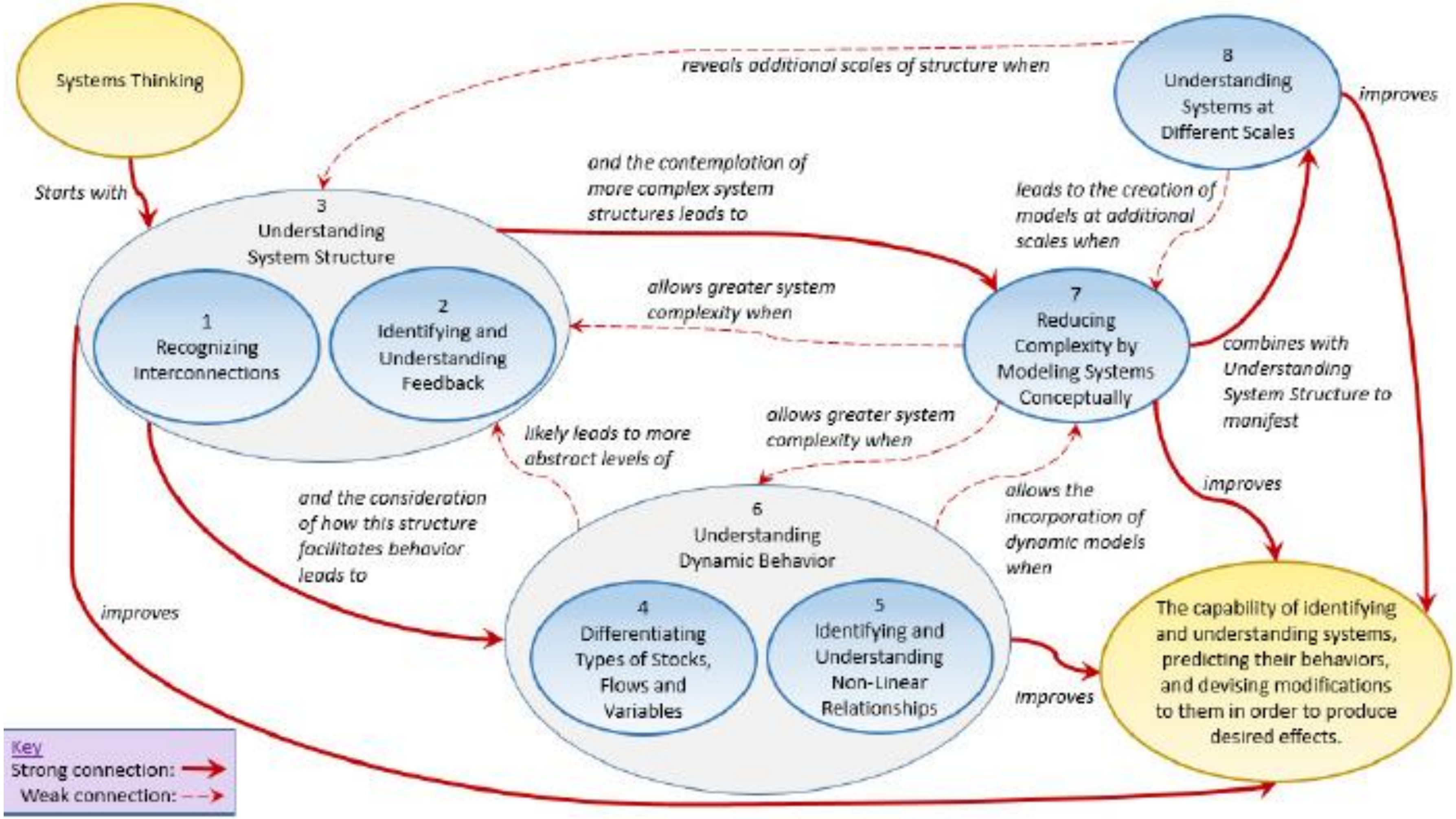


Figure 3.1 – Systems Thinking Systemigram (Arnold and Wade, 2015)

3.1.2 STS models and frameworks

Looking back at the general systems theory from von Bertalanffy (1968), and comparing it with more recent thinking, a systemic approach to safety (and performance) is advocated by Hollnagel and others (Hollnagel, 2004; Dekker *et al*, 2011), where they believe the focus should be on system interactions and the dynamic nature of these, and the unpredictability of their effects. Dekker *et al* (2011) say that *"…the behaviour of the whole cannot be explained by, and is not mirrored in, the behaviour of constituent components".*

Jens Rasmussen, throughout the 1980s and 90s, introduced concepts on human factors and engineering integration, and their application to safety (Leveson, 2017). His approach to safety was clearly influenced by systems theory, and with Vicente he went on to develop the abstraction hierarchy (AH), for the design of human-machine interfaces for supervisory control, using 'how' and 'why' relationships to model the work environment in complex socio-technical systems (Rasmussen and Vicente, 1992) (source: Leveson, 2004).

Later, Rasmussen and Svedung – based on their experiences gained across numerous sectors, including rail – developed a model in risk management (see Figure 3.2) that reflects social and organisational levels, using a hierarchical control structure (Rasmussen, 1997; Rasmussen and Svedung 2000). Rasmussen and Svedung (2000) proposed a dynamic approach to risk management, focused on gaining an understanding of three main areas: (1) the decision-makers and actors involved; (2) the part of the work-space under their control, and (3) the structure of the distributed control system (i.e. the communication channels through which the decision-makers cooperate). They indicated that there may be gaps in the way decisions are made based on the available information, and control of safety in the system should be considered using five specific themes (Objectives, Status Information, Capability, Awareness and Priorities). This approach was intended to be used proactively, since technological change, and public concern for safety, was increasing.

Whilst the flow of information and interfaces in the model look complicated, Rasmussen and Svedung asserted that risk management in complex systems requires an understanding of how pressures at each level affect decision making, and how decisions at one level affect decisions of the next level.

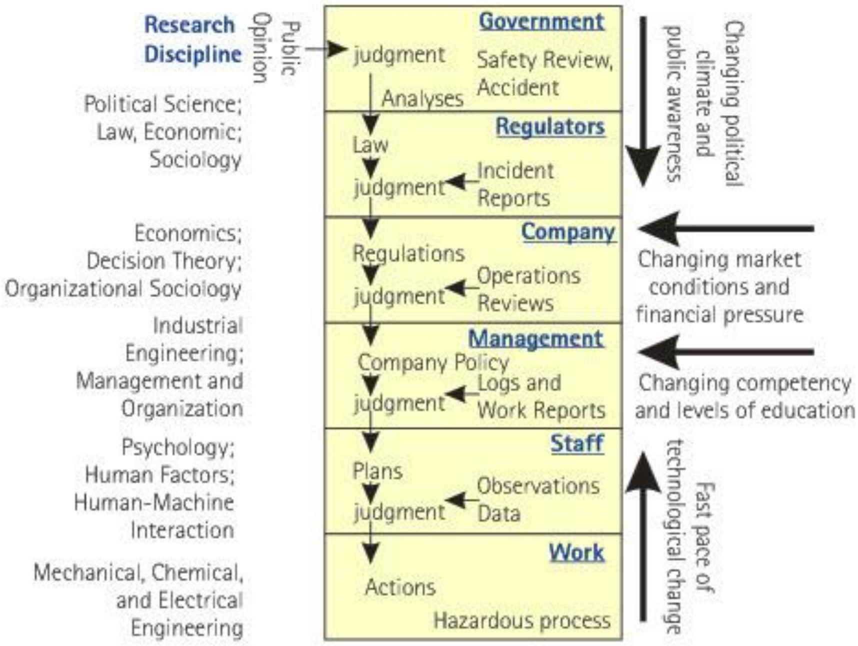


Figure 3.2 – Rasmussen / Svedung model in risk management (Rasmussen and Svedung 2000)

Some socio-technical system models or frameworks have been developed for specific tasks or goals. For example, Moray's (2007) 'onion' model has been used in healthcare, and railway human factors and safety. The model is used to specifically describe a number of levels of analysis of the socio-technical system with organisational, legal, societal and cultural pressures as outer layers, and management, team and group and individual behaviours as the next layers, with physical devices (such as a piece of railway infrastructure) at the centre of the 'onion'.

Some models have also been developed and applied across a range of other domains, such as transportation, outdoor recreation and public health, e.g. the AcciMap model (Rasmussen, 1997; Rasmussen and Svedung, 2000), which aims to shift the emphasis away from viewing accidents as the result of a single cause or the actions of a specific individual – the 'bad apple' theory (Dekker 2006) – such that accidents arise as a result of a complex set of events and conditions involving multiple layers and/or system components.

Numerous authors have proffered their views on accidents and incidents occurring through unexpected events or combinations thereof because of variability in the system or constituent sub-systems (Perrow, 1984; Reason, 1997). However, Rasmussen argues that "*…sequence-of-events and barrier models say nothing about the build-up of latent failures, about a gradual, incremental, loosening or loss of control that characterises system accidents"* (Rasmussen, 1997). The 'top event' in a barrier model, as acknowledged during this research, is often subjective, and at best a pragmatic choice.

Nancy Leveson advanced a slightly different approach to the Rasmussen and Svedung (2000) model; taking a broader view of accident mechanisms (Leveson, 2011), and questioning whether traditional event-chain models in complex socio-technical systems adequately describe the process and advocates an approach reflecting the pace of technological change, acknowledging that organisations often have a reduced ability to learn from experience and test systems and designs before implementation.

Organisations do not necessarily have adequate processes for learning either internally, or from similar organisations, often due to other real-world pressures, such as time or resources, or competing priorities (Baxter and Somerville, 2011).

Most organisations would probably identify safety as their number one priority, but it is often also the case that there are other pressures that make this difficult to achieve, particularly with the scale and pace of change, and technology introduction. Understanding competing pressures that make it hard for business leaders and engineers to undertake analysis that pays equal attention to socio- aspects of design is important. Human-centred design is certainly recognised (Woods *et al*, 2007), but as Hollnagel (1998) identified a decade or more before, in 1998, it was much harder to find real-world examples back then.

Organisations looking for best practice can turn to published frameworks like Managing Successful Programmes (MSP®)[28] for designing and running specific change programmes, to help deliver their strategy and gain measurable benefits from change (AXELOS, 2020). The approach is designed to help improve programme-level decision-making for professionals with programme management responsibility within public and private sector companies of all sizes.

Bringing systems-thinking and STS theory together, along with project management, is regarded as a positive step, especially for those working in sectors that deliver complex technological products such as defence and aerospace (Association for Project Management, 2018).

That said, there is little research on how an organisation that faces an array of challenges in a complex and changing rail industry uses the underlying principles from organisational theory, and STS and resilience engineering literature, to complement the development and application of processes. As an example, Rasmussen's (1997) dynamic safety model could be used to influence strategy or evaluate strategic approaches enabling rail managers to evaluate how they best deal with pressures and/or conflicts between safety and productivity. Such an approach could make the boundaries clearer to decision-makers (across the various levels), and to counteract the pressures that drive decision-makers beyond official work practices and drift toward the limit of or beyond the safety boundary, leading to the potential for loss or harm if not adequately addressed.

[28] Managing Successful Programmes (MSP®) (2020) represents good practice in the delivery of transformational change through the application of programme management. MSP was developed by the UK Government in 1999 and is used both within the public and private sectors. It has been adopted by many organisations, including Network Rail, and was used to help plan and organise the London 2012 Olympics.

Hollnagel (2012) defines 'resilience' as *"the intrinsic ability of an STS 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"*. How this can be achieved and the ability to effectively trade off such issues of safety, costs and productivity are questions posed previously (Wilson *et al,* 2009) but have yet to be comprehensively answered. Hollnagel (2012) encourages a focus on what is needed for everyday performance to go right, attention to 'work as done' as opposed to 'work as imagined' and how everyday performance may produce unexpected outcomes (either good, or unwanted). It is not known whether these are notions that are necessarily appealing to industry, and how easy it is to apply these effectively within industry contexts.

Several studies in the literature have helpfully started to explore these types of issues with senior business leaders. Reiman and Oedewald (2007) used interviews to investigate the cultural conceptions of key decision makers and their accounts of perceived barriers to change in their work, in the nuclear sector. Their interviews sought to understand whether individuals within the organisation were reactive in the search for errors and analysis of previous accidents and incidents, or if the focus was more on general safety attitudes and values rather than understanding organisational core tasks. They found the former to be the case, i.e., a tendency towards reaction not proactivity.

Reiman and Oedewald (2007) found that other challenges, such as anticipating the unexpected, are easier to communicate in an organisation if they refer to specific work and its uncertainties, and the concepts of organisational core tasks can help with identifying necessary precautions before accidents or incidents occur if the work the organisation is carrying out is better understood.

Later work by Reiman (Reiman, 2010) goes on to show that research on the maintenance function of an organisation has focused mainly on human errors and individual-level issues, though social and organisational factors do receive attention on occasion because of high profile incidents / accidents. Studies of normal work, practices and cultures of maintenance functions appear scarce in the literature, particularly for rail, and very few appear to have examined work or work processes and how these can affect the frontline staff and their immediate supervisors, particularly in influencing behaviours and decision-making.

Makins and Kirwan (2016) used interviews with sixteen top Executives across airlines (3), airports (3), air traffic management (6), regulation (2) and research (2) sectors of the aviation industry, whereby they noted that Executives look beyond safety data, and have discussions between those operating their organisations and the target setters. The study went on to highlight some of the senior-level business decisions that have to be made to protect aviation safety, but also how there can be a lack of visibility to those impacted by the decisions.

Both the Reiman and Oedewald work, and the Makins and Kirwan study, reveal current gaps in understanding and research of how senior business leaders make critical decisions concerning safety. In developing this type of consultative approach, it is important that such insights are balanced with similar consultation with other Senior Managers working alongside the very top Executives, to establish a broader view of safety performance.

Moving the STS approach forward, Carayon *et al* (2015) advocate far greater user/worker involvement in socio-technical systems implementation, and Flach *et al* (2015) discuss issues of communication and decision-making within socio-technical systems. It is recognised in the literature that organisations often have great difficulty coordinating and communicating across many different realities, organisational hierarchies, considering the experiences of various individuals, and work groups. Communication breakdown, across all levels, is often cited as a reason behind this (Flach *et al* (2015)).

The earlier work of Rasmussen (1994) and Leveson (2012), as well as the later research by Flach *et al* (2015), also discuss the importance of understanding local socio-technical work systems and the larger 'social context' provided by the wider organisation (the point being that no-one is in the privileged position of understanding the entire system, and coordinating information across the range of different levels is essential in complex systems).

Others have previously attempted to examine factors impacting safety performance, for example Dejoy (2005), and have identified that complex socio-technical systems make it increasingly difficult to explain the root-causes of incidents and accidents (Perrow, 1984; Leveson, 2011), largely because accidents often result from interactions among components, not just component failures, making it difficult to pinpoint what happened and why. Leveson has previously remarked that system design and accident analysis are much harder in the modern era compared to simpler work systems of the past (Leveson, 2012).

This literature review has helped to identify some important points to consider for the design of change in a complex industry, and how a socio-technical system framework or model might be applied in practice. The literature includes numerous examples of the application of the STS model, across manufacturing, healthcare, and transport (Waterson, 2015), particularly STS practice related to job and work design.

It is clear from some of the available case studies (Eason, 2007; Saurin and Gonzalez, 2013) that adopting a systemic approach helps to support successful implementation of change programmes, e.g. information technology roll-out, equipment upgrades etc. (often among other workstreams and competing priorities) such that they are not at odds with each other and are able to produce the desired outcomes. That said, there appears to be no 'magic bullet' to achieve safety (and performance) in a complex socio-technical system such as rail. The literature suggests that careful examination of the communication flows, decision-making authority and interfaces between system layers, is required (Waterson *et al*, 2015), and that practical advice and support for practitioners is needed for those wanting to use STS to improve the workplace (Waterson, 2015).

Baxter and Somerville (2011) also offer some research issues for further consideration, e.g. *"how can evaluation methods take organisational issues into account, for example, how organisational considerations affect the use of an interface….".* It is certainly important to understand how relationships work in an organisation, and between those that operate within the business, and the system(s) that support the multiplicity of processes in place (Norman, 1993).

Ryan *et al* (2021) helpfully present a framework, reflecting the role of individuals in establishing and maintaining system safety in railway socio-technical systems, to arrive at a common understanding of different types of goals, safety-relevant activities, and other human and system components that are important for describing work with an STS. They acknowledge that the model is complex, and there may be some merit in testing the framework against a relatively self-contained rail system, such as a metro or urban rail system before potentially widening its use.

3.2 Rules, procedures, standardisation, and compliance

The topic of rule management has previously been studied by Dekker (2006), and Leplat (1998), and their work looked at 'golden rules' and dealing with 'exceptions', by which the rules are extended, because the incident is not covered by an existing rule. There are copious amounts of rules in many technology-based, complex, systems such as those found in rail, aviation, and power generation (Clewley and Stupple, 2015), and often rely on an individual operator to implement and/or comply with a rule (Hollnagel and Woods, 2005). In safety-critical domains like the railways, rules can be used as system defences, and allow organisations a way in which to reduce variability and control outcomes (Katz and Khan, 1978; Reason 1997). Rules and procedures also perform a function in standardising team interaction and processes, defining tasks, and setting out organisational goals (Bieder and Bourrier, 2013).

Dekker (2006) formulated two models of safety rules, and how they come about, are developed, what their function is, and their strengths and limitations. One perspective is that humans create or reduce safety in the workplace and are 'bad apples', the second is that workplace incidents are symptoms of troubles within the system. In the first view Dekker posits the systems are already seen as safe and *"….it is humans that are unreliable, erratic or careless"* and who, therefore, contribute to non-compliance. In the second view, he suggests it is the people who have to try and work within the safety rules that find work-arounds, made more complicated by the organisational setting and thus *"…..safety is continually created and compromised".*

The way in which safety, and compliance with rules, is to be achieved is the subject of several papers, and examples include:

- goal and process rules to allow for flexibility (e.g. rules concerning the goals to be achieved, and the way in which decisions about a course of action much be arrived at, that then have a degree of latitude for the user of the rule. The goal rule might only define the goal to be achieved, but leave the way to reach the goal completely open (Grote, 2006);
- action rules for stability (e.g. prescribed 'concrete' actions) (Hale and Swuste, 1998); and
- the ability to adapt rules to the diversity of the work situation, where rules are dynamic, local, where competence of operators is seen to a great extent as the ability to adapt rules to the diversity of reality (Hale and Borys, 2012a,b).

The sheer volume of rules in complex industries such as rail have also been shown to be a barrier to use (Maidment, 1993; Hale and Borys, 2012a,b). What is apparent from the literature is that the level of generality (i.e. how fixed the rules are, or the degree of discretion permitted of the rule-follower to comply) can directly influence the size and content of the rules. Hale and Swuste (1998) postulate that *"….the more that regulations are phrased as 'action rules' the more rules there must be to cover a given breadth of activities or risks".* They also suggested that the extent to which the action rules are imposed correlates to the likelihood of compliance.

The ability of organisations to operate within a complex regulatory framework has been explored by Hale *et al* (2015), who found that increases in bureaucracy and the burden of compliance are often difficult for companies. Some of their other related work (Hale *et al*; 2011) has parallels with Grote (2007) and Klein (1991) around decisions that restrict operational autonomy (for instance, due to strict safety rules), but also how there might be adaptation of such rules if interfaces and working relationships are better understood and seen from different perspectives. Interestingly, the Office of Rail and Road (ORR, 2017) – as the rail regulator – have found evidence of informal non-compliance with Network Rail rules, procedures and standards, and their report stresses the importance of introducing non-technical skills training (for Network Rail staff and its contractors) *"…..to improve the prevailing safety culture and degree of compliance".*

What is apparent from what is written about rules, procedures, standardisation, and compliance, is that rules might well be imposed from above, but they ought to reflect the practical reality of every-day operations (and disturbances). The terms 'work as done' and 'work as imagined' are used variously in the literature to describe the difference between understanding systems that are real rather than ideal (Ashour *et al*, 2021). Early work on cognitive systems engineering (human-machine interaction) analysed the difference between the system task description (such as procedures) and the cognitive tasks (Hollnagel and Woods, 1983).

Woods and Cook (2002) went on to identify that it is likely that employees have a sense of what is risky and what is not, what works and what does not. They do not imply that the employee is right, but they do suggest that it is important to understand why people work the way they do, and that they may even depart from written guidance and rules.

Ashour *et al* (2021) observed that Lawton (1998) had previously noted that the gap between 'work as done' and 'work as imagined', is usually due to a combination of work conditions that do not favour set procedures, human variation and competing priorities in the workplace. This is significant when it comes to understanding who should write detailed rules, for example Ashour *et al* question if they should be written by subject matter experts for inexperienced individuals / teams, or only those with overly complex tasks to execute? They also ask about writing simple instructions for those with experience but perhaps needing refreshers or training as the need arises, and who would develop these instructions?

Compliance-based approaches may pay immediate dividends (Dekker, 2006), but creating safety in practice may require far more flexible thinking and approaches to rule making (Grote, 2006), with greater decision latitudes for rule users.

3.3 Risk Management

Given the aim of this research, much of the focus has been on the rail socio technical system and how sustained improvements in safety and performance might be achieved. It is important, therefore, to understand risk (and safety management) in this context, such that the prevailing issues of workforce safety and the increased attention on decentralisation (and thus more localised decision-making) are better understood and managed.

One might argue that risk management has been practiced for centuries, and individuals to this day assess risk before making decisions (Bernstein, 1996). However, formal risk assessment and risk management is probably not more than 50 years old (Crockford, 1982), often linked to [corporate] insurance. The topic started to appear in scientific journals (such as The Journal of Risk and Insurance dating back to the 1960s) and academic papers discuss some key principles, particularly around 'preventing accidental loss' (McCahill, 1971; Crockford, 1980).

The application of risk management has evolved since the 1960s, and numerous examples can be found of risk analytical approaches, barriers and safety prevention methods, in use across a range of industrial settings and sectors, e.g. finance, safety engineering, health, transport, nuclear, security, insurance, and the military (Bernstein, 1996). It seems, however, that there have been challenges in establishing suitable risk descriptions and metrics, and attempts have been made at standardisation (SRA, 2015).

Figure 3.3 depicts the evolution of the many risk assessment techniques, although Senge would argue that very few of these are capable of dealing with system complexity (Senge, 1990).

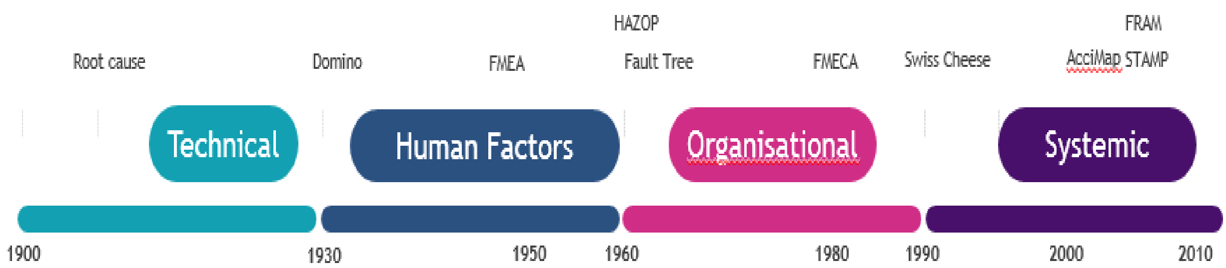


Figure 3.3 – Evolution of risk assessment (adapted from EUROCONTROL, 2009)

Rasmussen (1997) described a systems-based approach, and how accidents occur and migrate towards the boundaries, e.g. a drift towards failure (such as not identifying the full extent of non-compliance or unsafe practices), as illustrated in Figure 3.4.

Later in 2000, Rasmussen and Svedung suggested it was essential that these boundaries of safe operation be identified (e.g. understanding if the system workload increases, then the burden on workers, systems and equipment increases too) and then communicated. Rasmussen and Svedung (2000) developed a dynamic approach to risk management, recognising that risk management could no longer just be based on responses to past accidents and incidents, and instead required measurement of *actual* safety against agreed targets. Among other things they offer guidelines for improving top-down communications and bottom-up information flows in practical work environments depending on risks and related management strategies.

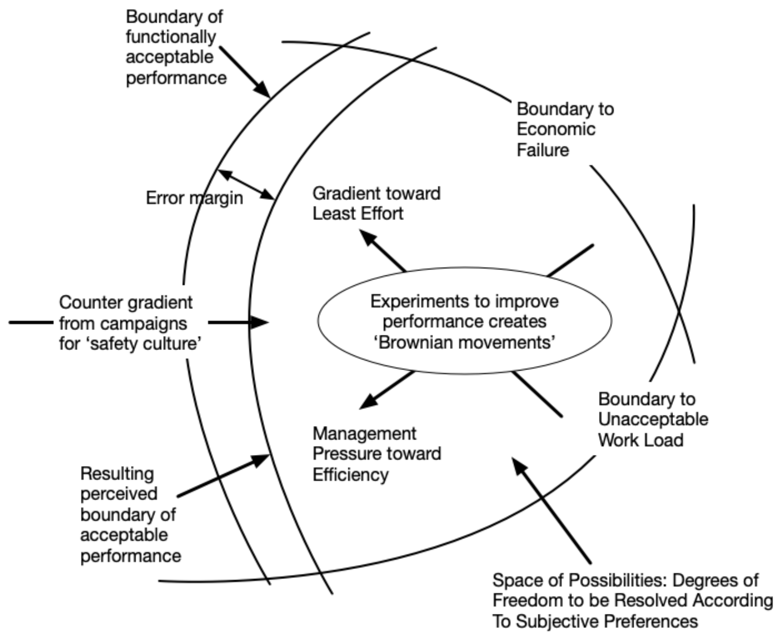


Figure 3.4 – Rasmussen's drift to danger model (Rasmussen, 1997)

Beyond the seminal work of Rasmussen, numerous academics and researchers have considered risk management and systems thinking-based risk assessment methods, across various domains including social work (Jan Waterson, 1999), probation services (Kemshall *et al*, 1997), construction (Harvey *et al*, 2018), and large-scale systems like healthcare (Waterson and Jenkins, 2010), to name but a few.

For those operating in or with the public sector (Kemshall *et al*, 1997, Jan Waterson, 1999) – akin to rail – there was concern expressed with the way in which risk management was increasingly focused on reducing or containing risks as a way in which to manage scarce resources (for example, when situations of high risk attract more resources than those where the risk is less). They posit that less attention was paid to the more positive side of risks (e.g. prisoner rehabilitation) due to resource constraints. The challenge seems to be, where there are public sector efficiencies, that tighter controls are exerted over risk management and mitigation.

What also emerges from the literature is that many industries, including construction, are still firmly rooted in more established approaches to safety: root cause analysis, risk quantification and a 'blame' culture. The work of Harvey *et al* (2018) suggests the need to integrate safety into core activities to increase engagement, to share lessons learnt, and encourage collaboration in risk management to incorporate employee expertise and ensure they feel valued. The work of Waterson and Jenkins (2010) supports such an approach, and they suggest consideration is given to issues of coupling between levels, as well as the communication requirements of 'actors in the system' which can shape the choice of assessment / analysis methods used.

For its part, the rail industry uses the common safety method for risk evaluation and assessment (CSM-RA) which provides a framework that describes a common mandatory (European) risk management process for the rail industry. Supporting guidance is available from the Office of Rail and Road (ORR, 2015a). It allows for the harmonisation of processes for risk evaluation and assessment and supports the collation of evidence and documentation during the application of these processes. CSM-RA does not prescribe tools or techniques to be used, but instead is intended to complement requirements in related legislation, e.g. *'suitable and sufficient risk assessments to be undertaken'*, per the Management of Health and Safety at Work Regulations (MHSWR).

The CSM-RA applies when any technical, operational, or organisational change is being proposed to the railway system; consideration must be given to whether a change has an impact on safety. If there is no impact on safety, then the CSM-RA process need not be applied. Various criteria help determine the significance of the change if there is an impact on safety; and in GB Rail there is a train of thought that even if the change isn't significant the risk assessment should still be undertaken to avoid duplicate risk assessment processes (RSSB, 2019)[29].

What becomes apparent from the literature review around risk management, and systems thinking-based risk assessment, is that supporting systems analysis methods and prospective and retrospective analyses tools are needed, to be used as part of an overall risk management / safety management system, to avoid taking the system far from its intended design parameters.

3.4 Systems analysis methods

As Jørgensen notes, various models and terms have emerged since the 1920s, used to analyse incidents and identify prevention measures (Jørgensen, 2011). This research does not look at all the theories and methodologies relevant to the broader term of 'risk management' previously referred to, and instead focuses on systems analysis methods, and their applicability to rail.

[29] Railway Safety & Standards Board (RSSB) guidance 'Taking Safe Decisions' https://www.rssb.co.uk/safety-and-health/guidance-and-good-practice/taking-safe-decisions

Accident analysis techniques have been developed over the years, recognising the importance of considering the situation / context, and the role played by systemic failings at differing organisational levels. Salmon *et al* (2012) note that three accident causation models generally lead in much of the available literature: Rasmussen's risk management framework (Rasmussen, 1997), Reason's Swiss Cheese model (Reason, 1990), and Leveson's Systems Theoretic Accident Modelling and Process model (STAMP) (Leveson, 2004), observing that each of these models have different ways for analysing accidents.

Some approaches are presented as frameworks or philosophies (e.g. Reason, 1997), while others are introduced as methods (e.g. STAMP – Leveson, 2004), but all of which have been used to analyse a wide range of domains, and scenarios.

The prevalence of different methods, and differences in understandings and application of each is usually because of the complexity involved. It can be a challenge for those seeking a clear 'route map' as to which technique they could best apply to the analysis of systemic failure and/or risk management (Waterson and Jenkins, 2010).

Ryan (2015) posits that it seems very appropriate, for both smaller and larger incidents and accidents, to try to find out what went wrong; to ensure that people learn from experiences (of themselves and others), to stop things going wrong again. He acknowledges investigators and managers often try do this, but with varying degrees of success. The literature review has, therefore, considered accident analysis models and analysis methods which provide for a system thinking approach, and the methods for undertaking both reactive and proactive systems analyses.

Of note, however, is the current limited use and application in GB rail of two of three methods (for which the researcher is familiar), and for which comment is made in Table 3.1 below.

Table 3.1 – a comparison of Bow-Ties, AcciMap and STAMP and their application in GB rail

Systems analysis method	Description	Application in GB Rail
AcciMap (which accompanies Rasmussen's risk management framework, 1997)	A generic approach used to identify and link contributory failures across six socio-technical system levels (Svedung and Rasmussen, 2002)	Examples can be found of AcciMap applied to rail accidents like Grayrigg (Underwood and Waterson, 2014), or understanding what factors influence risk at rail level crossings (Read *et al*, 2021), but the method is rarely used in practice by non-academics in GB rail and, if it is, then this is usually retrospective, following incidents (Underwood and Waterson, 2013).
Bow-Ties (based on the barrier model from James Reason, 1990)	Bowtie is one of many barrier risk models available to assist the identification and management and communication of risk (Turner, Hamilton, Ramsden, 2017)	Bow Tie approach has been used by Network Rail since 2013 primarily as a risk evaluation tool to analyse and demonstrate causal relationships in high-risk scenarios, and to graphically portray how risks are being managed such that resource can be focused in the most efficient way.
STAMP (Leveson's Systems Theoretic Accident Modelling and Processes model, 2004)	The STAMP model uses control theory and systems dynamics methods to describe the systemic control failures involved in accidents (Leveson, 2012)	STAMP appears to be a relatively new concept for rail, and some in the sector are only just beginning to evaluate this model alongside Causal Analysis based on STAMP (CAST) and Systems-Theoretic Process Analysis (STPA) which is a hazard analysis technique, also based on STAMP.

3.4.1 AcciMaps and the Risk Management (ActorMap) Framework

As described earlier, Rasmussen's (1997) risk management framework illustrates various systems levels to show the influence of various factors (e.g. management or Regulation). Svedung and Rasmussen went on to create AcciMaps as an accompanying accident modelling method, based on Rasmussen's framework (see Svedung and Rasmussen, 2002).

AcciMaps provides a graphical representation of the causal factors involved in an incident or accident. It is based on the proposition that behaviour, safety and accidents are emergent properties of complex socio-technical systems and, as such, these emergent properties result from the decisions and actions of all stakeholders in the system, e.g. government, management etc. (Cassano-Piche *et al*, 2009; Salmon *et al*, 2020).

The method is designed to identify and graphically represent the system in question, e.g. policy, regulation, management, processes and actor (staff) involvement, and involved the construction of a multi-layered causal diagram. Contributory factors are 'mapped' to one of six levels (per the example below in Figure 3.5) and linked across the different levels to reflect the cause-effect relationships (Salmon *et al*, 2020).

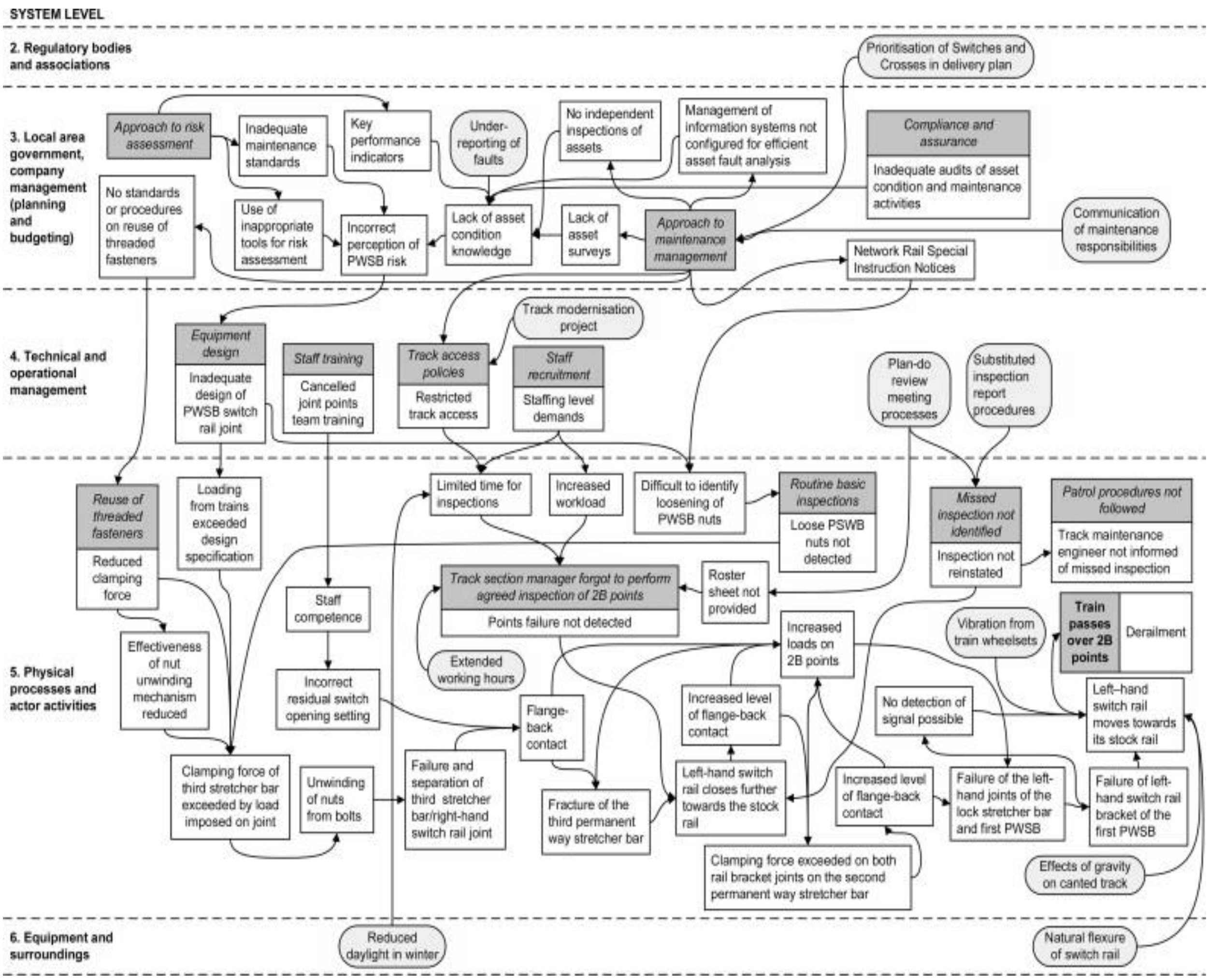


Figure 3.5 – AcciMap diagram of the Grayrigg accident (Underwood and Waterson, 2014)

The analysis method focuses on failures across the socio-technical system (Figure 3.5 is illustrative), but it does not use taxonomies of failures across these six organisational levels, nor does it have any categorisation to guide analyses for the novice user (Salmon *et al*, 2012; Farooqi *et al*, 2013). Importantly, however, whilst not usually used as a prevention tool – although it can be – so that human errors and system failures can be predicted (Farooqi *et al*, 2013), AcciMaps does allow for the retrospective analysis of incidents (Hopkins, 2003; Underwood and Waterson, 2013), and for making improvements in safety; targeting weaknesses found (Salmon *et al*, 2011; Stanton *et al*, 2013).

In their review, Underwood and Waterson (2014) note that the AcciMap approach does not apportion blame, and instead identifies the causal flow of events across the system levels to help improve safety. According to Rasmussen (1997), accidents are typically "*waiting for release*", with *normal* variation in behaviours that can lead to their 'release'.

Various researchers (Hopkins, 2003; Farooqi *et al*, 2013) suggest the use of Accimaps either as part of a risk management process or for analyses of particular accidents. They also say that AcciMaps affords insights into possible causes and identifies additional recommendations that are not addressed in incidents reports. However, despite being used in most safety-critical domains – defence, oil and gas, public health etc. (Hulme *et al*, 2019), Accimaps have mainly been applied within an academic context, and there are still relatively few examples demonstrating their routine use in accident analyses in organisations (including in the GB rail sector), perhaps explained by the difficulty practitioners have in using AcciMaps without domain specific taxonomies of failure modes to help them in their accident analysis efforts (Waterson *et al*, 2017).

Recent attempts to develop a generic AcciMap contributory classification scheme afford the opportunity to support future AcciMap analyses, which may help in building a multi-domain accident dataset to allow for comparisons of accident causation across domains (Salmon *et al*, 2020).

Accident prevention in complex systems requires an understanding of the factors across the entire system that increase the risk of these events (Read *et al*, 2021); aggregating accident analyses across safety-critical domains would clearly be an important step in future research.

3.4.2 Bow Tie Methodology

Various risk assessment methods have been developed to manage numerous sources of risk, with different interpretations, definitions, and classifications of the original 'Swiss Cheese' model (Reason, 1990). Reason's (1990) 'Swiss cheese' deals with system defences that can be typically traced to four levels of failure: 1. organisational influences; 2. unsafe supervision; 3. preconditions for unsafe acts; and 4. unsafe acts themselves. The system (as a whole) produces failures whereby hazards go through the defences resulting in an accident. See Figure 3.6 below.

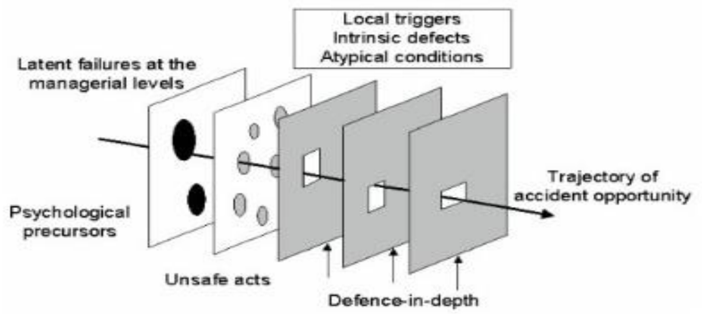


Figure 3.6 – Reason's accident causation model (published in Human Error, 1990), introducing the "defence in depth" concept as a label

Subsequent safety barrier systems have resulted, in support of risk assessment and risk management; designed to prevent, control, or mitigate undesired incidents or accidents (Sklet, 2006). It seems the main strength of the safety barrier approach (for example, using bow ties[30]) is as a qualitative tool to support quantitative risk assessment and management decisions, based on the Swiss cheese model, and to understand accident causation and other important factors that can lead to major accidents (Chen *et al*, 2017). The literature suggests that safety barrier-based models offer practical solutions for the challenges of risk assessment in dynamic operating environments such as oil and gas, nuclear, and the railways (Hollnagel, 2004; Sklet, 2006; Chen *et al*, 2017)

It was after Piper Alpha in 1988 that led the oil and gas industry to adopt the bow tie method, and Royal Dutch / Shell Group were the first (in the early 1990s) to use bow ties for analysing and managing risks, with the potential benefits recognised in other industries including aviation, defence, mining, maritime and health care (Visser 1998). Similar graphic representations of the causal flow of accidents have been used to good effect by industry for many years.

The structure of bow ties is considered useful in analysing past accidents and suggesting improvements to prevent further reoccurrence (Groeneweg, 2002). The methodology is adaptable for the quantification of occupational risks, and information about accidents and barriers are combined in a graphical model for integrating cause-consequence models (Bellamy, Ale *et al*, 2007).

More recent literature (Bellamy, 2015) suggests insights can also be gained into an organisation's risk mitigation strategies, so long as accidents from different hazard bow ties are not mixed, and small severity (more frequent) accidents can be used to also consider causation and prevention of large (more severe, but rarer) accidents. The belief being that this can provide a clear overview of possible incident scenarios, and the barriers that have been put in place to prevent those scenarios from happening, when restricted to the same hazard-type.

[30] A Bow Tie diagram is created by combining two established risk analysis tools, the fault tree and the event tree. Fault trees picture all possibilities that lead to an event. Event trees work inversely, starting with a single event and modelling all its consequences.

Experience from a range of organisations, industry sectors, and regulators has shown that the bow-tie approach is ideal for structured assessment and communication of risks and can be used to qualitatively assess and demonstrate control of all types of risk (not just safety-related risk) (Lewis and Smith, 2010). There is, however, agreement that safety improvements in dynamic and complex work environments will benefit from a change that perhaps the bow-tie method does not fully encompass, i.e. a model or method is needed that focuses far more on the safety-critical interactions between organisational and technical system components (Hollnagel, 2009; Wilson, 2014; Waterson *et al*, 2015) if a true systems approach is to be adopted.

3.4.3 The Systems Theory Accident Modelling and Process (STAMP)

Leveson (2012) notes that there has been a propensity by researchers and industry to search for 'root causes' in accidents, thus inhibiting examination of potentially critical influences of systemic, socio-technical factors. She, therefore, started with Rasmussen's model (Rasmussen, 1997), but developed this further to create a new model of accident causation called 'Systems Theoretic Accident Modelling and Processes'.

STAMP is based on systems theory, and Leveson (2012) says the crucial point is that accidents should be considered as a control problem rather than a component failure problem, noting Rasmussen tended to focus on system operations rather than system development and design (apart from it providing inputs to operations).

Leveson takes the view that the change in emphasis results in designing an effective control structure (see Figure 3.7) that eliminates or reduces adverse events, thus controlling and detecting migration toward a state of high-risk.

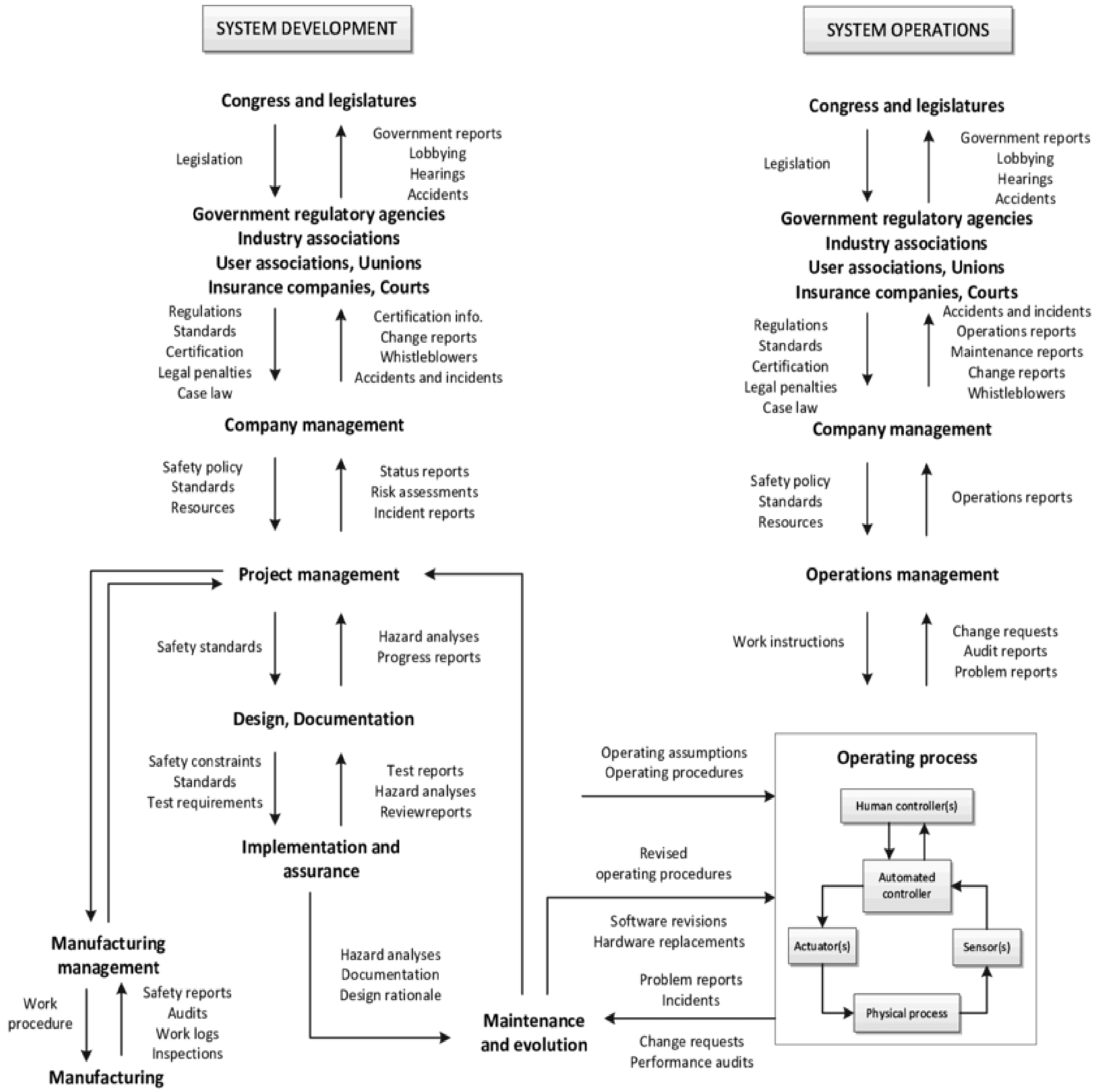


Figure 3.7 – Hierarchical safety control structure (Leveson, 2004)

Of note is that, quite often, the available literature refers to STPA (Systems-Theoretic Process Analysis) – which is a hazard analysis technique based on STAMP – or CAST (Causal Analysis, based on STAMP) – which is the equivalent for accident and incident analysis (see Figure 3.8 below to see how they fit together).

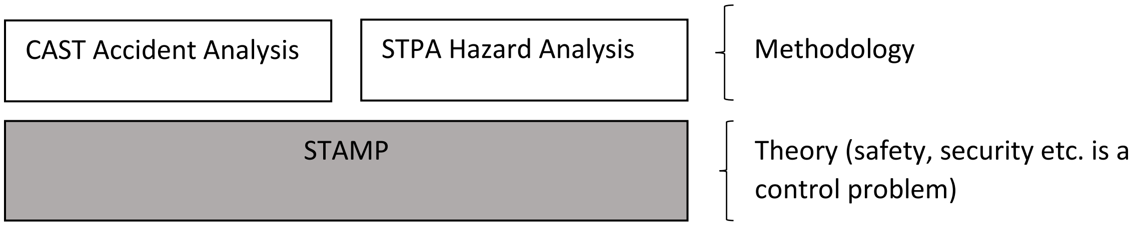


Figure 3.8 – STAMP, STPA and CAST: showing how the methods and theory fit together

Many examples on STAMP and its application, and the related tools, can be found at the MIT online resource (http://sunnyday.mit.edu/STAMP-publications-sorted.pdf). These numerous examples show STAMP, STPA and CAST used across diverse industry sectors, and examples of their application include aviation, air traffic control, space, the automotive industry, nuclear, railways, medical devices, healthcare, and nuclear.

STAMP, as a method, is generic and has therefore been applied to a number of complex systems, and examples include aerospace systems, friendly fire incidents, and the contamination of a water supply (Leveson, 2002; 2004). STAMP treats safety as an emergent property, and views accidents as resulting from the inadequate control of managerial, organisational, physical, operational and/or manufacturing-based controls, or when interactions between system components are not controlled (Leveson 2011).

STAMP is a systemic method supported by a variety of HFE research promoting the systems approach. When used for accident analyses, it produces a description of a system's control structure and then identifies failures in this that contributed towards the accident. The three basic concepts of the STAMP model are described in a book chapter by Leveson (Leveson *et al*, 2006), having been previously included in journal articles (Leveson, 2002; Leveson 2004) and are based around the following components (see also Figure 3.9):

1. ***a constraint***; a system-level constraint specifies system conditions or behaviours that need to be satisfied to prevent hazards (and ultimately prevent losses). The view being that accidents result from inadequate enforcement of constraints on behaviour at each level of the system (e.g. regulators, management, design).

2. ***a hierarchical safety control structure***; which is a system model that is composed of feedback control loops. An effective control structure will enforce constraints on the behaviour of the overall system. Each level of the control structure requires effective communication channels – a downward *reference* channel, and a *measuring* channel to provide feedback.

The control structure is NOT a physical model, it is a functional model. What this means in practice is defining expectations, responsibilities, authority and accountability at all levels of the safety control structure. The connections show the information that can be sent - they do not necessarily correspond to physical connections.

3. ***process models and control loops***; the controller must contain a model of the system being controlled, i.e. the process model must contain the current state of the system being controlled (i.e. beliefs based on feedback and information available), the required relationship between the system variables, and the ways in which the process can change. The view being that accidents result from inconsistencies between the *model* of the process, and the *actual* process state.

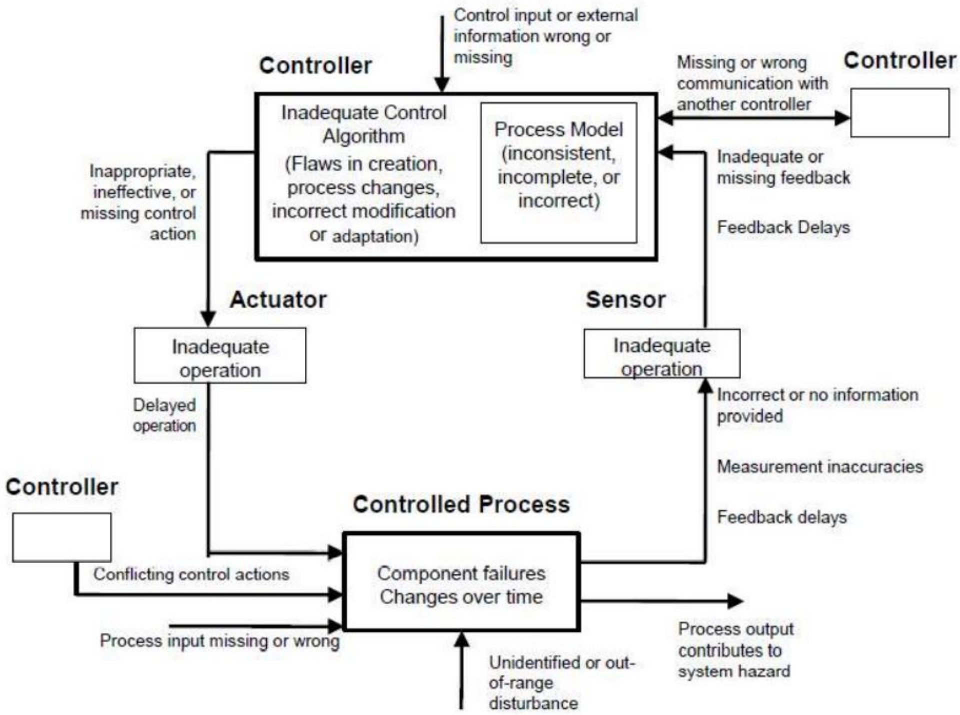


Figure 3.9 – Simplified version of a hierarchical safety control structure (adapted from Leveson, 2006)

These three concepts have been used by Leveson to create a classification of flawed control, permitting accident analysis or accident prevention activities, and helping to identify factors involved in the accident (Leveson, 2004).

Leveson (2004) argues that an advantage of the flawed controls scheme is that it allows for levels of analyses of accident causation at a number of stages of abstraction, for example it can identify control commands required for safety but not given, or control that stops too soon or is applied too long. Thus, the flawed controls scheme helps to identify the role played by the different components of the safety control structure, and the pressures that may have led to degradation of the structure over time (for example, when a worker thinks the scaffold will hold their weight, and now their additional heavy tools and materials, but it will not).

Previous research has, however, highlighted disadvantages to the use of STAMP too, particularly regarding the need for an increased level of guidance within the STAMP method (Almedia and Johnson, 2005; Qureshi, 2007)[31], and the fact that a significant amount of detailed data is required to conduct the comprehensive method.

Canham (2018) agrees that STAMP is complicated and found that the method needs specialist expertise to apply when examining the application of STAMP in the analysis of patient safety incidents. However, Canham did also consider that their research demonstrated the ability of STAMP to take into account the whole system and guide an analysis to the generation of recommendations for system measures to prevent future incidents.

STAMP clearly embodies the systems theory that underpins the various systems analysis methods previously referred to, and its application in a range of sectors is not being questioned here. However, using methods like STPA as a prospective analysis tool requires attention to be paid to latent or emerging risks as opposed to reacting to events after-the-fact; something which industry needs to do if it is to improve workplace safety beyond the tried and tested traditional approaches (Dekker, *et al*, 2013; Carayon *et al*, 2015).

It also suggested by Leveson (2012) that STPA can be used on technical design ***and*** organisational design, and supports a safety-driven design approach where:

- Hazard analysis influences and shapes early design decisions; and
- Hazard analysis can be iterated and refined as design evolves

The specific focus for this research is, therefore, on STPA as a prospective tool and hazard analysis method, and how this compares with more traditional techniques like the bow-tie method which is currently used in GB rail. The point being that the literature suggests STPA might be better for more complex safety-critical systems as they can display unsafe and undesirable behaviour that does not involve component failures, or these were unanticipated by failure-based analysis (Thomas, 2013).

3.5 Resilience Engineering

The Resilience Engineering Association (REA, 2019) cites various examples of 'resilience' and how this term has evolved over many decades; variously connected to the properties of timber, stress resistance in psychological studies of children in the 1970s, ecological resistance and engineering resilience years later.

Resilience engineering primarily emerged from the safety science community, where examples can be seen in aviation and medicine, and in safety critical areas like maritime, space flight, nuclear power, and railways (Woods, 2003). Resilience engineering is about taking a holistic view of systems, as several influential academics have noted.

[31] Source: "Human Factors Methods: A Practical Guide for Engineering and Design, Second Edition" (2013), Stanton, N., Salmon, P. *et al* (pp. 212-216).

Woods discusses resilience engineering, and in "Essentials of Resilience, revisited" (2019) he discusses 'surprises', i.e. unexpected events or disruptions (such as unpredictable demands for hospital beds during a health crisis) that occur when a system moves near the boundary, and how 'units' (a role or group at any layer of the system) have the competence to adapt within the system.

There is then Eric Hollnagel who describes four essential capabilities in a resilient system: 1. learning from experience; 2. responding to regular and irregular threats; 3. internal and external monitoring of system performance essential to the operation; and 4. anticipating threats and opportunities (Hollnagel, 2009(a)).

As Hollnagel further notes (Hollnagel, 2009(b)), the key to resilience is the managing acute pressures and conflicts between safety and performance goals and *"….understand and manage such trade-offs to prevent a loss of control over risk, rather than recovery from that loss of control"*. Hollnagel's ETTO (Effectiveness Thoroughness Trade-Off) principle provides a useful overview. See Figure 3.10 below.

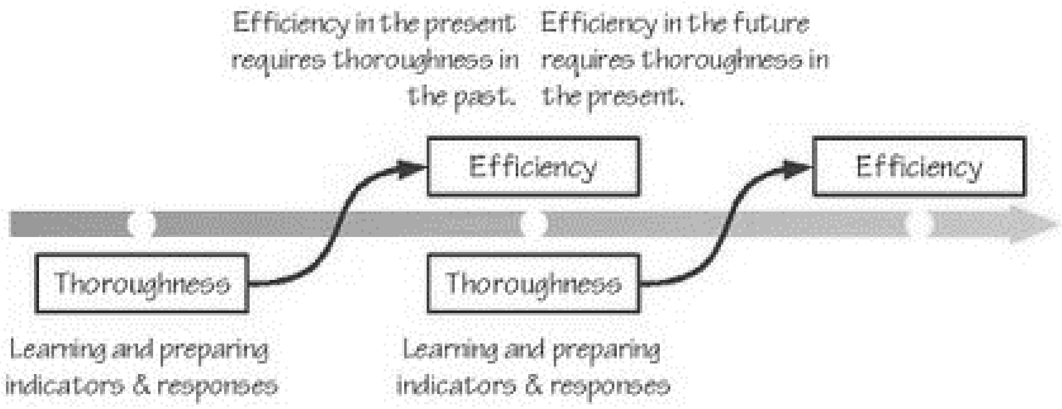


Figure 3.10 – The ETTO Principle (Effectiveness Thoroughness Trade-Off) (adapted from Hollnagel, 2009b)

'Resilience' is defined by Hollnagel as *"the intrinsic ability of an STS 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"* (Hollnagel, 2012).

How resilience can be achieved and how to trade off issues such as safety, reliability, costs and productivity remains a challenge for the rail industry (Wilson *et al*. 2009). In the context of GB rail, it needs to understand safety, performance, and service conflicts with other organisational goals – such as the drive for greater decentralisation – and the studies included in this research seek to explain how this 'effectiveness thoroughness trade-off' occurs in practice.

Dealing with conflicting organisational goals and operational demands is addressed by several authors. The literature certainly suggests there are times when operational staff can encounter conflicts between organisational goals and operational demands which might influence their perceptions of 'true' safety priorities (Carayon *et al*, 2015). Carayon *et al* (2015) discuss conflicting messages to employees from senior management in terms of safety priorities, and that these do not necessarily reflect how safety versus productivity trade-off decisions are actually made. Hollnagel *et al* (2006) emphasise the importance of understanding where these trade-offs might lie, and Woods (2006) has suggested that safety should be put first as an organisational goal to be clear of what is expected.

The advantage of a systems thinking approach is to recognise that there may be necessary trade-offs. Woods (2006) previously compared short-term production goals and the long-term goals of an organisation, and posited that they are frequently in conflict. Carayon says it is, therefore, necessary to clearly understand how to balance the trade-offs between the various goals (Carayon, 2009), and Hollnagel (2009b) suggests that having work-related, individual and collective ETTO 'rules' can help in managing a given situation, e.g. workload or task difficulty, so creating an adaptive / resilient system.

Woods (2015) suggests resilience includes the capability of foresight; to anticipate and mitigate against failures that arise as organisations, technologies and/or processes change. The idea is that when the system cannot maintain the regular way of working, for whatever reason, resilience is required to respond through the adaptation of strategies (Hollnagel, 2012; Hollnagel and Woods, 2005).

Resilience engineering studies cover multiple areas, especially complex or safety critical / high hazard domains (Nemeth *et al*, 2011). Domains reported as being investigated include aviation (22%), healthcare (19%), the chemical and petrochemical industry (16%), nuclear power plants (10%), and railway (8%) (Righi, Saurin, & Wachs, 2015). An article, related to healthcare practice, helpfully describes what resilience can mean for people, systems, and safety (Smith and Plunkett, 2019), and how staff at the 'sharp end' of organisations know that to create safety in their work, variability is essential to allow for good outcomes in both favourable and adverse conditions.

Interestingly, Hale and Heijer (2006) have previously explored whether resilience is necessary in safety critical domains, as in the case of (Dutch) railways, suggesting that resilience is only one strategy for achieving very high levels of safety. They looked at both passenger safety and maintenance track worker safety, and their analysis of railway safety operations in the Netherlands revealed poor to mixed resilience levels. Table 3.2 summarises their verdict on eight criterion that they specifically developed about the resilience of railways. The list of topics came from five characteristics developed by Woods (2003), used to indicate a lack of resilience in organisations, and was expanded upon during a workshop with Hale and Heijer (2006), such that the criterion could be used assess the Dutch railways on.

Table 3.2 – summary assessment of resilience in railways (adapted from Hale and Heijer, 2006)

Criterion	Conclusion (+ resilient, - not resilient)
1. Defences erode with production pressure	+/- mixed evidence and gaps
2. Past performance leads to complacency	+
3. No shared risk picture	Was +, is now becoming -
4. Risk assessment not revised with new evidence	? No data from the study
5. Boundary breakdown impedes communication	- and getting worse
6. No flexible response to change / unexpected	-
7. Not high enough devotion to safety	+, but under threat
8. Safety not inherent enough in design of system	-, but gaps in data from the study

The conclusion of Hale's and Heijer's work suggests resilience exists to an extent in rail passenger safety, whereby safety is achieved through trade-offs around punctuality, but not on track maintenance worker safety where the trade-offs are in the other direction, e.g. train punctuality is chosen at the expense of safety. They consider that the Dutch railways are not very resilient and are threatening to become even less so due to the difficult nature of communication and coordination in a complex system, with regular staff turnover, and across a whole country (the Netherlands).

Their work is certainly informative, but it also exposes that the pace of major technological and organisational development provides an opportunity to increase inherent safety, but can also lead to wrong choices, as the railways have still to introduce change management into their safety management systems. Mechanisms are needed to create foresight, anticipate, and defend against failures as the systems, technology, and structure changes.

Interestingly, Rasmussen (1990), and Weick *et al* (1999), suggest that resilience comes when organisations are able to adapt and absorb variations, and deal with change, especially unforeseen events, and disruptions beyond what the system is already designed to deal with. The complexity seen in the Dutch railways – and analogous to other safety-critical sectors like healthcare – highlights the importance of firstly understanding how success is obtained, for example how people learn and make trade-offs, before focusing on the contributors to failure (Cook *et al*, 2000). Hollnagel, Woods, Leveson (2006) posit that safety can be created through proactive resilient processes, rather than reactive barriers and defences, but they also argue that this very much relies on workers and managers having information about changing vulnerabilities, and then the capability and means to address these.

3.6 Organisational Learning

Organisational learning is not a new concept, and it did flourish in the 1990s, encouraged by Senge's *"The Fifth Discipline"* (1994), and related work where much of the effort by academics was devoted to identifying standardised templates or checklists that could be emulated by organisations (Garvin, 1993; Easterby-Smith, 1997), or further developed by business schools in support of complexity and leading change (Kotter, 1996).

Senge's work introduced the basics of system theory to help make sense of organisational challenges / issues. System thinking is the foundation of his approach, considering the system as a whole, and the inter-relationships between the various functions, departments, teams and individuals within the system. For example, Senge (1994) introduced the idea of using 'systems maps' to show the inter-connectedness of systems, e.g. what depends on what? what is causing what? where are information flows? where are decisions made? what information flows are critical? His work is analogous to the work of Rasmussen (1997) and the social organisation, with decision making that needs to be understood across all levels.

Senge's work also suggests that organisations are made up of skilled people capable of creating, acquiring, and transferring knowledge, with these organisations able to adapt to the unpredictable more quickly than the competition. Kotter (1996) says that businesses can successfully transform when they consolidate improvements and learn from their mistakes.

Morgan (1986) showed that there is a multiplicity of perspectives on what makes up an organisation and how it learns, and Easterby-Smith (1997) identified six main clusters in which a distinct ontological base and disciplinary focus could be derived, going back to the literature which had appeared since the 1970s (see Table 3.3).

Nonaka and Takeuchi (1995) had previously thought that 'knowledge management' should also be a discipline straddling psychology, strategy, and cultural anthropology. However, it seems that different views emerged, and much of the academic literature on organisational learning went on to emphasise it as either a technical (e.g. at an organisational level) or social process (group / individual / cognitive orientation). Some of the work was based on studies of organisational practice, others having relied on theoretical principles, such as systems dynamics[32], from which implications for design and implementation have been derived (Easterby-Smith *et al*, 1999).

Table 3.3 – Disciplines of organisational learning (adapted from Easterby-Smith, 1997)

Discipline	**Ontology**	**Key Ideas**
Psychology and organisation design	Human development	Cognitive organisation; development; communications and dialogue
Management science	Information processing	Knowledge; memory; feedback; error correction
Organisation theory	Social structures	Effects of power and hierarchy; conflict and interests; ideology and rhetoric
Strategy	Competitiveness	Organisation/environment interface; learning between organisations
Production management	Efficiency	Learning curves and productivity; design to production times
Cultural anthropology	Meaning systems	Culture as cause and effect of organisational learning; values and beliefs

[32] System dynamics was originally applied in the 1950s and 60s almost exclusively to corporate/managerial problems. It is a methodology and mathematical modelling technique to frame, understand, and discuss complex organisational issues and problems, and is still used today in public and private sectors for policy analysis and design. having been created by Professor Jay Forrester of the Massachusetts Institute of Technology some 50+ years ago (Radzicki and Taylor, 2008).

Garvin *et al* (2008) later recognised that a method for understanding how an organisation learns and learns better, remained elusive, with Garvin and colleagues suggesting that the 'ideal' of the learning organisation had not yet been developed, believing three factors impeded progress:

- Early discussions about learning organisations were 'ideologies' rather than concrete prescriptions;
- The concept was targeted towards CEOs and senior executives rather than managers of smaller departments and units where critical organisational work is done; and
- Standards and tools for assessment were lacking, so limited comparisons with others and allowed for progress to be declared, perhaps prematurely.

Garvin *et al* (2008) stress that their two decades of organisational research had revealed three broad factors that are essential for organisational learning and adaptability: 1. a supportive learning environment; 2. concrete learning processes and practices; and 3. leadership behaviour that provides reinforcement. They developed a tool to measure the learning that occurs in an organisation across a range of levels, to benchmark across other organisations.

Unfortunately, there is little evidence in the literature beyond this, until a decade later, when Basten and Haamann (2018) posit that organisations continue to struggle to implement practical approaches to organisational learning because of the abstract approaches of the learning theories.

Reports published into the Challenger and Colombia space shuttle accidents exposed organisational constraints as the greatest impediment to organisational learning (Hall, 2003; Leveson, 2008). For example, in both cases working-level engineers most familiar with the relevant systems expressed timely concerns that could have averted the disasters, but they were overridden, and they did not challenge things like seal failures as these had become regarded as 'normal' over time.

The same can be said to be true of other sectors, including rail, who have also been found wanting after accidents (ORR, 2020), and whilst often different in nature come down to remarkably similar organisational problems and imply that lessons that should have been learned are not.

William Blake's judgement that *"hindsight is a wonderful thing but foresight is better, especially when it comes to saving life, or some pain!"* encapsulates a frustration that the rail industry has had for a number of years; the two track worker fatalities at Margam in 2019, and the subsequent RAIB report (2020), identify thorny and persistent issues around organisational failings and their inability to learn from previous track safety incidents and accidents, and warnings to improve systems for smart and accurate planning.

Schein (2013) suggests that often organisations fail to learn, believing this may come from communication failures between three organisational "cultures", composed of the organisation's operational, engineering, and executive cultures.

Schein (2013) says that operational culture relates to local culture and is about human interactions, engineering culture is more to do with technology support and its application, and executive culture is concerned with the economics and administration of the organisation. He posits that learning failures occur because of the lack of an inter-cultural dialogue, and thus requires mutual understanding and solutions for the three cultures to apply.

The wider literature, specific to organisational learning, also suggests that learning can occur at different levels in an organisation (e.g. at an individual level in the event of specific incidents, or a team level where colleagues can learn from incidents experienced by others) (Hollnagel and Woods, 2005); the hypothesis is whether, in the present environment – where organisations face huge pressures to reduce costs and curtail budgets – there is the 'will' to learn or simply react to the next event.

3.7 Summary of the Literature

The literature suggests that challenges remain in addressing the increasing complexity and intractability of socio-technical systems (STS). Keeping this in mind, the focus has been on understanding the complexities of the GB rail sector, and how it designs systems and processes during periods of significant change, that continue to support human performance and are resilient to unanticipated events. This has meant the exploration of resilience engineering, and available systemic accident analysis methods and the potential application of these in a real-world context. Opportunities for prospective approaches and analyses are described in later chapters, sensitive to the railway environment still beset with hazards, trade-offs, and multiple goals.

The chapter has specifically introduced the areas of literature relevant to support the development of a description of the GB rail-socio-technical system, and the extent to which the systems approach is applied within rail industry processes and practices. Also, the relevance of rules, procedures, standardisation, and compliance in the workplace has been investigated.

Several authors have theorised about the future direction for the HFE discipline (Karwowski, 2006; Rasmussen, 2000; and Vicente, 2008), particularly around taking a systems approach, being design driven, and the related effects on performance and wellbeing. As technology advances and grows it will be interesting to see how we can begin to properly understand peoples' behaviour in a complex socio-technical system such as rail, at the same time as having a richness of data to support future design and implementation of change.

Finally, in reading the literature on organisational learning it is apparent that understanding how to learn is far from straightforward for organisations and the various models, methods and different practices involved in understanding incidents and accidents suggest that a move towards a more (non-linear) systemic approach will yield improvements, particularly so if performance variability is proactively monitored and controlled, and anticipation is greatly enhanced (Hollnagel *et al*, 2013).

4. Research methods

Mason suggests developing an overall research strategy to determine which methods to use, and how (Mason 1996); Silverman also supports this approach (Silverman 2013).

This chapter, therefore, provides a description of the research methods considered, and then the choice of methods used for the studies undertaken, noting that the overall aim of this Doctoral Thesis is to evaluate the GB rail socio technical system and to develop guidance that supports implementation of sustained improvements in safety and performance. Consideration has been given to the wide range of quantitative and qualitative methods as well as data sources available to the researcher, and in the context of the four research objectives referred to in Chapter 1 (para. 1.2).

4.1 Familiarisation work

Familiarisation work was undertaken in the early stages of developing an overall research strategy, and identifying an appropriate methodology to be adopted (e.g. the methods for managing and analysing quantitative and qualitative data for different aspects of the research.

The familiarisation work involved desk-top reviews of GB rail related documentation such as published safety management systems, annual safety reports from the Regulator, discussions with rail colleagues to help understand the structure of GB rail (past, present, and future), and an initial review of available safety and performance data – both within Network Rail, but also across the GB rail network.

Consideration was given to how such texts could be collected and analysed in support of the five studies undertaken (see Chapters 5 to 9), through sourcing and reading material, as well as capturing narratives through interviews, undertaking surveys etc. One important point here was knowing (in advance) how much data the researcher was going to be able to gather, especially when the research work was likely to be of an exploratory nature (Adler and Adler, 1987).

When considering the four research objectives, thought was given as whether it would be best to use observations, textual analysis, and/or interviews, for the quantitative and qualitative research, recognising that much would depend on the depth and breadth, and level of understanding required of the results (Silverman, 2006). The decision was made by the researcher to use a mixed-method approach, having identified gaps in previous research and theory that needs to be addressed.

As can be seen later, interviews were used for Studies 1 and 2 (Chapters 5 and 6), before an employee survey was undertaken for Study 3 (Chapter 7), and observations were undertaken in parallel (over 6 years) for the longitudinal study (see Study 5, Chapter 9).

These studies, in addition to the systems analysis tools evaluation in Study 4 (Chapter 8), provide for a detailed and coherent programme of work.

4.2 Research framework

A framework was developed (see Figure 4.1) which provides the background that supports the investigation outlined in the research problem statement. The framework allows for a simple presentation of the research problem, and how the researcher is trying to understand the reciprocal relationships between theory and practice (in GB Rail), i.e. considering what STS theory says, and what this means in the GB Rail context, linked to the literature identified as part of the early familiarisation work.

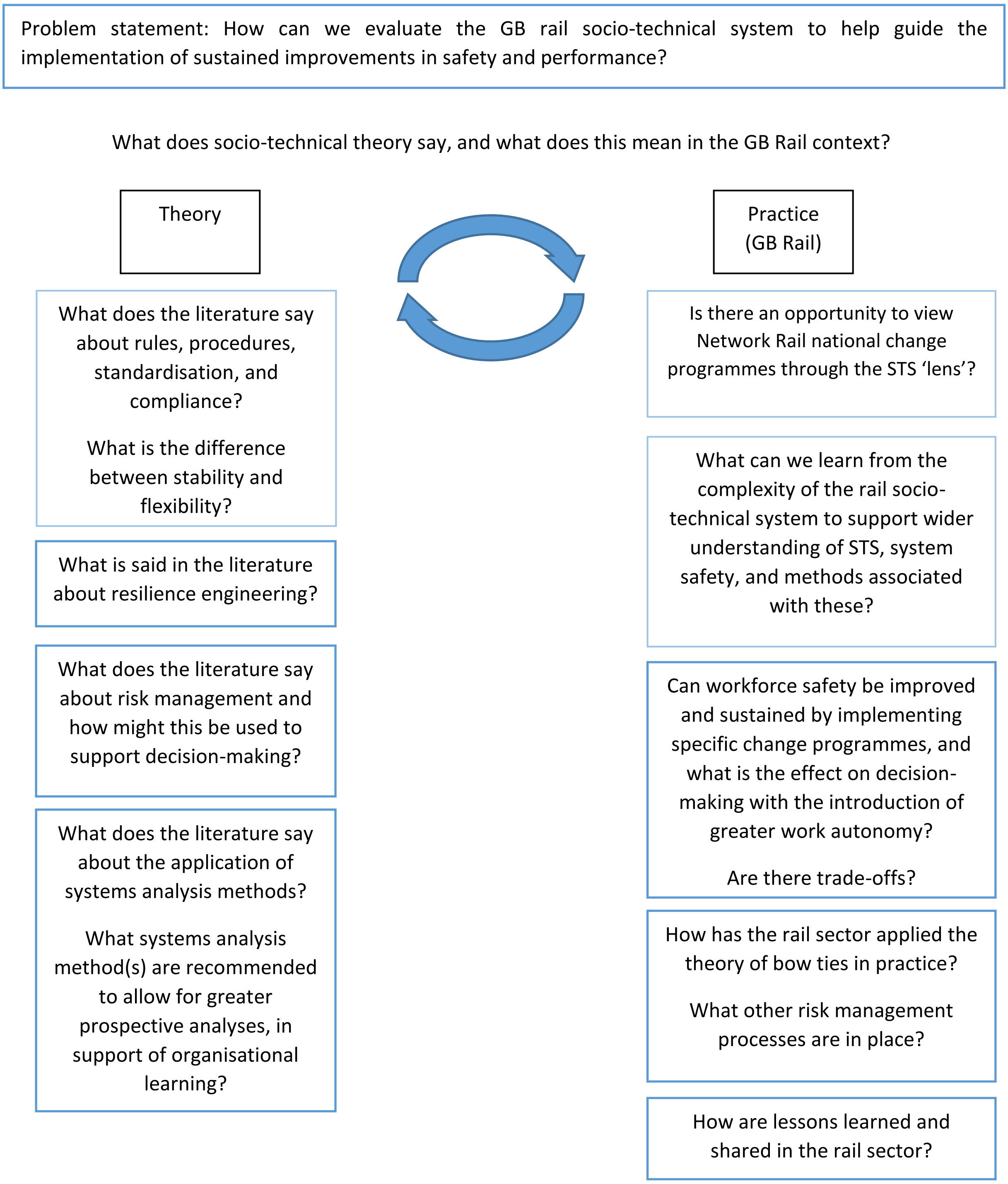


Figure 4.1 – Research framework for questions to be explored

4.3 Method selection

4.3.1 Context of the research

As part of method selection, consideration has been given to the various ways to consult with people, taking the view that different approaches would be needed for different participant groups across GB Rail, factoring in their experience, what people do, what people think others do, the intentions of leaders, people's availability for interviews, the likelihood of responding to requests for questionnaire completion, and that researcher would be studying change over quite a lengthy period of time.

Understanding the various elements of the study and scope, e.g. national change programmes, risk management in GB Rail, and the range of 'actors' involved, enabled the researcher to produce an outline plan for data collection and analysis.

Similarly, having access to a range of 'artefacts' such as procedures, manuals, and other corporate documentation in support of data collection and analysis was behind the thinking to develop a structured approach to capturing, recording and reviewing this.

4.3.2 Types of information needed

Given the time and resources required to undertake the research and complete the respective studies over a 6-year period, a pragmatic approach was taken to developing multiple-methods for data collection and analysis (Scott and Briggs (2009)), considering the researchers unique position in being embedded in the organisation (i.e. with access to, and knowledge of the industry), but also needing to remain unbiased and objective (Ryan, 2020).

The problem statement was developed as part of the research framework – see Figure 4.1 – and viewed within its broadest context, leading to research inquiry, and a better understanding of, and ultimately finding solutions to the problem. The opportunities for collecting data, what types of data might be needed and how best sourced were considered before an approach and method of analysis for each study was developed. For example, such factors included:

- the need to account for different situations;
- understanding the experiences of different people and groups;
- be able to discuss some issues in more detail;
- be adaptable and flexible in the approach;
- use pre-existing data sources that are readily available within the GB Rail industry;
- collect data over a long timeframe as the situation changes over the course of the part-time PhD, and consider the potential impact of future interventions.

With interviews, consideration was given as to how these could help with understanding specific work processes, collecting details and background information from people's experiences, discussing, and exploring issues in different work contexts, with a view to the interviews being undertake with a limited number of senior people in decision-making roles.

Similarly, the use of a survey and questionnaire, seemed the best method for sampling a much larger population on a defined set of topics.

Pre-existing data sources, such as corporate documentation, policies, and procedures, were thought likely to be valuable for extracting relevant content, and supporting subsequent collation and analysis, relevant to change programme implementation and outcomes.

The production and use of documentary data has formed a part of qualitative analyses in a range of settings, including analyses of school reports (Woods, 1979), classifications of causes of death (Prior, 1985), patient handling (Hignett *et al*, 2003), and medical education (Walker, 1989). Indeed Silverman (2006) posits that there are many research questions and research settings that cannot be investigated adequately without reference to the production and use of documentary materials.

The practicalities of undertaking a longitudinal (observational) study in parallel with interviews, survey work, and data collection was also a key feature of how the research framework was developed.

Finding literature on the definition of, and thereby what constitutes, a longitudinal study is quite difficult. It seems a major reason for the lack of longitudinal research and what it is (and is not) stems from the uncertainty about how it should be conducted.

As noted by Lance, Vandenberg, and Self (2000):

> *"The measurement of longitudinal change has been a long-standing and controversial topic (Burr & Nesselroade, 1990; Collins, 1996). Even today, there is little consensus, either in theory or in practice, on the best methods for the analysis of longitudinal change (Chan, 1998)."*

As a result, there were a multitude of challenges to consider. Firstly, there is little guidance as to how one addresses the theoretical and conceptual issues involved with developing a longitudinal study. Secondly, decisions need to be made about the methods and design of the study, e.g. appropriate spacing of repeated measurements, handling attrition, overall duration etc. Finally, there may be no change to measure, or the measures are not sensitive enough to reflect changes (Chan, 1998).

Finally, to develop a framework that supports organisational learning from a risk management and safety-driven design perspective, it was identified that tools might be needed to help predict how future interventions in change programmes might manifest themselves. The intention being to apply a selected method to design a safety-driven concept of Network Rail's future organisation structure, looking at how teams / individuals might interact with each other (rather than the more usual deterministic safety assessment focused on component level interfaces, e.g. the train with the signalling system).

Recognising a ‘systems thinking’ approach would be needed in this instance, an exploration of how an existing method in the academic literature, e.g. STAMP / STPA[33], can be applied as a prospective analysis tool to sit alongside / complement other areas / methods of research was undertaken.

4.3.3 Main theory supporting the choice of methods

There are qualitative researchers who suggest that the different methodological perspectives are informed by the actual importance placed on the research, e.g. it depends on resources, so in the case of interviews (for example) one respondent may be all that is needed (if that is the person of most interest) (Wolcott, 1994). This played a part on the method selection, especially when the researcher was intending to undertake the studies part-time over a 6-year period and had the opportunity to use a range of approaches including a longitudinal (observational) study that would enable some adaption of methods over time, and as the studies evolved.

Oppenheim (1992) considers quality rather than quantity to be the essential determinant of numbers, i.e. how many interviews to conduct, and selecting the types of questions to ask (e.g. open vs. closed questions), where each has its advantages and disadvantages, thus needing a mixture of the two. Oppenheim makes it clear that however subtle the question, and however cooperative interviewees have been, the main purpose of the research is measurement, hence his practical teaching on data processing, code books and coding frames.

Oppenheim’s thinking played a part in the research method selected for the studies, and how the researcher would ultimately capture and analyse data. It also became clear that the selected method(s) would need to focus on either what is done in public through observation or done in private through interviews or questionnaires if the results were to reflect real-world application (Robson, 2015).

4.4 Methods used

4.4.1 Interviews

A method was required to enable consultation with Government and Regulatory personnel, Network Rail Executives, and senior managers, building on the previous early familiarisation work. Thus, drawing on the main references in the literature around understanding and documenting others’ understandings, (Silverman, 2006; 2013), choosing qualitative interviewing seemed most appropriate as a means for exploring the points of view of those familiar with ‘real-world’ application, whilst recognising the potential for interviewees to respond using familiar narratives, rather necessarily than their own insights (Denzin, 1991).

[33] System Theoretic Process Analysis (STPA) is a hazard assessment tool derived from Systems-Theoretic Accident Models and Processes (STAMP), and is a hazard analysis method developed at the Massachusetts Institute of Technology (MIT) for modern complex safety-critical systems (Leveson, 2004).

Interviews were selected as the best means to elicit information and help describe the GB rail socio-technical system, and to better understand the two national change programmes used as contexts to framework consultations within the overall study. It was expected that the interviews could help provide detailed information about a particular issue or give context and allow for discussions / exploration of given topics.

No criterion was set to decide when to stop sampling; the notion of theoretical saturation derives from Glaser and Strauss' account of grounded theory, i.e. theoretical saturation is described as *"a process in which the researcher continues to sample relevant cases until no new theoretical insights are being gleaned"* (Glaser and Strauss, 1967).

This qualitative research studied a good number of interviewees, acknowledging that there were not always many of them in their types of groups or area(s) of expertise, e.g. there is only one Chief Executive and one Chairman of Network Rail, but many more participants were classified alongside these as 'Executives'.

The benefits of the qualitative research with a select, group meant that the interviews have afforded the time to delve more deeply into the roles of individuals, settings, and sub-cultures, to generate an understanding of how and why participants perceive, reflect, interpret, interact etc. This type of research can be far more open-ended and follows emergent empirical and conceptual findings, often in unexpected ways (Adler and Adler 1987).

What this allowed in practice – and building on Kanter's earlier discoveries (Kanter, 1977: 296) – was the opportunity for a further round of interviews to test some earlier propositions and explore perceptions of how change is managed within a complex sector such as rail. It also means that the findings and recommendations are based on a much wider range of data than perhaps initially anticipated.

4.4.1.1 Approach to the interviews

The interviews were exploratory in nature, though were structured around a number of common topic areas to guide the discussion. An allowance was made for enough variations of circumstance in each interview to be able to explore different workings of processes in different situations (e.g. 'normal' operations, versus 'degraded' mode following a major accident) – known as an idiographic approach – built from an understanding of particularity, i.e. participants 'represent' categories of people with similar experiences, or particular situations, but not the wider population (Mason, 2002).

That said, the focus of the interviews remained relatively constant, based around a standard template of topics for discussion, although they did evolve to an extent after the initial few as the participants raised issues, allowing for emergent ideas and directions to be included in the interview study. The questions were generally 'open' in nature to elicit participants' feelings and views more fully exploring how processes work in particular contexts, under certain sets of circumstances, and in particular sets of socio- and/or technical relations.

There were several phases to the interviews carried out, primarily because they related to separate studies and so some were with the same people, but using different questions, and others were with different people because of their expertise relevant to one area of study but not another.

Careful thought was given as to how interview responses would be treated, e.g. gaining direct access to 'experience' and opinions and perceptions, rather than a pre-determined 'narrative' where the participant might offer a specific response depending on what they think should be said rather than how they actually feel. As a result, interviewees did not see questions in advance, but were given an indication of the likely topic areas, e.g. national change programmes, the structure of the industry, interface management and relationships etc.

There is acknowledgement that 'experience' over 'narratives' is legitimate (Riessman, 2011; Gubrium, Holstein *et al,* 2012). For example, the researcher's approach to questioning guarded against using language that would lend itself to the interviewee simply reproducing what they were hearing or saying what they thought the researcher was driving at, rather than the lived experience (Denzin, 1991).

Later interviews, carried out across the various studies, were generally more 'closed' in nature. Issues raised by earlier interviewees were discussed with later participants (without divulging the source of the topic), allowing for some group comparison but also testing specific hypotheses based on emerging findings.

4.4.1.2 Method of analysis of the interviews

For this research comments from participants have been interpreted using the knowledge from the review of documentation and literature (Mason, 2002). This approach led to the systematic organisation of information and coding, supporting the extraction of recurrent issues, helping to identify relevant supporting or contradictory evidence, and whether based on a particular topic or a participant's opinion. This theme-based content analysis (Mayring, 2000) enabled the researcher to classify interview (and later survey) responses, and the kinds of qualitative observations made as part of the interviews was impactful and significant, and allowed for outcomes that are quantitively measurable as well (Silverman, 2006).

The range of different organisations, functions and responsibilities that were included in the interview programme gave an opportunity to develop a picture of the complexity of the rail industry, and from a range of perspectives, but also from people best placed to answer. It also meant that once the data had been coded qualitatively, it afforded the opportunity to also quantity some of it, with 'counts' being an effective way of providing a summary of the data set as a whole, e.g. 80% of senior managers responded 'x' compared to 12% of executives who said 'y'.

4.4.2 Surveys

To capture respondents' attitudes or values the design of a questionnaire was given careful consideration (Alkula *et al* (1994) in Silverman, 2013), and a survey was developed as part of study 3 (see Chapter 7) to support the investigation of the impact of selected Network Rail national change programmes on frontline staff behaviour.

A sample survey was chosen as it affords the opportunity for wider reach, gathering opinions and the way people in particular settings think, feel, or behave – with questions seeking to answer the 'how often', 'who' and 'when' types (Robson, 2015), whilst recognising it would not be feasible to survey the whole population. This approach, therefore, required the population to be identified from which the sample was drawn; this is often referred to as the sampling frame (Robson, 2015), and the population of interest can be drawn from a published list.

As with the interviews, potential participants were identified who would go on to form the population for the study. A questionnaire was developed for the four identified workforce groups, mindful that questions can be open or closed, or offer respondents multiple choices, or to choose a statement that mostly nearly describes their response to a statement or item. Differing types of questions were developed to glean the most important / relevant information, e.g. rating scales where these gave an indication of importance, or yes / no responses requiring definitive responses (Robson, 2015).

4.4.3 Longitudinal (observational) study

Given that change in this type of research context (i.e. across two national change programmes) was expected, and the part-time and extended nature of the PhD, it was possible to track both the business-critical rules and planning and delivering safe work programmes over a period of 6 years.

A longitudinal (observational) study was undertaken considering the range of documentary evidence that might be available, for example: the minutes of Network Rail programme board meetings, safety reports, incident reports etc. It is in this context that the longitudinal study was developed to give insight into the two change programmes and how the changes played out over time in seeking to protect workers, and the lessons that can be learnt from this – using observations at defined intervals, and the examination of documents and similar artefacts, to provide the basis for qualitative analyses.

A structured approach was developed to observe programme board reviews. Also, given the researcher's background in accident investigation, a selection of incident-related reports and digests, and a class investigation, all published by the RAIB were revisited, and analysed, to understand how the GB rail industry (but mainly Network Rail) had responded to varying events, including staff fatalities, and calls for a significant and sustained improvements in track worker safety.

Finally, there were unplanned events that occurred during the longitudinal (observational) study that were likely to impact on change implementation, and so these were also factored into the process for data collection and analyses.

4.4.4 Systems analysis methods

Whilst much has been written about traditional techniques and methods to analyse variations and deviations at an individual component failure level, faults, and combinations thereof (e.g. hazard and operability studies (HAZOPs); BSI, 2002), more complex safety-critical systems – such as nuclear, aviation, rail, space, oil and gas – can exhibit unsafe and undesirable behaviour that does not involve any component failures, or was never anticipated by failure-based analysis.

For example, components may operate exactly as designed and may perform their intended function perfectly at the component level, while their interactions can lead to unexpected or unsafe system level behaviour. This is reported as occurring when engineering assumptions are incorrect, requirements are incomplete or otherwise flawed, components behave in conflicting or otherwise unanticipated ways, and/or when human interactions are not fully understood or anticipated (Thomas, 2013).

The Systems-Theoretic Accident Model and Process (STAMP) and Systems-Theoretic Process Analysis (STPA) (Leveson, 2011) use a model called a control structure to determine how controls, feedback, and other interactions between failed or non-failed parts can lead to incidents / accidents. STPA treats safety as a dynamic control problem rather than a failure prevention problem, and the emphasis is on enforcing constraints on system behaviour rather than preventing individual failures.

Given the pace of change, and the complexity of the current structure of GB Rail, it was considered that systems analysis might be beneficial, and a management tool such as STAMP or STPA ought to be introduced that might offer insights as to what controls are necessary in creating better change programmes, system designs, and communication processes that have increased involvement of the frontline workforce.

Having attended a STAMP Masterclass[34], the researcher identified that the STPA method should be the chosen approach, to be applied to a Network Rail organisational change programme, specifically to anticipate, and address the various organisational interfaces, relationships and dependencies thought likely to emerge as the organisation design evolved. To gain a better perspective on how hazards are controlled in real-world settings, the researcher, supported by a HFE colleague, set out to use the STPA method over an agreed number of hours; the details of which are reported in study 4 (Chapter 8). In addition, observations were undertaken of facilitated workshops, where the Bow-Tie technique was being applied by Network Rail. This afforded the researcher the opportunity to evaluate the STPA approach with the more traditional bow-tie method.

Between the researcher and their HFE colleague, a 'problem space' was identified, i.e. the Network Rail organisational change programme – to decentralise national functions to more localised Routes – was leading to organisational uncertainty, and a series of steps were taken going through the various stages of the STPA method to prospectively challenge the 'system safety constraints' among interacting components of the organisation design (i.e. in its present form), such that the future design might be modified before final implementation.

[34] Massachusetts Institute of Technology, STAMP Masterclass, Manchester, 8th-11th April 2019

The results of the STPA approach when evaluated alongside the bow-tie technique are also intended to allow for observations to be made about the use of the tools and their real-world application, e.g. their suitability / future utility as hazard analysis methods in Network Rail and other possible settings / industries.

4.5 Summary of research methods

This chapter has described the methodological approach that has been adopted to address the research questions. It moves through the specific methods of data collection, interviews, surveys, analysis etc.

Based on the research context (Chapter 2), a range of research methods, as well as data sources, were selected to be used in this research; these are summarised in Table 4.1. For each research objective, methods for data collection and analysis are listed. The final column shows where these are reported in the thesis. The methods aim to respond to each research objective, and report on their important contributions. Chapters 5, 6, 7, 8 and 9 go on to describe each of the five studies in a detailed manner, and the research methods within each setting / context, and give indications about the transferability of the methods and the findings to other organisations / sectors.

Table 4.1 – summary of research methods used to address the research objectives

Research Objective 1 To develop a description of the GB rail socio-technical system, including consideration of the multiple objectives in relation to safety and performance	• Desk-top review of corporate documentation • Safety and performance data analysis • Rail socio-technical system familiarisation interviews • Qualitative interviews of Senior Executives / Managers • Survey, using a questionnaire, of frontline personnel (across four specific participant groups)	Studies 1, 2 and 3 (Chapters 5, 6 and 7)
Research Objective 2 To investigate the extent to which a systems approach is applied within rail industry processes and practices	• Desk-top review of corporate documentation • Qualitative interviews of Executive level national change programme Sponsors, senior management, and Subject Matter Experts • Survey, using a questionnaire, of frontline personnel (across four specific participant groups) • Longitudinal (observational) study	Studies 1, 2, 3 and 5 (Chapters 5, 6, 7 & 9)
Research Objective 3 To investigate the perceptions of senior business leaders, managers and frontline staff on policy and processes intended to improve workforce safety and performance	• Desk-top review of corporate documentation • Qualitative interviews of Executive level national change programme Sponsors, senior management, and Subject Matter Experts • Survey, using a questionnaire, of frontline personnel (across four specific participant groups)	Studies 2 and 3 (Chapters 6 and 7)
Research Objective 4 To apply systems analysis tools (e.g. STPA, bow ties) and determine their suitability as prospective tools for industry to use to support future interventions in change programmes	• Desk-top review of corporate documentation • Observation of workshops applying the Bow-Tie technique in Network Rail • Two interviews with 'experts' on the Bow-Tie approach used by Network Rail • Use of STAMP / STPA – including practitioner involvement – reviewing its possible application to GB rail	Study 4 (Chapter 8)

5. Study 1 – To identify important components of the GB rail socio-technical system, and how STS theory can be applied in support of sustained safety and performance improvements

5.1 Chapter overview

The rail industry in Great Britain has faced unprecedented demand for its services in the past decade, whilst addressing technological transformation, and with multiple objectives in relation to safety and performance. Sociotechnical systems theory seems to offer solutions for these challenges, but there has been little research on how rail organisations can establish processes and build resilience during periods of significant change that are complementary with this type of theoretical approach.

This study sought to identify important components of the GB rail socio-technical system, and how STS theory can be applied in practice in support of sustained safety and performance improvements. The research included an investigation of how senior business leaders discuss the management of change in a complex rail socio-technical system. Twenty-five interviews were carried out with senior executives and managers in the railway industry. These interviews were designed to explore the perceptions of these people in policy setting and senior management roles and what they see as barriers to change within a dynamic, fast moving, industry. This included exploring both the 'work as imagined' in the corporate strategy and company procedures, as well as their understanding of 'work as done'. Two national change programmes that affect the frontline rail engineering workforce used as contexts to frame consultations within this study.

The results identify some important points to consider for the design of change in a complex industry, and how a socio-technical system framework or model might be applied in practice. Guidelines have been developed in support, that build on sub-themes resulting from the interview analysis, setting out how managers could design, implement, and embed change, and assist them in delivering their objectives in relation to safety and performance.

5.2 Introduction

Sociotechnical systems theory (STS) (Trist, 1959; Trist, 1981) and resilience engineering (Hollnagel *et al*, 2006) are two approaches that have been described within the literature and show how organisations – nuclear, healthcare, military etc. – can develop an evolving picture of safety in complex systems (Stacey, 1996; Holland, 2002) that emphasise how outcomes emerge from the complexity of the given situation. There are compelling arguments about how these approaches help organisations in the type of decision-making and associated activities that can occur across the levels of the system (government bodies, regulators, the organisation, management, staff and the work (processes)), interacting to shape behaviour, safety, incidents and accidents (Rasmussen, 1997) and the trade-offs and adjustments that are needed to manage uncertainties in this type of complex and high risk system (Hollnagel, 2012; Wilson *et al*, 2009; Grote, 2015).

Similar to the experience and insights gained from the multi-disciplinary research of Rasmussen, Hollnagel and others, railways also operate within a complex landscape which includes national and international organisations and devolved government bodies, regulators, train and freight operators, suppliers, trade unions, trade associations, and safety and passenger bodies. Successful operations require continuous improvement in safety and performance (Network Rail, 2020), and depend on managing social and technical interactions effectively, both internally, and across the wider rail industry.

Whilst railways are generally reported to be safer than other forms of public transport (ORR, 2020), there is still room for improvement, particularly within workforce safety. Railways face increasing passenger numbers (Network Rail, 2019) at a time of ageing infrastructure and technological transformation to meet the huge increase in demand, and multiple objectives in relation to safety and performance. In Great Britain, Network Rail's safety leadership has strengthened and broadened through new Regional structures, and there are closer alliances with train and freight operators to address safety and performance, and to balance sometimes conflicting goals. At the frontline, its staff must constantly make critical business decisions. These require an understanding and continuous dialogue about how the system works (e.g. prioritising train paths, such as a faster running passenger train ahead of a slower running freight operator), and the consequences of any trade-offs.

The overall aim and objectives of this study were, therefore, to identify important components of the GB rail socio-technical system, and how STS theory can be applied in practice towards sustained safety and performance improvements. The study included an investigation as to how senior business leaders in the rail industry speak about common concepts relevant to STS theory and resilience engineering that are evident in the literature and how they use these in managing change in the complexity of this sector.

Two national change programmes that affect the frontline rail workforce were used as contexts to frame consultations within this study. The first of these was a programme to reduce an extensive set of industry standards to a much shorter set of "business critical rules". The second was a programme to implement new safety roles for the supervision of engineering tasks, "delivering safe work". These interviews were also carried out during a time of a transformational change programme in which power was to be decentralised from a national to a regional level within Network Rail, requiring a new matrix model to operate with key stakeholders / alliance partners. This had the potential to influence the focus and content of the consultations with the interviewees.

5.3 Methods

5.3.1 Participants

Interviews were carried out with twenty-five individuals operating at a strategic level in policy setting roles in the industry and familiar with the challenges of working in this fast-paced, dynamic sector. Participants were identified and recruited to the study under the categories of Government, Regulators, Company Executives and Senior Managers. For the purposes of maintaining anonymity, analyses are reported in groups of Executives (n=8) and Senior Managers (n=17).

5.3.2 Approach to the interviews

There were two stages to the interview process. Twenty Executive and Senior Managers were interviewed in the first stage. Five additional Executives and Senior Managers took part in interviews in the second stage, including further discussion on findings that emerged from analysis of the first stage of interviews. The interviewees were contacted directly via email, receiving details of what they were expected to do as part of the study. Participants were asked to give informed consent for participation. Approval for the study was provided by the University of Nottingham's Faculty of Engineering Research Ethics Committee (UofN, FoE). Each interview took between 60 and 90 minutes and was carried out face-to-face. The responses were recorded in hand-written notes, as well as the use of a digital voice recorder.

5.3.3 Interview content

The two national change programmes, affecting the frontline rail engineering workforce, were used to frame the interview questions. It was assumed that interviewees in these business roles may not be familiar with some of the academic concepts and terminology (for example, of a socio-technical system). Therefore, questions were phrased using general terminology and concepts that would be familiar in the industry (e.g. culture, organisation design, standards, rules, trade-offs etc.). The interview questions included the following topics, linked to Rasmussen's STS social and organisational levels:

- Asking for an overview of the interviewee's current job role and extent of their decision-making authority within the system (similar in approach to Kirwan's study of airline executives).
- Examples of organisational goals / objectives and priorities, and views on accountability and responsibility, and any system boundaries (whether performance, economic or workload related).
- Examples of their understanding of key interfaces, complexity, workflows, capability and risk management, and the need for any trade-offs (akin to Reiman's and Oedewald's (2007) assessment of complex socio-technical systems within the nuclear sector).
- Views and perceptions of how change is managed within a complex sector such as rail and effects on the employees, structure, funding (e.g. organisational change, culture change, programme change) and relevant learning from this (reflecting on earlier studies by Clarke (1999), and Farrington-Darby *et al* (2005)).
- Examples of demonstrable leadership, thoughts about relationships between safety and performance, and what resilience might mean in the context of managing and mitigating safety and production risks (Wilson *et al* (2009)).
- Asking for views on organisational learning and the extent to which interviewees believed lessons learnt from incidents and accidents were shared, and effectively actioned in a complex GB rail system (the thinking here was around the organisational failures at NASA identified after the Columbia and Challenger accidents, some 17 years apart (Hall, 2003; Leveson 2008)).
- Examples of what 'corporate memory' means to the interviewees part of the business, and especially ownership of this (building on the work of Birkland (1997) on disasters as focusing events, where attention is given to their causes but does not always lead to changes in policy, thus there are repeat accidents as time elapses and historical events are forgotten).

The questions asked were generally open in nature for the initial 20 interviews (5 Executives, 15 Senior Managers) to elicit the participants' feelings and views, and explore how organisational processes work in particular contexts, environments, and settings. A variety of circumstances were introduced in each interview to explore how a range of processes may be applied in different situations (e.g. 'normal' operations, versus 'degraded' mode following a major accident). The second stage of interviews was more narrowly focused on issues that were raised from the first phase interviewees (without divulging the source of the topic).

5.3.4 Method of analysis of the interviews

Content analysis was selected as an appropriate method for the interviews, as it can provide a systematic and comprehensive overview of the data set as a whole and allows for some quantitative analysis of initially qualitative data (Ryan and Bernard, 2000).

The analysis was designed to explore questions such as how decisions are made on the information that is available; the capabilities of the organisation and individuals; the flow of work and how people use technology and apply processes; and how the goals and functions of the organisation are achieved in real life situations. The interview voice recordings were transcribed and captured in an interview record form, enabling categorisation and comparative analysis across the interviews.

Five themes based on Rasmussen's and Svedung's (2000) risk management framework (Objectives, Status Information, Capability, Awareness and Priorities, see Table 5.1) were used in an iterative process of theme-based content analysis (Mayring, 2000) to classify the interview response. Further coding was undertaken to identify sub-themes within each of the five main themes (e.g. 'clarity of objectives / vision' was assigned as a sub-theme in the main theme of Objectives). This approach led to the organisation of information, supporting the extraction of often repeated themes and helping to identify relevant supporting or contradictory evidence and/or comments. Responses from executives and senior managers were compared alongside each other to identify if particular issues / challenges were mentioned by both groups and/or contrarily.

Table 5.1 – Themes related to the information available to decision makers and their capability of safety control: adapted from Rasmussen and Svedung (2000)

Objectives: are objectives and values with respect to operational as well as safety issues properly communicated within the system?
Status information: are the individual decision makers (staff, management, regulators etc.) properly informed about the system status in terms comparable to the objectives? Are the boundaries of acceptable performance around the target state 'visible' to them?
Capability: are these decision makers competent with respect to the functional properties of the organisation, of the technical core and the basic safety design philosophy? Do they know the parameters sensitive to control of performance in a changing environment?
Awareness: are decision makers prompted to consider risk in the dynamic flow of work? Are they - continuously during normal work - made aware of the safety implications of their every-day work business decisions?
Priorities: are decision makers committed to safety? Is management, for instance, prepared to allocate adequate resources to maintenance of defences? Does regulatory effort serve to control management priorities?

5.4 Findings

Findings from the interviews demonstrate the extent to which rail business leaders are aware of aspects of the socio-technical system within rail engineering. These include the awareness of competing goals, how different sources of risk can be made more visible and how an industry restructure might be needed to simplify the current complexity and help build resilience in the system.

There were more than 30 hours of interviews that were transcribed, including 323 coded key words / phrases. Table 5.2 shows the relative frequencies in each main theme.

Table 5.2 – Counts content in each main theme from Rasmussen and Svedung (2000)

Main theme	No. of key words / phrases
Objectives	61
Status information	42
Capability	155
Awareness	36
Priorities	29
Total	323

The counts of content also allowed for qualitative analysis to identify constructs, such as what the themes mean in practice and/or are interpreted as meaning and afforded systematic comparison across executive and senior manager responses. What emerged from this was that whilst the main themes may appear equally important in the way Rasmussen and Svedung (2000) portray them related to the information available to decision makers and their capability of control, in practice – from the GB rail interviews – it would seem that the theme of 'capability' has more overall relevance and importance in the minds of business leaders because of the need for competent decision making in a complex (safety critical) industry, where change is almost constant. Even when the number of questions asked was broadly in equal proportion to the other main themes, the responses often related more to capability than other areas.

5.4.1 Objectives

Rasmussen's and Svedung's (2000) first theme relates to how objectives and values for operational and safety issues are properly communicated within the system. Executives and senior managers were asked about their views on the challenges they perceived in delivering organisational objectives.

Discussion with the interviewees revolved around the organisational context and how the safety vision, objectives and goals are communicated and delivered. The change to decentralise parts of Network Rail into 5 Regions, with 14 Routes, as part of a matrix structure, with national functions in support, (e.g. Route Services, the Technical Authority etc.) were mentioned as was the understanding of the collective accountabilities for safety and operational performance, delivery and continuous improvement of current performance, bounded by national functional strategies and policies.

Wider industry issues were also reviewed, particularly around the significance of the changes being brought about and the pace of change being sought within the rail sector, and how operational as well as safety matters could be effectively communicated within the wider system.

Sub-themes were identified in the analysis of the interviews around the clarity of the objectives and vision, how and to who these are communicated, and the operation of the system as a whole, including economic considerations.

5.4.1.1 Clarity of objectives / vision

On the overall theme of objectives, 40% (forty percent) of the responses from Executives and Senior Managers referred to the need for a greater clarity of objectives and/or vision, hence its inclusion as an important sub-theme.

Figure 5.1 shows three key challenges that emerged around this sub-theme (having counted the frequency of responses to questions); these reflect the interview responses about delivering organisational objectives.

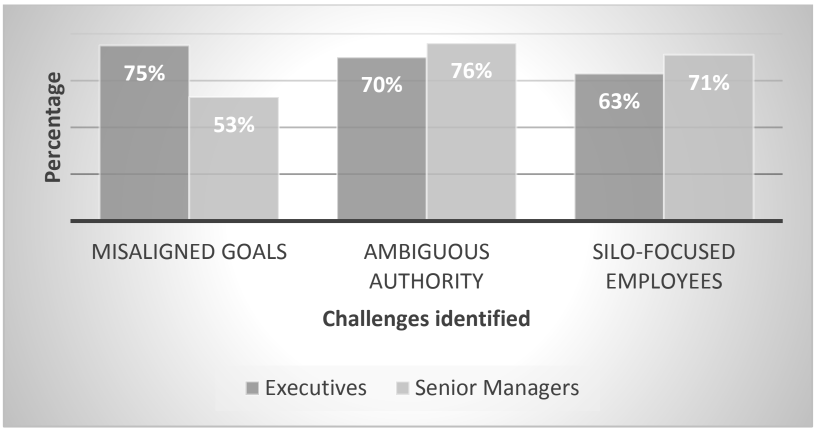


Figure 5.1 – Comparison of the challenges that were identified from interviews of eight Rail Executives and seventeen Senior Managers

In the first 'challenge' identified, the GB Rail Executives and Senior Managers were concerned about 'misaligned goals', and many of the Executives raised the primary importance of safety (as a goal). Both sets of interviewees reported that goals need to be aligned among many different dimensions, such as the business functions, geographic regions, and others in the railway environment.

A quote from a Senior Manager puts this into context:
"We need to develop mutual trust and understanding between the different levels of the organisation and industry. We all believe in safety first, but some might say that does not always manifest itself in our actions, and especially how we communicate expectations of those we want to deliver our goals."

[Senior Manager 4]

The second 'challenge' identified was around ambiguous authority, and what came out from the interviews was that 'ownership' is lacking whilst ambiguous authority prevails. A significant proportion (over seventy percent) of both Executives and Senior Managers said they thought there was still a conflict between safety and people's actual autonomy within the system, and to address the gap would require clear decisions on ownership of particular activities / tasks by the business function. There seems to be a widely held view that Network Rail's organisation needed to mature such that the decentralised Regions were able to realise the autonomy sought.

A Senior Manager said:
"We need to better engage with our people….so there is 'ownership' of objectives and delivery of goals around safety, performance etc. We cannot continue with ill-defined accountabilities and responsibilities, and the ambiguity this brings, and people can hide behind."

[Senior Manager 9]

The third 'challenge' was around silo-focused employees. Both groups of participants in almost equal proportion expressed concerns that whilst Network Rail was reorganising itself with decentralised Regions and Routes, in practice people were still working very much in their old ways. As a result, organisational silos continued, regardless of the aspirations for the business to operate within a matrix structure (see Figure 5.2). Some of this was attributed to not preparing people adequately for the changes, whilst several others thought it was down to a lack of commitment in both horizontal and vertical dimensions of the matrix to make the relationships work effectively, and….

"….old ways of working were not going to go away overnight"

[Senior Manager 3]

One Senior Manager reported their specific concerns around decentralisation, and what they saw as the reality in the workplace, saying:

"We still expect decisions to be made within a hierarchical structure, yet we have devolved accountabilities locally, but unwittingly cause confusion and blur lines of responsibility when we are not clear on expectations and the role of individuals within the system."

[Senior Manager 5]

There were some managers, and an Executive, who also said that Network Rail's organisation still has multiple / overlapping cultures within the organisation that fragment into subcultures across a group or groups which are blockers to change.
As one advised:

"The industry cannot stand still; it is becoming more complex. Network Rail must evolve, and at pace, which I think it is starting to do, but there are individual cultures, and local cultures, even within specific teams that make change so damned difficult at times."

[Executive 6]

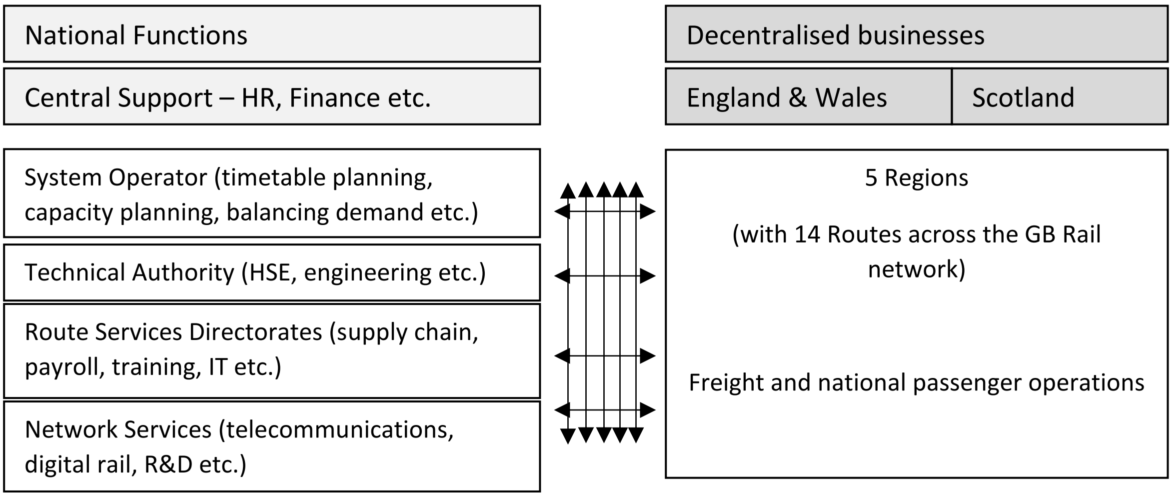


Figure 5.2 – Network Rail Matrix Structure: adapted from Network Rail (2020)

Rasmussen and Svedung's (2000) risk management framework emphasises the importance of improving integration across different, vertical levels in a system and the importance of system wide feedback and acknowledging the impact of decisions at one level and actors at another level. The interviews highlight how Executives and managers are aware of the need for people to better understand goals, plans and expectations across the system as whole, and how this can be achieved through clearly defined and shared objectives, and communication of the part people play in this and the structure.

5.4.1.2 Objectives communicated within the system

On the overall theme of objectives, 55% of interviewees said communications within the system was a critical component if goals and plans were to be delivered effectively. Objectives, and the way these are communicated and to whom, within the system, emerged as a specific sub-theme.

All of the Executives and more than two thirds of the Senior Managers interviewed report positively or fairly positively about the organisational change Network Rail has embarked upon, although some did acknowledge improvements were needed in the way the changes were being conveyed and messaged to different audiences.

As one Senior Manager warned:

"….the system is complex technically, is diverse geographically, and there are multiple stakeholders to consider."

[Senior Manager 2]

Those interviewed from across the rail sector also believe the changes being made will not always be smooth because of the complexity of transferring large portions of Network Rail's business into Regions and Routes, and for the revised interfaces to be understood across the whole system – both internally and externally to Network Rail.

"There's a genuine willingness to learn and improve, but it just takes time, and the road will be a bit bumpy along the way. We need to encourage sharing of best practice in the devolved model, and communicate, communicate, communicate!"

[Executive 8]

Many interview participants felt that consistent, and repeated, engagement with those affected by change will help improve ownership and understanding of the railway operating as a system, and help clarify objectives, with those best placed to implement the transformation programme(s) able to do so in the knowledge that they will be supported, not fearful of change.

"Change in the organisation is often feared and therefore resisted. Making changes in Network Rail is extremely hard; there is a deeply embedded conservatism that we have to overcome if we are to be more dynamic in delivering on our objectives and vision for the future."

[Executive 5]

In summary, the interviews identified the need to prepare people for change – clearly setting out the safety and operational objectives to be communicated within the system – supported by strong, and consistent, messaging across the diverse range of stakeholders / audiences. Again, as found by Rasmussen and Svedung (2000), the lack of integration can be caused by a lack of communication across levels of a complex system, which in turn can lead to misaligned goals or the potential for loss.

5.4.2 Status information

Rasmussen's and Svedung's (2000) second theme relates to 'status information' and whether individual decision-makers are informed about the system in terms of comparable objectives, and if there is visibility of what is considered to be acceptable performance. Executives and Senior Managers were asked about their views on decision-making within the organisational hierarchy. Three sub-themes were identified in the analysis of the interviews: one around decision-makers being properly informed, another about the visibility of acceptable performance, and one was concerned with the alignment of organisational structures to objectives.

Discussion with the interviewees revolved around the organisational context and the range of decision-makers at different levels within the industry, e.g. frontline staff, management, Regulators, and particularly the impact of decisions within a complex structure influenced by politics, funding, and unforeseen issues such as the Covid pandemic (that required decisions at pace, and across the entire sector during the period 2020/21).

5.4.2.1 Decision makers being properly informed

On the overall theme of status information, 40% of interviewees said safety and [operational] performance must go hand in hand if the system was to remain safe and effective. This, they said, required decision makers to understand the part they played in the system.

Organisational objectives around safety and performance were reported as being impacted by multiple factors, often caused by mismatches in systems thinking, planning, data, or risk approach. For example, a third of the Rail Executive and Senior Manager interviews identified a number of contemporary challenges of the matrix organisational form that need to be addressed if objectives and plans are to be achieved.

It was acknowledged by several interviewees that the industry needs to move away from 'tick box' compliance to one of competence of frontline roles (e.g. supervisors), to arrive at the right solution for a specific situation. To do this, decision-makers need to be properly informed about working practices across multiple levels, such as undertaking engineering tasks across adjacent worksites, with several train movements in between.

"It is important to appreciate the position individuals find themselves, mainly around risk perception, and the abilities of staff to effectively challenge decisions when they themselves are also having to make real-time, operational, decisions often unsighted by what is happening elsewhere."

[Executive 6]

Of note also is how some believe that decision-makers can affect the operational agility of their organisations by monitoring short-term developments, safety and operational performance data, but also threats.

"We need to be able to spot any 'warning signs' as decisions are made and changed. If not, we struggle to recover from this downstream, and we go on to hold an 'inquisition' as to why things were allowed to get out of control."

[Executive 1]

Studies have found (Hanover Research, 2013) that views vary between top-level and Senior Managers as to the challenges associated with matrix structures. This was also the case with those interviewed with a range of opinions expressed. Some were more in support of decentralisation than others, though Senior Managers interfacing with those at the 'sharp end' on the frontline felt that there was not always visibility between objectives and the way the organisation was presently structured to deliver these.

This 'tension' was reported as a concern to some interviewees, and one suggested that:

"….[poor] decisions which are later questioned can get down-played because decision-making isn't always transparent to others within the system, and especially around how the decision-making itself was informed (e.g. through knowledge, experience, data analytics, or the use of artificial intelligence)."

[Executive 8]

Rasmussen and Svedung (2000) have commented on how safety emerges from the decisions of all actors involved in the system. The interview analyses identified how Executives and Senior Managers seem to recognise this, elaborating on how the whole range of decisions makers in the rail sector need to be properly informed; clear on their objectives and the part their decisions collectively make towards delivering a safe and performing railway.

5.4.2.2 Visibility of boundaries of acceptable (safety and operational) performance

Of the 25 interviews carried out, it was clear that many participants felt very strongly that safer and better operational performance could be achieved through better decision-making and planning, and the indicators of safety and operational performance were probably not visible to their respective organisations, across all levels, despite monitoring and reporting of trends across a number of data sets. There were clear concerns that whilst there was plenty of information, this was not necessarily readily accessible or visible to those that could make best use of it. Another point, made by several, was that the reactive nature to indicators of unacceptable performance led to a *'firefighting'* approach, and a tendency to find counter measures as quickly as possible to avoid a deteriorating trend, without necessarily adopting the right solution due to the haste. The move to a more considered and proactive approach was certainly the preferred choice for many interviewees, but how to achieve this was seen as complex, and one senior manager said it felt like they were *'asking to boil the ocean'* whenever the subject arose with their teams because of how the data seems so elusive to them.

The Executive and Senior Manager interviews reveal a desire to get better, from a position where there is inconsistency around the use of data and management information, how this is shared, and with whom. Several cited *'the need to improve the quality of information being provided'*, particularly to local management, especially relating to the safety performance of staff working on or near the track, to enable better monitoring and decision making, as well as a greater focus on proactive assurance processes, competence management etc. This, they felt would *'better support those at the 'sharp end' in their own decision making'* and provide visibility of acceptable performance targets / goals to a much wider audience.

Indicators of acceptable performance should also focus on positive aspects of safety, and measure organisational features that enable safe everyday interaction, e.g. instructions, workplans, workforce capability (Hollnagel, 2008; Reiman *et al*, 2015). Senior rail personnel were invited to discuss how these indicators might be developed and used as part of the safety management system to gain an understanding of the system (Hollnagel *et al*, 2006) – with many suggesting they thought this was already happening in some instances, but not consistently.

5.4.2.3 Alignment of structures to objectives

The alignment of organisational structures to objectives, the issue of *'roles and responsibilities'*, and *'levels of authority'*, came up regularly during the interviews. Much discussion revolved around how the Network Rail organisational structure, and the wider industry structure, need to be properly developed, understood, and communicated, to support delivery of objectives.

When asked, many interviewees were able to describe their respective safety management systems, and supporting structures, but could not do so in the context of the wider integration required across the levels of the wider rail system beyond their immediate sphere of control or work area.

There were, however, two Executive level interviewees with experience in other transport-related sectors. They had strong views on how they saw the value of operating in a clearly defined system, particularly if it is a complex one with multiple layers.

They talked about:

"…having common goals and objectives across organisations."

[Executive 3]

"….and interactions and dependencies needing to be made clear across all levels of the system."

[Executive 6]

Such a hierarchical model of safety control can be found in the literature (Rasmussen, 1997), but it is not a model easily described by those in rail beyond a very generic understanding akin to a diagram developed by the ORR (2016) providing an overview of the GB rail industry (see Figure 5.3 below).

Several questions were posed regarding what might happen, for example, in the event of a major incident or accident, and decisions required in relation to line closures, media handling and the like. Individuals reported that they would operate within the boundaries of their knowledge and experience, but they were aware that this may not extend to a full appreciation of what others did or might decide to do. Very few of the interview participants could meaningfully describe, for example, all the rail safety organisations and their roles and responsibilities, and even fewer understood the part industry organisations (such as the Rail Delivery Group – who have responsibility for bringing together the companies that run Britain's railway, to deliver a better railway) directly play in decision making.

Some Senior Managers went on to say that, given the current complexity, they felt that the Network Rail organisation should consider restricting the span of control and decision latitude of those on the frontline to alleviate some of the issues around interfaces (e.g. track access for maintenance over train running). Others, however, wanted the staff to be far more autonomous (recognising that interfaces vary within the system considering circumstances, events and decisions made or being made), and they wanted frontline staff directly involved in decision-making, not as 'bystanders' to central decision making.

Several interviewees considered autonomy as being synonymous with the new structure, allowing for decision making to be made by the person best placed to do so, and not constrained by hierarchies or inadequate integration of different levels of the system. This should not come as a surprise as research on designing safe organisations questions how best to manage concurrent demands in the face of uncertainty. Indeed, Grote (2020) posits that the contradiction of centralised versus decentralised decision-making still lives on – with the classic approach to safety favouring centralised-decision making through hierarchical control which provides for stability and 'compliance' to standards etc., as opposed to newer research suggesting that decentralised decision-making enables flexibility through fast local adaptions.

This research exposes the differences between Rasmussen's (1997) hierarchical model of safety control and the actual practice of GB Rail organisations; reflected in the Rail Executives' and Senior Managers' recognition that a systems approach is not always easy.

Most of the interviewees could describe how decisions made at the higher levels within the complex rail structure should flow down through their organisations as the information flows upwards (e.g. management need to be informed about safety and performance against objectives). However, they admitted that this is not always how things work in practice due to a range of factors including commercial imperatives and political drivers.

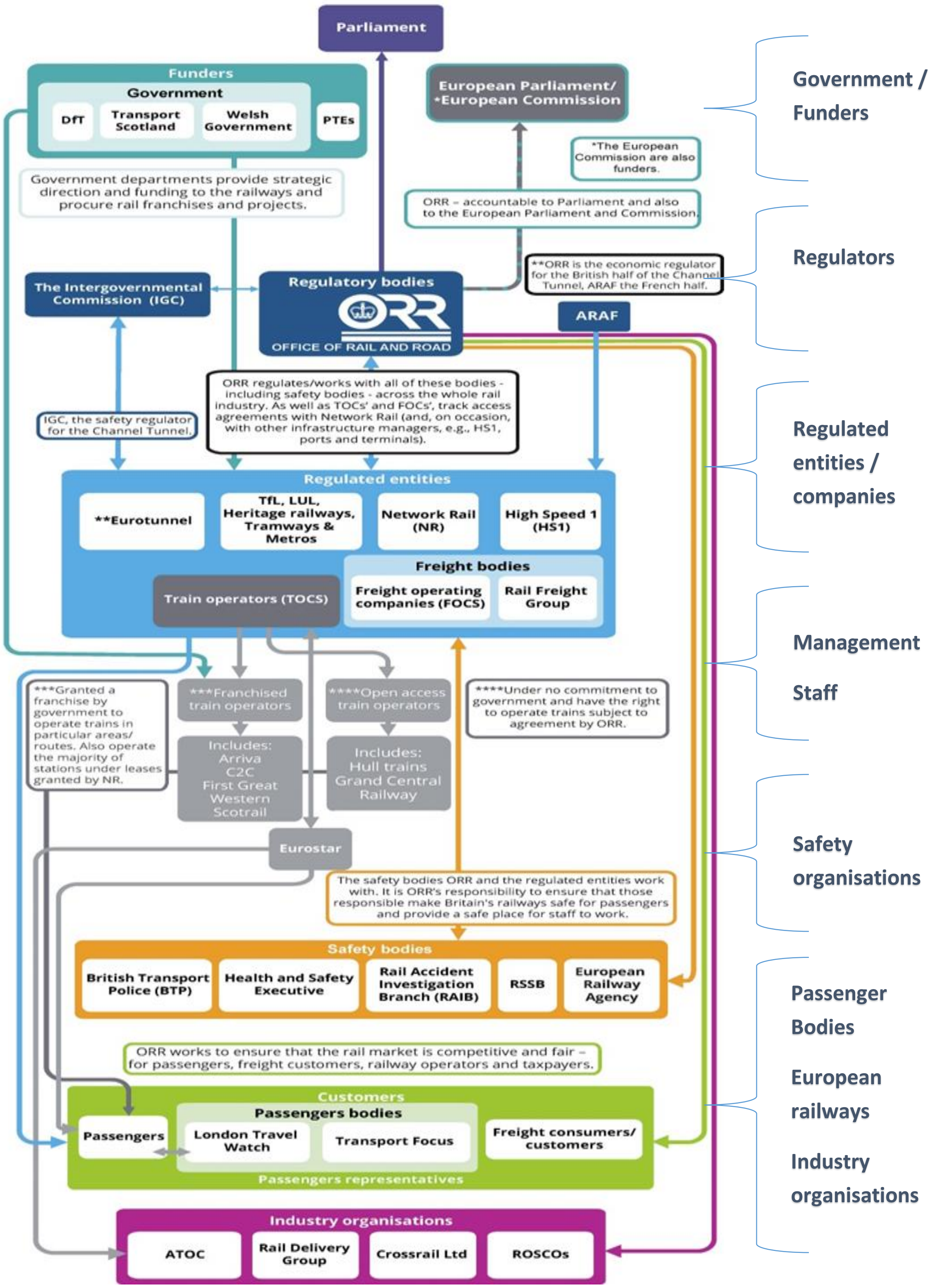


Figure 5.3 – An overview of the rail industry in Great Britain (ORR, 2016)

5.4.3 Capability

The overall theme of capability was the most common category to emerge from the interviews, and has a broader organisational perspective used in the context of organisation design, systems or processes, and competence of people and behaviours. Questions on the topic of capability informed the creation of the sub-themes: competent decision-makers, functional properties, and parameters affecting (safety and operational) performance in a changing environment.

5.4.3.1 Competent decision makers

The Executives and Senior Managers discussed the complexity of the interactions within the sector, with engineers / subject matter experts designing the flow of work, the use of assets, and defining how equipment will be used and maintained without necessarily the involvement of those on the frontline, or an understanding of human factors as part of the control system. Many were concerned regarding the pressure to get work done and without the time to think things through during perturbations. A number of interviewees said they thought this could import additional risk that is then uncontrolled or unmitigated, because people might ‘cut corners’ or ‘deviate’ without permission. Further questions elicited concern that getting the right people to make competent decisions was still a challenge, primarily because the various levels of control, sign off and approval of work blurred accountabilities.

A view expressed by some was that very few decisions get made without recourse further up the chain of command. Some of the Senior Managers were clear that whilst the organisation change had improved the relationships and interfaces in the decentralised functions, there was still some way to go, i.e.:

“Behaviour change and the way people think and make decisions is critical to success; this is a cultural challenge as some dislike the ambiguity of risk-based decision making and want everything controlled by standards, whereas we should be aiming for control through capability…..Too much emphasis is on everyone wanting things to be 'black and white' and standardised in a way that precludes individuals from thinking for themselves….It’s time we trusted people to do the right thing, in the knowledge they are trained and competent.”

[Senior Manager 1]

“The matrix decision-based approach is still lacking, so individuals tend to make decisions within a hierarchy. Accountability and responsibility are blurred because of chains of command and who has the final 'say'.”

[Senior Manager 6]

To summarise, the over-riding issue that emerged was around having the right people who are competent, and with the knowledge, to discuss the control of work and work practices; having to make decisions in a dynamic state. Interviewees said that pressures on people meant individuals trying to optimise getting work completed whilst influenced by local constraints and operational realities. Rasmussen (1997) and Snook (2000) agree that these types of deviations should be shared so that the organisation can either adapt, or identify new risks requiring mitigation, without which the capability of safety control may be lost.

5.4.3.2 Functional properties of the organisation and its design

Whilst there seems to be a belief that the case for organisational change has been spelt out, many of the Executives and Senior Managers who were interviewed believe that the challenges ahead for the rail sector rest on the long-term future structure of the industry, and therein the competence (and behaviours) of individuals (and their specific technical capability), who will need to be able to adapt at pace to deliver their objectives. Much of this discussion centred around the volume and scale of change, and capacity of existing resources to deal with this.

"….we expect too much of some of our people. Looking at the change programmes in isolation makes them appear achievable; put them all together and it exposes the enormity of the task. The same resources, usually the frontline, are impacted over and over again. We need to understand the impact of changes in the broadest sense."

[Senior Manager 9]

Rasmussen and Svedung (2000) previously noted that decisions makers need to be competent in regard to the operational, technical and safety related elements of their organisation, but achieving this is in practice across a complex sector requires the communication structure and information flow to be understood, suitably aligned to the control requirements of known hazards. The issue of blurred lines of responsibility arose in several interviews, with the view that as the industry seeks to restructure these blurred lines will need to be removed (or managed), and effective coordination of competent decision making is going to be required at all levels if risks are to be controlled.

5.4.3.3 Parameters affecting (safety and operational) performance in a changing environment

Several of the interviewees expressed strong views regarding controlling performance (and capability) in a changing environment. Responding to events – regular and irregular – in a rational way was a skill that was identified by some interviewees as critical for success; they thought developing people capable of knowing what to do in a dynamic situation would be a precondition for future frontline appointments, and for ongoing role-based skills training.

"Responsibilities always evolve; they are never completely static, and I think this is true whether in normal operations or periods of perturbation. My big worry is how we have failed to develop people with the necessary skills to deal with the railway as a system, and this needs addressing."

[Executive 3]

"We don't generally have a positive behavioural impact on our people; they often feel 'done to' and we need to develop a workforce with a degree of autonomy, improving their decision-making skills, and making better use of their technical abilities. We need our people to know what is expected of them, like making risk-based decisions in a forever changing system, and without fear of blame."

[Senior Manager 6]

Uncertainty, complexity, and conflicting requirements can be found in safety-critical organisations (Reiman *et al*, 2015; Woods *et al* 2010; Dekker, 2011), like Network Rail. As such risk-causing characteristics need to be understood – for example poor information flows, and system accidents – and then managed and monitored. The interviews identified 'capability' and 'competence' as the key watchwords, which have resonance with the points made earlier regarding decision making and functional properties.

Getting the right balance between sufficient resources planning a task, versus the resources to undertake the task, may require a trade-off (e.g. poor planning could lead to poor execution, but if resource is scarce where does the effort best go in?). The interviewees certainly had mixed views on whether some things – like resource allocation – are truly 'tradeable' and if some individuals would know where to best place their efforts. As Hollnagel (2009) discusses the Efficiency and Thoroughness Trade-off (ETTO), it may be necessary for rail organisations, in future, to develop these skills, allowing for a blend of efficiency and thoroughness, e.g. providing adequate time and resources to undertake a track inspection, whilst ensuring the checking process is in itself thorough (i.e. not cutting corners or running the risk of later delays caused by missed defects).

5.4.4 Awareness

Rasmussen and Svedung (2000) ask whether *"decision-makers are prompted to consider risk in the dynamic flow of work, and whether – continuously, during normal work – they are made aware of the safety implications of their everyday business decisions?"*

Similar questions were put to interviewees and two sub-themes, based on the main theme of 'awareness' arose when discussing work processes, normal operations and then any operational perturbations. These sub-themes are concerned with the implications of decision-making and risk as part of work activities across all levels, and then learning lessons.

5.4.4.1 Implications of decision-making, and risk considered in the flow of work

The implications of decision-making in a safety-critical sector such as rail are not to be under-estimated. The very essence of operating within a system of systems means that communications and information flow are so important for a myriad of reasons, not least because of the operating environment and the reliance on the dynamic flow of work and a mutual understanding of risk (e.g. train driver talking to a signaller about an unlit signal).

Almost all the interviewees expressed concerns about the potential for a disconnect between goals, objectives, roles and responsibilities, and authority. Many believe this situation may continue for a while in a complex sector, operating under emergency measures during the Covid pandemic, and facing more uncertainty following the publication of the Williams-Shapps 'Plan for Rail' (DfT, 2021), which is seeking to create a new structure for rail (addressing issues of consolidation, efficiencies, and greater customer engagement).

The majority of the Executives felt that people will need to get on with the job in hand whilst the changes are being made, although one was concerned that employees remain fearful of making mistakes, especially if they do not have the 'full picture' as they see it.

"……we need to operate effectively in a 'live' railway, accepting some people may make mistakes. We need to allow for a 'fail fast, learn faster' mindset. By stifling decision-making, we stifle creativity, and we don't take advantage of the opportunities to learn."

[Executive 4]

A number of those interviewed advised that they thought the implications of decision-making are not always well understood across the whole system, particularly with the pace of change. The analysis of responses suggests risk assessment and risk perception will need to be better managed at all levels, requiring adaptation, empowerment, and the confidence to make decisions.

One Senior Manager said:

"Safe and efficient operation comes about by our adaptation of the tasks we are confronted with daily...yet we give no credence to the frontline who do the adapting, especially if things don't go quite to plan. We empower our people, but that doesn't mean we don't then subsequently challenge them, so it's no wonder they revert to managers for the tougher decisions to be made."

[Senior Manager 15]

Some of the rail industry leaders said the sector, for its part, does well to get the right balance between prescription and autonomy, whilst others suggested to the contrary and reported that operational realities mean that there is not the time to consider the various interfaces (e.g. the engineering supervisor with the signaller regarding track access) and risks within the work process, and make adjustments needed in any way that is meaningful, or proactive. As one Executive went on to explain:

"We have recently created an opportunity for people to challenge our standards, but very few of these challenges come from the frontline which makes me suspicious in as much that we know we have people taking decisions out there but probably not following procedures. Making 'live' decisions without recourse to requesting changes to a Standard is a whole lot easier! Therefore, the risk of non-compliance is sure to exist, but I am not convinced we want to hear that, or indeed know what best to tackle first given the likely scale."

[Executive 4]

Dekker (2003) indicates that organisations should be monitoring the difference between procedures and practice, and thereby develop people to know when and how to adapt for given situations. This might be difficult in practice where the railway culture is to drive compliance and expect people to blindly follow procedures, even though some are willing to acknowledge that this is not the reality 'on the ground'.

5.4.4.2 Learning lessons

Many of the interviewees reported a real desire of Network Rail to continuously improve, and an almost relentless pursuit of information and real-time data to inform decision-making for every-day activities.

A number felt that the use and/or introduction of technologies was occurring at such a pace that this makes it exceedingly difficult for the frontline worker to keep abreast of their part in decision-making – either directly or indirectly – because of diagnostic tools, and system apps seemingly doing some of this risk analysis 'work' for them.

As Leveson (2011) has previously identified, and a number of those interviewed stated, learning from past events (i.e. knowing what happened, why, and what to do), and sharing this, must be a prerequisite for the organisation if it is to become more resilient.

"Organisational learning must be a source of the knowledge from where our improvement programmes and activities should be driven. This way we have good, closed-loop learning processes."

[Senior Manager 9]

"We need to start combining our various data sources – investigations, report recommendations, inspections, audits, assessments – and supplement them with more systemic approaches that allow us to avoid surprises. We've introduced bowties in support of risk management as an example, but they are really complicated for the frontline, and I am not sure we go back and properly revisit them in light of incidents. Why not?"

[Senior Manager 15]

Published reports of NASA's Challenger and Columbia accidents suggest that organisational constraints are also often an obstacle to learning (Hall, 2003; Leveson, 2008). Several Executives acknowledged during their interviews that railway accidents and the lessons from these are not always considered more broadly 'in the round' across the organisation, or organisations.

Some proffered this is because of a reluctance to share issues more widely, and instead keep things 'within'. One Executive said, *"we don't like washing our dirty laundry in public"* and added *"….it boils down to trust. We manage to get most things done through the effective working relationships we have, but if these relationships are poor then sadly, we all suffer for it."*

5.4.5 Priorities

Rasmussen and Svedung (2000) have previously posited that decisions-makers need to be deeply committed to safety. They also challenge whether regulatory efforts help or hinder management priorities, for example issuing of fines for breaches of the law and whether this is an adequate incentive to correct matters. These and related questions were put to the interviewees and several additional sub-themes, in support of the main theme of 'priorities' emerged from the interview analyses. Primarily, these came about where the interviewees had strong, collective, views on the part resilience and trade-offs play in successful risk management, and the conditions necessary to support change.

5.4.5.1 Resilience

Resilience engineering is about taking a holistic view of systems. This perspective, known as systems thinking, has been influenced by the likes of Hollnagel, Woods and Leveson (2006), and Jens Rasmussen (1997), in recent decades. When the Rail Executives and Senior Managers were asked about their understanding of the term 'resilience' and what this means for safety performance, and operational reliability, they often went on to describe resilience through the people aspects of the system (e.g. resourcing, competence, knowledge) or the assets or technologies within the system (e.g. component reliability, IT resilience). Rarely did they mention the system as a whole.

Many of the interviewees proffered their views on managing complexity in a rail system, and that this is, or will be, a (required) core skill, including an awareness of the impact an individual's decisions have on others. Some said that decision-making can be a reaction to the pressure, and it may not be the right decision, but reputation management can become pervasive.

Others also said there are times – when safety needs to be improved – whereby any compromise is simply not acceptable and resources, monies, and other considerations are nugatory. Thus, to "become resilient", Woods (2006) suggests organisations *"..adapt to handle unanticipated perturbations that call into question the model of competence."*

The required qualities of a resilient system (adaptability, high levels of redundancy, quality information) were discussed with interviewees, and the Executives and Senior Managers acknowledged their importance to deliver successful operations in a dynamic system.

All eight of the Executives interviewed said they would welcome the ability to adapt and change procedures, processes and/or their organisations at pace. Many said they would reprioritise accordingly, so long as everything was able to shift at the same time (e.g. not have lagging policies or processes which can negate the effectiveness of change).

5.4.5.2 Trade-offs

Twenty of the twenty-five interviewees were clear in their responses that an organisation such as Network Rail depends on the flow of money in order to prioritise delivery of goals and objectives. The design of the system, optimising the whole system performance, also needs an understanding of the flow of money, the revenue and costs associated with operations, and the impact on performance. How the Executives and Senior Managers achieve such a fine balance is a difficult area to address. More than half (16 out of 25 interviewees) explicitly said operational trade-offs are necessary.

One Senior Manager said that risk management in the rail system requires them to understand how pressures in the overall system – meaning government, the Regulator, management and the frontline – affect decision-making. This means decisions affect several other layers, and many interviewees reported that someone usually must make some kind of trade-off, usually at quite a junior level within the hierarchy.

An example cited was a timetable change and the differing priorities of the Government, the Regulator, the infrastructure owner, train operator and local management – all of whom have different organisational contexts or conditions influencing them, and it might be the local planning team that ultimately makes the trade-off. That said, there was also a suggestion by several interviewees that they wondered if trade-offs between safety and performance will be possible in future. Their concern centred around increasing system complexity, and how those in the system would be able to intelligently manage the various interactions – design approvals, communications, real-time data reporting, information systems, media management – such that they could be anticipated, managed and/or guarded against. One Senior Manager said:

"….the interfaces are already a problem and I can only see the situation worsening in some cases if we don't sort out the industry structure."

[Executive 3]

Understanding conflicting issues of safety, performance and service with other organisational goals is difficult (Wilson *et al*, 2009). For example, what is espoused as corporate safety priorities (e.g. fatigue management to help staff and managers reduce excess working hours) does not necessarily reflect how trade-off decisions are made, especially where thoroughness is often sacrificed for efficiency (usually because of poor time management, or process bureaucracy). The question, therefore, is whether systems thinking can address and reconcile this difference (lack of agreement)? The answer probably lies somewhere in between.

5.4.5.3 Conditions to support change

During the interviews some of the participants said that to be able to deliver results, and create the right conditions to support change, there needed to be targets in place that everyone bought into, and adequate resources available to maintain effective operations. However, several managers also said that this was not straightforward within a complex, highly regulated, landscape and within an ever-changing environment and the 'resilience' of the people and system should not be taken for granted.

An Executive was clear when they said:

"We employ thousands of people, and they play an active part in the way we operate, and yet it is our management that often designs poor organisation structures, creates complicated and bureaucratic processes, and asks our staff to manage conflicting goals almost on a daily basis. How we expect them to be resilient – and many are – is a credit to them because of a shared sense of purpose to deliver for passengers, and a commitment to dealing with whatever increased demand is placed upon them. Are we resilient? Yes, but we must avoid sharp-end workarounds and adaption at any cost…..that's how mistakes and accidents happen."

[Executive 1]

In summary, none of the interviewees thought that change wouldn't / couldn't happen, but some did feel they were encumbered by a system and structure where communicating and collaborating with decision makers was overly complex, and that the competing priorities of some within the sector would continue unless industry-wide reform was made and sustained.

5.5 Discussion

Much of the literature on complex organisations (Grote, 2020), loosely (and tightly) coupled work systems (Bernard *et al* (2020), systems-thinking (Leveson, 2011), and resilience engineering (Hollnagel *et al*, 2006), point to well-known management theories (Taylor, 1911 (scientific management and work measurement); Trist, 1959 (socio-technical systems)). Whilst these approaches help to highlight the importance of integrating safety and human factors into a socio-technical system framework or model and conceptualise the way in which such approaches can be developed, they often lack details on how to turn the theory into practice. The aim of this current study was, therefore, to investigate how senior business leaders in the rail industry speak about common concepts relevant to STS theory and resilience engineering that are evident in the literature and how they (actually) use these in managing change in the complexity of the rail sector. For example, phrases were used like *"needing to strengthen systems for things to go well"* and *"system robustness"* when discussing safety, risk management, and resilience.

There have been benefits of undertaking qualitative research with a select group of interviewees. Opportunities to gain access to such an important group of influential people in the rail industry are rare. The interviews were carried out in–depth and have helped to generate an understanding of the multiple goals and objectives of a range of organisations, and the business functions and responsibilities in this sector. This helps to present a picture of the complexity of the rail industry, and from different perspectives.

Using the five themes based on Rasmussen's and Svedung's (2000) risk management framework allowed for the grouping of interview responses, and within these themes 13 sub-themes were identified. This sub-division was based on the author's interpretation of the interview responses, and the labels are intended to characterise the challenges of, and barriers to, organisational change based on the perceptions of the people best placed to answer, having the experience and authority on the subject matter at hand.

The analysis provides a level of detail beyond the five themes from Rasmussen and Svedung (2000) and is intended to demonstrate how the risk management framework can support understanding of a real-world STS currently in operation in GB railways. There is also wider value to safety science, and for other sectors, where the themes and sub-themes are readily translatable to system design, analysis, and operation within a hierarchical safety control structure.

The sub-themes also help bring greater definition as to what information should be available to decision makers and thereby their capability of safety control.

The results clearly identify some important points to consider for the design of change in a complex industry, and how a socio-technical system framework or model might be applied in practice, related to systems approaches, understanding and managing trade-offs and dealing with uncertainty, and flexibility vs fixed approaches to control.

5.5.1 Recognition that a systems approach is needed to support change

The Executives and Senior Managers interviewed, many with differing experiences, talked about their current job roles and associated pressures of operating within a regulated industry and cited numerous examples of their understanding of the key interfaces, complexity, successes and barriers to change related to how the industry currently operates.

The interview analysis has produced descriptive details to elaborate on a number of the enablers and barriers to change that have also been considered by earlier researchers (see Eason *et al*, 1996, Eason, 2014; Mumford, 2000). Examples include integrated approaches for effective implementation of new technology into work organisations, such that both technical and social systems are considered.

Both Eason's and Mumford's work also suggest that successful change depends upon effective key stakeholder participation; an approach that considers technical, organisational, economic, and social needs. However, the interviews with rail leaders suggests that such an integrative approach is rather difficult in practice because of the hierarchical nature of the organisation(s) involved and the tendency to focus on technical 'silos' rather than across disciplines, functions and layers. Even when change is initiated, the Executives and Senior Managers recognise that it does not actually happen in the way envisaged at the outset. Thus, the participation or buy-in can be piecemeal at best, or even non-existent in some cases.

Rail is increasingly complex, and the interviews show that whilst there is a highly connected system of people, resources, processes and organisations involved, there remains an issue of capability (around competence, capacity, and readiness) to manage change at scale and/or risk across the entire system, and hence the tendency to focus on discrete interventions which are then narrowly monitored. The idea of a systems approach is not new to the railways; timetabling and system operations are good examples of how systems, design and risk are considered in the round, but the broader understanding of the social factors (human interactions, wellbeing) and the part they play in overall system performance are usually lacking, primarily because of the tendency to focus on technical solutions rather than the people aspects of change.

5.5.2 Understanding and managing trade-offs within a complex regulatory framework

The interview analysis helped to highlight some key facets of socio technical system theory and resilience, and how these concepts are applied in practice. For example, some interviewees suggested that the focus tends to be on the very traditional risk-based approach in managing change and thereby the controls, policies and procedures needed for compliance.

Others, however, acknowledged that there is a far greater need to focus on the whole system and operational reliability – needing to be more agile in responding to what happens as change is delivered and occurring at great pace, anticipating future threats and opportunities, and understanding the need for and managing trade-offs. As Hollnagel *et al* (2006) identified, it is more than recovering from threats and stresses. For rail, putting resilience into context, should be about how systems perform under a variety of conditions, not just about how they remain safe.

5.5.3 Dealing with uncertainty, and flexibility vs fixed approaches to control

Interviewing rail industry leaders and decision makers to identify perceptions of and barriers to organisational change, has helpfully provided an understanding of the workplace organisation and behaviours that facilitate or impede change implementation in the GB rail industry.

The research has revealed how Network Rail has consciously embarked on a programme of greater decentralisation, enabling flexibility by empowering frontline workers in decision-making. However, this work has also shown that this is not necessarily happening in practice as some very Senior Managers say they still prefer centralised control, which they believe provides stability and control over defined processes, whereas others are firmly of the view that decentralisation remains the right ambition. The interview analysis certainly exposed the tension in advocated direction (e.g. centralisation for some and standardisation for others), but in response to the need to deal with fast pace of change and uncertainty, many want high performing and well informed frontline staff who can make decisions.

Grote (2000) posits that “uncertainty is a moderating influence in the safety-autonomy relationship” and suggests exploring whether a deliberate increase in uncertainty for given situations may promote safety in some cases, whilst also encouraging worker participation.

The interviews would certainly suggest that there remains a belief that railway rules and procedures are rather more ‘fixed’ than ‘flexible’ whilst decentralisation is progressively rolled out, and therefore end-users being involved in future change design, and seeking their views on where tasks should be flexibly specified, might be a way to test the current level of ‘uncertainty’ already within the system.

5.5.4 Supporting guidelines

Guidelines (11 no.) have been developed and are proposed in support of the study’s findings that emerged through the analysis work and are concentrated around the sub themes identified, setting out how managers could design, implement, and embed change – See Figure 5.4.

Figure 5.4 – Proposed guidelines, and links to the five themes, and sub-themes identified

Theme	Sub-Theme	Proposed Guideline(s)
1. Objectives	• Clarity of Objectives / Vision • Objectives communicated within the system	1. There is a need for transparency about the roles people play, preparing people for change through clearly defined and shared objectives, supported by strong messaging using media to suit the difference audiences. 2. There is a need to understand goals, plans, and expectations in the overall context, i.e. the flow of work and the system as a whole.
2. Status Information	• Decision makers properly informed • Visibility of boundaries of acceptable (safety and operational) performance • Alignment of structure to objectives	3. Being clear on processes and the limits of control, safe performance, and operational constraints will help with achieving agreed targets, and enable informed, decision-making 4. There is a need to align the organisational structure, accountabilities of staff and knowledge and skills of people to achieve agreed targets, and conduct continual, systematic, evaluation of its effectiveness
3. Capability	• Competent decision makers • Functional properties • Parameters affecting (safety and operational) performance in a changing environment	5. It is important to have the people with the right knowledge to make informed, co-ordinated, competent decisions 6. Blurred lines of responsibility need to be better managed to build resilience, and effective coordination of decision making is required at all levels 7. It is important to agree the resources required to achieve sustainable performance and understand the trade-offs to deal with unforeseen disturbances
4. Awareness	• Implications of decision-making, and risk considered in the flow of work • Learning lessons	8. Implications of decision-making need to be understood and managed across all levels 9. Risk assessment and risk perception need to be managed within the flow of work; analysis of the interactions between tasks, technology, information and organisational elements may identify conflicts that introduce new risks, priorities and a change in work flow 10. Closed loop learning processes are needed to model past, present, and future system interactions, to give the organisation the foresight to manage operations intelligently
5. Priorities	• Resilience • Trade-offs • Conditions to support change	11. Regulatory efforts need to be balanced; there may need to be socio-, technical- and economic trade-offs

5.6 Study limitations

This study focused on Executives and Senior Managers within GB Rail and did not include contact with frontline workers to examine where there may be process, people, or technology issues *during* change implementation. The interviews were limited to those currently best placed to influence change in the GB rail socio-technical system and did not include follow up interviews with others to better understand how the different levels of management, influencers, and other sources of complexity across the sector impact on key decision-making – particularly as Network Rail forges ahead with greater decentralisation.

Study 2 and 3 address these limitations (see Chapters 6 and 7) and help expand the insights gathered from this initial study to determine their relevance across events and states, and whether the guidelines identified in Study 1 would still hold true in other contexts.

5.7 Conclusions

The overall aim and objectives of this study have, therefore, been to identify important components of the GB rail socio-technical system, and how STS theory can be applied in practice in support of sustained safety and performance improvements. The investigation has also established how senior business leaders in the rail industry speak about common concepts relevant to STS theory and resilience engineering, and how they use these in managing change within a complex, highly regulated, rail sector.

The study very clearly outlines the perceptions of and barriers to organisational change in a complex rail industry, from the perspectives of the Executives and Senior Managers that operate within the system. The research has reflected on the applicability of aspects of Rasmussen's and Svedung's (2000) proposed dynamic approach to risk management in the context of complexity, and gathered insights into decision-making, and the decision-makers subsequent capability of control.

The results identify some important points to consider for the design of change in a complex industry, and how a socio-technical system framework or model might be applied in practice.

Analysis of interviews with Executive and Senior Managers identified 13 sub-themes as an extension to the five main themes defined by Rasmussen and Svedung (2000). These were used to form a set of proposed guidelines that could be used by managers to support their approach to designing, implementing, and embedding change, whilst recognising that there should be a continuation of the development of the sub-themes as other related studies progress; especially as the focus so far has been limited to rail business leaders and Senior Managers.

6. Study 2 – To investigate the inter-connectedness of human actions, decisions, and technological factors as part of an overall 'systems approach' to change

6.1 Chapter overview

To help achieve its safety performance targets Network Rail identified two national change programmes to support the transformation of workforce safety (see Chapter 2, para.2.3). The first involves simplification of rules (known as the Business-Critical Rules (BCR) framework); the second requires the implementation of new processes for planning and delivering safe work (PDSW).

The challenge for the organisation has been whether there is a clear understanding of how the company is best able to deeply embed change in a complex socio-technical system.

This research study, therefore, investigates the inter-connectedness of human actions, decisions, and technological factors as part of an overall 'systems approach' to change. Interviews have been used to help focus on how the two national change programmes have been designed and implemented to transform worker safety across Great Britain's railways. The study reflects how some things have changed over time since the programmes were first introduced and identifies the factors that have significantly influenced this.

6.2 Introduction

The Business-Critical Rules programme, earlier described in Chapter 2, seeks to replace the very complex suite of Standards that Network Rail has in place with a simpler, risk-based, rules framework which is underpinned by the bow-tie methodology of risk management. The aim is to improve the way risks to people, assets and the success of the business are managed, by providing a clear understanding of the controls necessary, including individual role accountabilities, responsibilities, and capabilities – see Figure 6.1 below.

Figure 6.1 – Building blocks of the BCR framework (source: Network Rail, 2013)

Unsurprisingly, given industry concerns regarding workforce safety, the planning and delivering safe work (PDSW) programme also focused on frontline process improvements, by delivering a change in the way Network Rail approaches the management and planning of work to reduce harm to its people.

Roll out of the new processes and introduction of technology began in 2015, and made one person accountable for managing task, site, and operational safety risk, with that person involved in the planning of their worksite.

Both these national change programmes, with their focus on workforce safety, have at their heart a requirement to improve how work is planned and undertaken, remove potential for error, increase understanding of the way tasks are executed and risks are managed, and make it easier to share best practice through standardisation. However, they have generally evolved as separate initiatives and the approaches to implementation have been different, including the level of end-user involvement, and how change is managed and measured.

As the literature tells us about systems approaches, most problems and most possibilities for improvement belong to the system (Hollnagel, 2004; Dekker *et al*, 2011). Understanding the system holistically and the interactions and inter-connectedness between elements of the system has been a key feature of the research. This study very specifically sought to understand the extent to which a systems approach is evident, viewed through the 'lens' of the two national programmes.

The views of programme sponsors and change programme managers, at an Executive, senior and middle management level, were captured in interviews. This aided the researcher's understanding of the system beyond a component level (a person, a department, an infrastructure asset). The interviews included discussion of the connections and interactions between human actions, decisions making, and technology roll out as part of the programme's visions.

6.3 Methods

Interviews were undertaken with a number of Executive, senior and middle managers across Network Rail and its supply chain to develop a picture of the intended programme outcomes, informed by their perceptions of the inter-connectedness of human actions, decisions, and technological factors as part of an overall 'systems approach' to changes.

6.3.1 Interviews

Interviews were carried out with 13 individuals – Executives, senior and middle managers in the rail industry including four practitioners (e.g. change managers) involved with, or impacted by, the Business Critical Rules, and Planning Safe Work Delivery change programmes. The participants were selected for their knowledge of one or both programmes. The aim of each interview was to develop an understanding of the respective change programmes, from those having knowledge and experience of the content and effectiveness of their implementation during a lengthy period of roll-out.

For the purposes of maintaining anonymity, and due to the small numbers involved in some elements of the national change programmes, analyses are reported as manager (no.9) or change manager (no.4). It should also be noted that six interviewees from Study 1 also participated in Study 2, but different questions were used. These interviews (largely) took place on the same day, diaries permitting. Care has been taken to treat the two studies, and thereby the responses, separately to avoid overlaps or repetition. The studies serve different purposes, and this was explained to interviewees when questions were put to them, using different question sets (and informed consent forms) for the two separate studies.

6.3.2 Approach to the interviews

The interviewees were contacted directly via email, receiving details of what they were expected to do as part of the study. Participants were asked to give informed consent for participation.

Each interview took between 60 and 90 minutes and was carried out face-to-face. The responses were recorded in hand-written notes, as well as the use of a digital voice recorder.

A small number of follow up interviews were conducted in 2020 with 3 of the 13 participants because of the currency of their knowledge and experience specifically related to two improvement notices issues by the ORR[35], and how these notices and the response to them was aligned to the fatal accident at Margam and resulting report recommendations (RAIB, 2020).

Approval for the study was provided by the University of Nottingham's Faculty of Engineering Research Ethics Committee (UofN, FoE), including the three additional interviews undertaken.

6.3.3 Interview content

The interview questions centred around the two national change programmes, and were phrased using general terminology and concepts that interview participants would be familiar in the industry (e.g. standards, procedures, rules, planning of work, safe access, decision-making, technology etc.).

The interviewees were asked to describe:

- the organisational imperatives and vision for safety and performance improvement in relation to the two specific change programmes.
- examples of, and the approach taken, to deliver the intended programme outputs.
- the various stages of development of the BCR framework and PDSW roll out, focusing on the key goals and timings within the programme phases, including any national trials envisaged, before going on to discuss implementation.

The questions asked were generally open in nature for the 13 interviews to elicit the participants' feelings and views, and explore contexts, environments, and settings regarding the two national change programmes.

[35] The ORR issued two Improvement Notices on Network Rail in July 2019 which are designed to eliminate planned work taking place on railway lines that are open to traffic where the only protection is a lookout.

A variety of circumstances were introduced in each interview to explore how the changes in each of the programmes had been designed, implemented, or subsequently paused, and how and why these things might have come about. For example, why national trials were reduced significantly in scope very quickly after being rolled out (Network Rail, 2016).

The three follow up interviews took place in 2020 and were specifically focused on the content of the Margam report recommendations (RAIB, 2020), and the intentions of Network Rail in response to these and the resulting ORR improvement notices[1]. The interviews also sought to establish how the two national change programmes were likely to be impacted by the report and improvement notice outcomes, and their 'fit' with a more recently established track worker safety taskforce.

6.3.4 Method of analysis of the interviews

Given how Network Rail seeks to drive programme change – and the likelihood of some familiarity / awareness of this process by the interviewees – the interviews were deliberately coded using Network Rail's Critical Success Factors in Managing Successful (Change) programmes framework (Network Rail, 2013)[36] (MSP4NR), which itself is modelled on the original MSP® concept.

The responses were coded, initially linked to the high-level critical success factors, but then also aligned to the 18 dimensions of change that MSP4NR also references, e.g. sponsor behaviour in the context of effective change leadership – see Table 6.1 below.

This approach was useful in being able to highlight the relative importance of issues arising from the interviews, using the 18 dimensions as an effective way to analyse and review individual responses, and to explain things arising from the interviews.

[36] MSP© (Managing Successful Programmes) and developed for Network Rail (MSP4NR) (Network Rail, 2013(a)) is the project and programme management framework used to drive business change and project delivery in Network Rail.

Table 6.1 – Managing successful (change) programmes (Network Rail, 2013(a))

Network Rail (2013) Critical Success Factors	Dimensions of change
Effective change leadership: occurs when change leaders provide direction, guidance and support for the people implementing change and the people transitioning through the change	**Effective change leadership:** 1. Sponsor behaviour 2. Confidence in change agents 3. Informal influence
Committed local sponsors: role models, supporting people through local managers	**Committed local sponsors:** 4. Role modelling 5. Local manager support
Shared change purpose: When people involved in a change understand why change is a necessity, why things cannot remain the way they are, where the organisations needs to get to, and how it will get there	**Shared change purpose:** 6. Organisational imperative 7. Future state vision 8. Solution visibility
Personal connection: personal imperative, solution viability, and being successful	**Personal connection:** 9. Personal imperative 10. Solution viability 11. Being successful
Engagement processes: scope of involvement, learning, and communication	**Engagement processes:** 12. Scope of involvement 13. Learning 14. Communicating the plan
Sustained performance: financial impact, work relationships, levels of responsibility, and learning curve	**Sustained performance:** 15. Financial impact 16. Work relationships 17. Level of responsibility 18. Learning curve

6.4 Findings

13 interviews were undertaken, and there were more than 20 hours of interviews needing to be transcribed, resulting in a total of 235 coded key words / phrases being identified by the researcher from the interviews, and then subsequently linked to the 18 dimensions.

Figure 6.2 shows the count of key words / phrases related to each of the 18 dimensions, whereby the interviewees said something related to these dimensions, noting that some interviewees may have used particular words / phrases several times during their interview.

The 18 dimensions were either directly referenced during the interviews, or questions prompted a response related to these. For example, role modelling was specifically mentioned by an interviewee when asked about the role of sponsors, both nationally and locally. Other questions were more direct, like asking about objectives, which were then linked by the researcher during the analyses to the dimensions related to a 'shared change purpose'.

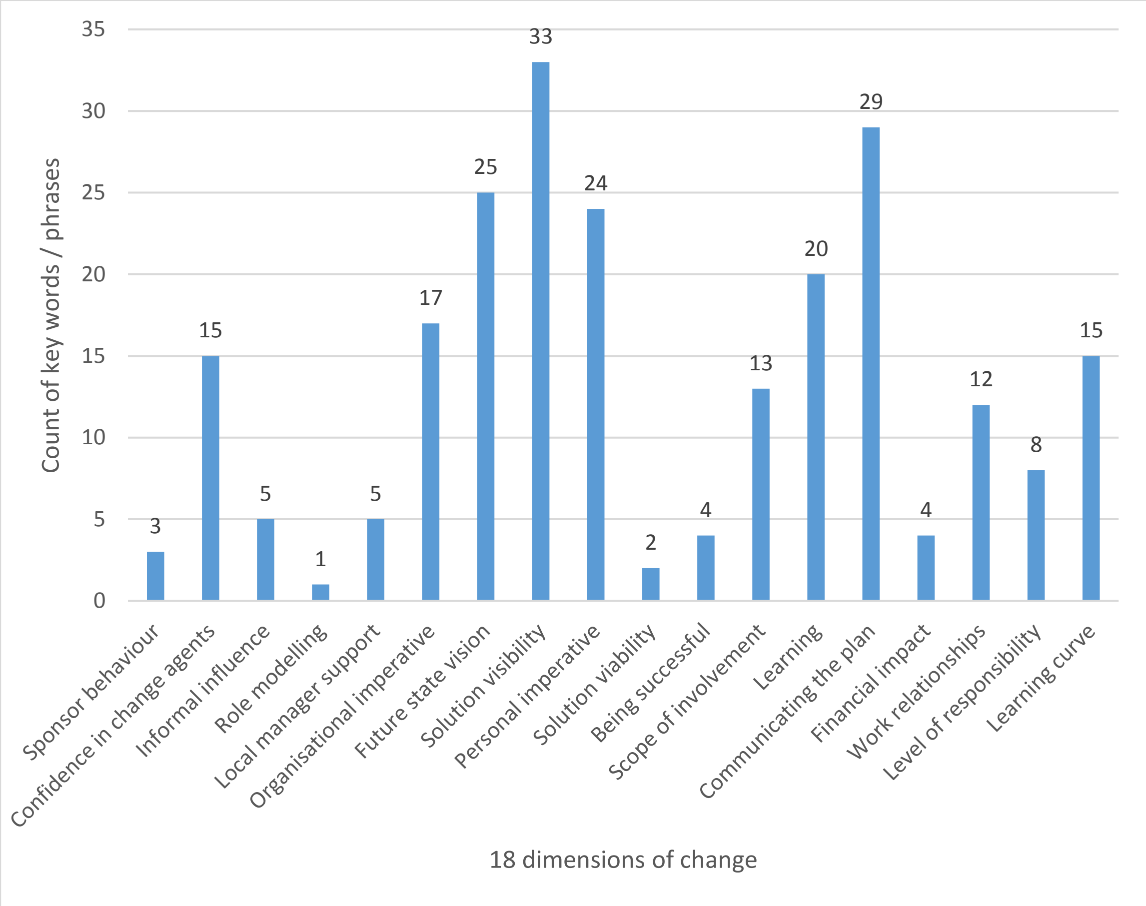


Figure 6.2 – Count of key words / phrases related to the 18 dimensions of implementing successful change programmes

Using the 18 dimensions of change, and their 6 main headings, allowed for an analysis of the various phrases that were coded. This helped identify some of the barriers to success which have affected the BCR and PDSW programmes since their inception. See Table 6.2:

Table 6.2 – Analyses of the interviews which identified a number of barriers to change

Dimension grouping	**Interview responses**
Effective change leadership	10% (no. 23) of the overall responses refer to concerns regarding effective change leadership and the capabilities of the change agents involved. The lack of readiness and capacity to manage change within a complex system of systems was a common feature of the interviews.
Committed local sponsors	Whilst not a significant issue to emerge from the interviews, 3% (no. 6) of the responses flagged the lack of local manager support as a reason for the change programmes to struggle at the implementation stage. Reasons cited included not having the right people with the knowledge to support, or the time / capacity to do so.
Shared change purpose	Of 75 responses related to having a shared sense of purpose around the change programmes, 44% (no. 33) suggested the programmes had been poor at creating a vision for change such that the people involved still did not understand why change was necessary and the part they could play in this. A further 33% (no. 25) said the organisation had not shared where it was trying to get to with its long-term vision, and how it would get there.
Personal connection	30 interview responses included comments regarding insufficient attention paid to the people element of the change programmes, particularly regarding what people do / need to do. This led to discussions around the failure to appreciate how important the change programmes would be to organisational culture.
Engagement processes	More than a quarter of the interviewees said something in their responses specifically about needing better engagement to share the organisational vision and plans.
Sustained performance	39 interview responses refer to a lack of experience in programme governance. Some interviewees acknowledged that the newness of the 'managing successful programmes' process meant that there was always going to be an element of risk in tracking the changes. The term 'steep learning curve' arose in a number of these related discussions.

Detailed below are the views expressed on the BCR and PDSW programmes, based around the key, emerging, issues from the interviews. The headings reflect the dimension groupings or combination thereof given the issues and their similarities, although sometimes slightly re-titled to suit the comments emerging from the analysis.

6.4.1 Views on the effectiveness of the change programmes, and whether having a shared vision is important to change success

Visibility of the objectives of the two national change programmes is important to those likely to be affected. Many interviewees were clear that the intended 'vision' and where the organisation needed to get to should be clearly communicated to afford people the opportunity to commit to the changes (examples included *"wanting people to feel part of the change"*, and *"having a sense of purpose"*).

A third of interviewees recognised that the way to tackle engagement, and involve people to understand the changes, was through more regular communication and reminders of the 'vision' for the national programmes. However, some also said that the change teams did not always appreciate that employees might require different information and training targeted at specific challenges relevant to their organisational level, such as front-line staff implementing new technology for the first time. Several concerns were raised about technology introduction and related behaviours which are further explored as part of Study 3, in Chapter 7.

Two noticeable points were made:

> *"We need to develop solutions [technology, training, processes] that not only simplifies how we plan work, but also how we deliver work. We will not change behaviours if we fail to understand the business areas prior to the design and build phase of the new tools. We need stakeholders within the process to have a proper say. If it's done to them there's no ownership and we go back to doing what they know and trust - which isn't always the right (or safe) thing to do."*
>
> *[Manager 2]*

> *"Increasingly we see colleagues keen to use the new technology available, so this gradual shift in our culture is a good thing, but we don't usually involve those on the frontline early enough – some of whom I think are still technophobes – to understand and appreciate how they might interface with the new systems or use the tools we provide."*
>
> *[Manager 8]*

When specifically asked for their views on the two national change programmes, particularly the effectiveness of these to-date in terms of BCR and PDSW implementation, the interviewees' responses were almost unanimous. Most felt that although there was a genuine intent to improve safety, there was also a desire to realise the safety benefits as quickly as possible, leading to a pace of change that the organisation was not prepared for. The majority of interviewees, given their knowledge of one or both change programmes, felt that the scopes of the national programmes were vast, and required significant changes to underlying processes, organisation, and technologies. Four of those interviewed specifically referred to a lack of the necessary resources or capability to manage or support the changes being put in place. One said:

> *"…..because of how programme managers are selected, usually based on their availability, rather than experience or knowledge of the actual change, we find ourselves facing an uphill battle when it comes to engagement and sharing the vision."*
>
> *[Manager 1]*

The original Network Rail control (standards) framework was discussed with interviewees, and they acknowledged it had evolved over time, mainly in response to accidents and incidents. Many considered the framework to be overly prescriptive in nature, consistent with the legacy culture of the rail industry, and as result it is seen as complex, restrictive, and onerous to comply with. Almost all the 13 interviewees agreed it was right to introduce the BCR programme, but several had serious reservations about the scale of change and the organisation's ability to roll out on such a large scale.

> *"I have 30 years' experience working across most parts of the railway; it is by its very nature a complex structure that is difficult to always grasp / understand, but I have never known anything be attempted on this scale before, and I think we lack proper planning and engagement to get the changes delivered."*
>
> *[Manager 7]*

> *“We have lost a number of years by poor IT solutions, implementation and embedment, so we need to get back to basics. If we can now use a 'discovery' phase to establish what's really needed on the ground then we might just succeed in getting to a point where we can roll out the changes - initially through pilots - and then at scale where we start to see the difference the programme can make in the way work is planned, undertaken, and experienced.”*
>
> *[Manager 8]*

Similar discussions took place regarding the PDSW programme, and every participant said they were frustrated by the lengthy delays and problems with the planning solutions that were initially developed, despite the initial urgency to deliver the changes *“in a big bang”* and *“at pace”*. They welcomed a change in direction, but also acknowledged that there should have been earlier interventions to avoid such waste (time, money, and resources). Many said there was a perceived risk that if any element of the programme failed then the whole programme would be likely to falter.

Overall, it seems that to achieve successful change many of the interviewees felt that each programme should have been developed into specific tranches of work, trialled in specific areas of the business, and then – following a ‘lessons learnt’ review – rolled out further into the organisation. The term *“big bang approach”* was used by several managers to highlight their concern at the scale and scope of the programmes; this phrase has also previously been used during programme boards by others, who were not the selected interviewees, and observed as part of the researcher’s wider study activity.

Some managers and change managers said they felt more time should have been spent at the outset in agreeing the approach to implementation and the ‘change purpose’, including how best to roll out. The change programmes did not consider the impact of both near and distant future activities, or potential disturbances, which led to reactive rather than proactive decisions in the way the programme solutions were sequenced, and then implemented.

That said, positive comments were made about certain elements of the change programmes. Interviewees cited various examples of the approach(es) taken to identify and deliver the different programme solutions, e.g.:

- the development of some of the bow-ties involving subject matter experts to help analyse and demonstrate causal relationships across a range of high-risk scenarios.
- the later revisions to the track worker standard, for planning and delivering safe work, that came about as a direct result of the systems approach taken (i.e. reviewing all recorded areas of non-compliance across all of Network Rail’s Regions, and considering the wider system rather than local context).

The view being that without having adopted methodological (and repeatable) approaches, seeking to understand accountabilities and interfaces as part of the changes being made, the Trades Unions would not have supported the revisions to the work processes or the supporting documentation.

6.4.2 Views on the preparedness for change on those people most affected

Interviewees, when talking about transformation in the context of the two change programmes, mentioned the need for more inclusive communications with end users, and industry stakeholders. Several managers also said they believed a proactive approach to include trade unions is key to the change programmes' success, and they thought better communication of the benefits of the changes could bring dividends through 'visibility' of the intended end state / solution.

Interview participants recognised the part they must play in supporting and cultivating a culture of cooperation, communication, openness, and a greater tolerance of small mistakes through greater employee engagement and less seeking to apportion blame when things do not quite go according to plan. However, some said that the ultimate source for driving the organisational (and safety) culture may lie outside the organisation. Public pressure on Government may focus the minds of rail executives on 'on-time' running, rail fares, and passenger safety; similar pressure might be necessary from the Regulator to generate equivalent attention to workforce safety and risk management.

The inference from the interviews is that adequate planning, training, resources, and system testing are necessary to engage the workforce in the change programmes – but this will take time and money *("not the threat of enforcement action")* that the Regulator could fund to help gain the confidence of end users, and for the change programme benefits to be realised.

Some interviewees particularly felt that far more should have been done to consider the people from the outset who are at the centre of the programme changes, building in some criteria to determine their readiness for change, but also recognising that the way that they carry out tasks, and are motivated to work, may be very different in practice. Consequently, individuals may feel marginalised, or have no real engagement or desire for involvement in the change.

Pertinent to 'preparedness for change' are two quotes: one from a general manager, and one from a change manager.

> *"Network Rail has failed to structure / organise itself in a way to be able to handle constant change. There is a clear cultural resistance to change, so it is always seen in a negative light rather than a force for good."*
>
> *[Manager 1]*
>
> *"It is inevitable in an organisation the size of Network Rail that we will have a number of change programmes running in parallel. Change cannot be managed as simply as deciding to deliver them in 'series', but we need to help 'condition' people for this."*
>
> *[Change Manager 1]*

When questioned about taking a systems approach to change, including the impact on employees affected by change, some interviewees suggested that the programme teams missed the opportunity to synthesise their plans so that their combined impact on individuals and processes could be understood and managed.

When probed further, these interview participants agreed that this meant the organisation was not easily adaptive (or 'dynamic') because there was a lack of understanding on what people 'do' in practice, and how this might have needed to change.

Examples of how this synthesis might be achieved in future were discussed with the interviewees, and they referred to things like the need for workload assessments, technical and behavioural based training. One said:

> *"We need to explain why change is a necessity, but as part of that we also need to understand why our teams think things should remain the way they are. If we know both sides of the 'argument' then we can make informed choices. At some point we have to agree to the same goals or we miss the chance to make a positive difference, else we get yet another stalemate and what people 'do' is not necessarily what we want 'done'."*

[Manager 4]

6.4.3 Views on leadership, and how this can influence organisational readiness for change

The lack of organisational readiness and capacity to manage change within a complex system of systems was a common feature of the interviews. The comments captured during the interviews seem to suggest that whilst the 'case for change' has been spelt out for the two programmes, many interviewees believe the challenges ahead will depend on the abilities of the organisation to lead the business and its people through change, in a complex industry, and to have the necessary tools and training in place before programmes are implemented.

Some interviewees, following questioning around the role of rules and procedures as part of the intended changes, discussed the culture of the organisation and the rationale for implementing the change programmes such that *"risk-awareness among employees would be further encouraged"*. This has resonance with the work of Hopkins (2005), and the view that it is impossible to devise a set of safety rules which adequately covers every situation, but that rules are still essential and so must be *managed* (i.e. kept up to date, reviewed regularly etc.) in a dynamic industry.

When asked about the intended safety improvements to come from the change programmes, many of the interviewees were clear that workforce safety was at the heart of these. Those with a detailed understanding of the BCR programme said:

"…..the ambition is that there are clearly defined parameters (and rules) around risk-based decision making, and the way work is planned and delivered."

[Manager 1]

"Setting critical-limits and being transparent on what is mandatory in line with control documentation should help make the boundaries clearer."

[Change Manager 4]

The interviews went on to cover how Network Rail leaders and managers talk about expectations around safety, reliability, and efficiency, often requiring stability, yet operating in a dynamic industry requiring flexibility when it comes to new ideas and innovation or dealing with perturbations or unforeseen events. They talked about things like *"the sustainability agenda"* and *"new technology introduction",* but also how this affects industry processes and practices, and the balance required between further prescription versus autonomy as these are rolled out. The point being made here, at least by some, is that organisational coordination seems to better suit stability demands, whereas personal coordination and autonomy helps to create flexibility and the move away from a reliance on highly routinised work processes, such as maintenance of assets or signalling of trains.

Among many, related, things discussed was the intention to have far greater autonomy at a local level (perforce, allowing for more flexible work routines [Grote, 2015]). The interviewees concerns were, however, with training, and the fact that people are not 'drilled' to apply the appropriate rules and procedures until they are second nature. Some managers said they would clearly prefer a move away from a more stable, rigid approach, but stability (fixed rules and processes) continues to have influence over more flexible approaches for fear of failure (loss of control).

What the interviews highlighted is that whilst some managers believe the changes have clearly empowered the workforce to make risk-based decisions at the lower level, and that the change programmes have provided tools and capacity for this, there are contrary views too. Some suggest that 'change' and 'business as usual' are expected to be handled in the same way by very busy people, and so individuals are conflicted by workload and priorities. Several felt that change leadership was essential here. One manager said:

> *"For change to work Network Rail has to decide who the key decision makers are; the military approach (leadership and management, or command and staff as more commonly known) means that people are developed for their capability but are not given roles without the prerequisite experience and competence to 'step up'……Commitment to change at a local level needs line manager support and role modelling."*
>
> *[Manager 1]*

6.4.4 Views on programme governance to deliver sustained performance

Of the 13 interviews undertaken, many of the participants suggested that Network Rail had been so determined in the early days of the change programmes to get them implemented that some fundamentals were missed, and the lack of programme governance at times played a significant part in this. Examples cited by Managers and Change Managers included the lack of a collaborative approach in developing improved processes – that could have been coordinated through programme sponsors – resulting in different asset groups doing their own thing, and technology introduction very belatedly involved the end-users, thus decreasing the chances of successful delivery.

Four managers specifically acknowledged that these 'bumps' along the way, whilst not having an immediate detriment to safety, meant that the two major change programmes have not delivered on their intended outcomes. Three of these four interview participants thought these failings should have been identified sooner through better governance and tracking but one did also say that the organisation [when it realised there were problems] was prepared to pause the change programmes, critically evaluate the lessons learnt, and re-design processes as necessary.

Finally, when questioned about sustaining performance during or as part of the programme changes – and whether this be financial, or safety, or operational performance – some of the more senior managers were keen to emphasise that Network Rail and its employees work hard to provide a safe, reliable, railway. One saying:

"….our people do the most adapting, often despite the clarity of objectives or culture that is required for change to be as effective as it could be".

[Manager 5]

6.5 Discussion

From the interviews, viewed through the 'lens' of the two major change programmes, it is apparent that the inter-connectedness of human actions, decisions, and technological factors as part of an overall 'systems approach' to change is largely understood. However, it was also identified that:

- There is a need in Network Rail for a greater emphasis on considering both the socio- and technical- aspects of change, particularly with participative initiatives that involve the frontline staff in decision making, so that programmes are well designed and implemented (aligned to Rasmussen's (1997) view of 'capability' and the parameters sensitive to control of performance in a changing environment).
- There is a need in Network Rail to focus on the effective management of change if programmes are to be successful, such as communicating plans and reasons for change, and developing new processes that have clear accountabilities. This is analogous to Clegg's (2000) work around system ownership by managers and their users, particularly the enabling of local 'experts' to help problem-solve and adapt systems appropriately, through their congruence of the system, task perspectives, and an understanding of organisational goals. Rasmussen's earlier work (1997) also talks about the importance of information being available to decision-makers, i.e. 'status information' and whether the boundaries of acceptable performance around the programme's 'future state' are visible.

Review of the literature suggests that, had a more systemic approach been used by Network Rail (for example, Clegg's nineteen principles related to the socio-technical system approach (Clegg, 2000), then the inter-connectedness (i.e. interactions, dependencies and potential conflicts) of the change programmes might have been better understood, and mitigated, before each phase of 'go live'. Clegg recognised that many organisations lack an integrated approach to change, and he developed his principles to be used alongside other methods and tools such as accident analysis and investigation.

The literature also suggests success can be brought about when organisations (and their people) are resilient, such that they adapt to and cope with variations, changes, conflicts, and disruptions – especially things that fall outside of the set of disturbances the system is designed to handle (Rasmussen, 1990; Weick *et al*., 1999; Hollnagel and Woods, 2005). The study results go on to show that Network Rail sought to implement the two major change programmes whilst considering a host of complex systems and processes as part of the two national change programmes; notably new technologies for e-permitting and planning work, and revised standards for safe working. They had to factor in how people and the things they do affect others, the tools and equipment needed to undertake work, job design, and decision-making authorities, but they did not necessarily do this in a systemic way. They would have needed to spend more time in identifying all the processes and practices, and people, likely to be most affected by the change and then ensured that there was the capacity or capability to change at pace. Instead, they focused on 'big ticket' items and missed the opportunity to provide conditions where there are no surprises and no time pressures to deliver sustainable performance.

Comments, related to questioning around goals, demonstrate to a large degree a real desire for improvement from a position where performance, in terms of safety, and operationally, still falls short of Network Rail's ambitions, particularly true of workforce safety. There is clearly an emphasis that Network Rail's transformation plans around decentralisation require a focus on taking decisions faster, thereby requiring as much effort on developing the right kind of culture and behaviours in the organisation as the technological and process factors that have previously held sway.

Study 1, through its findings on the complex rail socio technical system, and the necessary trade-offs required to operate within a complex regulatory framework, revealed that those in the GB Rail industry must continuously adjust the balance between stability and flexibility to secure successful performance. The interviews as part of this second study went on to uncover numerous examples of the change programmes being launched, paused, restarted, reprogrammed, and yet the impact on these changing demands on human actions (teams and individuals) was addressed belatedly rather than proactively, and without appropriate coordination mechanisms across the two national change programmes.

The findings of study 2 expose how difficult getting the right balance between stability and flexibility can be in practice. This is because stability comes from Network Rail and its leaders routinely talking about reliability and efficiency, and operating in a highly regulated industry, yet with the demands of being a dynamic organisation requiring flexibility when it comes to innovation or dealing with uncertain situations (like new or untried technology introduction).

Perhaps the work of Grudela Grote might help here (Grote, 2015), who concluded that when uncertainties are managed well, a basic prerequisite for good risk management is established, i.e. it is important to get the right balance between stability and flexibility, while matching control and accountability of those involved. Switching modes and being adaptable may be required in certain conditions (Grote *et al*, 2009).

There would be value to Network Rail if it were to undertake an evaluation of reducing, maintaining, or increasing uncertainty during the various (remaining) phases of the change programmes. For example, related to revised work processes, a routine track maintenance task (high stability, low flexibility) might be followed by having to deal with an emergency such as a train derailment (high stability, high flexibility). Consideration should be given as to how these uncertainties are managed and executed as part of the changes, and the systems approach thereby required.

6.6 Study limitations

Given the significance of the changes being brought about, and the pace of change apparent in the timescales for implementing the two major change programmes, it was important that further research was undertaken to provide Network Rail with a timely perspective on the state of implementation, as part of building assurance that the actions they are taking are appropriate and likely to deliver the intended benefits. A limitation of this study (study two) was that it only included the perspectives of Executives, Senior and Middle Managers, including some change practitioners. This limitation was addressed in study three (Chapter 7) in which a survey was conducted with frontline staff to help assess the change practices in Network Rail. This meant questioning around the impact of the Business-Critical Rules programme, and planning and delivering safe work programme, on safety and operational performance. The purpose was that the learning from the two major change programmes can be considered when setting up and implementing further changes so the intended culture is achieved, and systems are effective.

6.7 Conclusions

Study 2 investigated the extent to which the inter-connectedness of human actions, decisions, and technological factors as part of an overall ‘systems approach’ to change is understood in Network Rail and its supply chain, and applied to programme change. It also explored whether decision-makers in Network Rail are aware of systemic influences in the BCR and PDSW national change programmes; the interviews focused on how these programmes have been designed and implemented to transform worker safety across Great Britain’s railways. The study reflects how the programmes have changed since they were first introduced – including their various pauses, reprogramming, revisions to work processes, and new technologies – and identifies the factors that have significantly influenced this.

Examples of a systems approach in some elements of the two national change programmes were cited by interviewees as being considered ‘good practice’ given their procedural approach and consideration of the wider aspects of change than purely the technical solution, e.g. the development of the bow tie approach as part of the BCR programme involving subject matter experts, and the later revisions to the track worker standard informed by a rail systems view across all levels rather than a local perspective.

What could not be demonstrated – following questioning – was a jointly optimised (be it technical, social, and/or economic), and necessarily dynamic, (Hollnagel and Woods, 2005) system, developed for both the BCR and PDSW programmes. Whilst the need for managing the inter-connectedness of human actions, decisions, and technological factors was largely understood, the realities of this in practice, and the efficiency-thoroughness trade-off espoused by Hollnagel (2009b), proves difficult when there aren't perfectly controlled situations, and where disturbances and perturbations are minimal.

Interviewees suggested many competing real-world pressures and, without the luxury of starting afresh in terms of the design of work processes, they had to work with what they had. To resolve this, some recognised the need to consider the railway as a system, i.e. as a whole, not individual parts, to help keep the entire organisation (regulators, management, and the workforce) engaged in change across all levels, albeit with them operating in an industry still fraught with hazards, trade-offs, and multiple goals (Rasmussen, 1997). Some interviewees suggested that continuing to revise or reframe processes simply led to stale or narrow system changes; they said that what was needed was a continual effort to create and sustain effective change strategies, anticipating potential issues long before they arise, especially what is needed for things to go well and for performance to be effective across the system (Hollnagel, 2012).

Finally, there are clear parallels between the two major change programmes and their intended outcomes that the interviews identified (e.g. simplifying standards, improving workforce safety, maturing the safety culture of the organisation), but there are other related programmes too within Network Rail, such as the track worker safety taskforce, and so the challenge remains of:

- whether there may be contradictions in intended outcomes of multiple change programmes;
- a lack of a clear strategy and detail regarding implementation of potentially overlapping change programmes, and the inadvertent problem of creating 'risk transfer' from one part of the system to another (e.g. in introducing new technologies for planning work that in turn reduces the risk of lookouts operating without protection, but instead increases the workload and possible fatigue of the signaller having to deal with the rise in requests for track possessions).
- limited understanding of the impact on Network Rail's maintenance teams, and what support might be required pre- and post- implementation to those affected by the changes.

Opportunities exist for further research to understand how Network Rail's wider programme commitments could be better coordinated, and how adopting a more holistic view of the complex system, and applying systems-thinking to this, might bring greater success for organisational change (e.g. further decentralisation) and the revision of work processes (e.g. track worker safety).

Some of the available literature helpfully suggests careful examination of the communication flows, and decision-making authority and interfaces between system layers, is required (Waterson *et al*, 2015), and that practical advice and support for practitioners is needed for those wanting to use socio-technical system approaches to improve the workplace (Waterson, 2015). These points are, therefore, considered further as part of Study 5 (see Chapter 9), around organisational learning and the development of a framework to support a systems approach to safety-driven design.

7. Study 3 – To investigate the perceptions of frontline staff on policy and processes intended to improve workforce safety

7.1 Chapter overview

This research has sought to investigate the perceptions of frontline staff on policy and processes intended to improve workforce safety, related to the Business-Critical Rules (BCR) and Planning and Delivering Safe Work (PDSW) programmes (referred to in Chapter 2, para. 2.3).

The study focuses on a survey of more than 1000 frontline (mostly maintenance) staff, consulting them on how the two national change programmes have aided the transformation of workforce safety, at a local level within Network Rail and its supply chain[37]. The work has been supported by a longitudinal (observational) study that has tracked the BCR and PDSW change programme's progress over time; see Study 5 (Chapter 9).

This chapter explains the methods used to gather the views of frontline personnel, and to integrate these with best practice ideas identified in the array of literature available. Survey participants were asked for their perceptions on the practical application of technologies introduced by the two change programmes; these are employees who were identified as being best placed to have an appreciation for the demands of implementing change within a complex work system on the frontline. The research explores how 'work as imagined' in the formal rules and procedures applicable to the two national change programmes has been interpreted, as well as the 'work as done' during technology introduction, and maintenance regime change (see Hollnagel *et al*, 2006; 2013).

The questionnaire was designed to investigate the perceptions of frontline staff on policy and processes, including how things have changed (e.g. technology, processes, work practices, safety and performance) for frontline staff over time since the two national programmes were first introduced. The study reports on the possible implications of the pace of change and the challenges of user-influenced design in the context of a railway system where there are rapidly evolving technologies, and a need to consider the skills workers will need to engage with them. The study chapter concludes by acknowledging the difficulties to date in bringing about the intended organisational, process, and safety-related changes envisaged, and highlights how the research brings awareness to real-world situations that businesses face, and where the human factors/ergonomics field can help.

7.2 Introduction

High-quality engineering and operations management has been described as *"….key to meeting all the requirements of a successful railway – quality of service, reliable and safe performance, and maximum possible use of capacity"* (Wilson *et al*, 2007). Wilson and his co-authors describe the railway as a socio-technical system and that human factors are at its core, thus requiring a strong integrated ergonomics contribution.

[37] Note the survey reports on perceptions of staff behaviour which, it is acknowledged, may be different to actual behaviour.

This study sought to address organisational needs with respect to managing changes to technological systems and processes to improve workforce safety in a complex rail industry, considering the cognitive and social elements of the system.

The researcher has previously identified important components of the GB Rail socio-technical system as part of Study 1 (Chapter 5), and investigated the extent to which a 'systems approach' to change is in evidence as part of study 2 (Chapter 6).

This third study goes further, to the heart of the socio-technical system, and particularly the social system around people, the tasks they undertake, and the way in which they perceive that change programme introduction has contributed to improving their safety.

The overall aim of this third study has been to investigate the perceptions of frontline staff on policy and processes intended to improve workforce safety. This study has included a survey of frontline staff tasked with implementing or impacted by two national change programmes (involving the simplification of rules (known as the Business-Critical Rules framework) and implementing revised processes for planning and delivering safe work (PDSW). The views of four distinct groups of frontline staff were captured through a questionnaire designed specifically for the survey work, which has helped with understanding the workflows, interactions, and interdependencies of the two change programmes.

The two selected national change programmes have far-reaching implications for the way work is planned and undertaken on GB rail infrastructure. The systems described as part of the programme changes are there to govern, approve and manage around 100,000 maintenance plans per month, requiring the checking of competence and qualification of the colleagues undertaking the work, and the risk assessment of the location and the work taking place.

Of note, is that the survey work was carried out during the process of change implementation, and before Network Rail had finalised extensive changes to its overall structure, albeit decentralisation and the move from a national to a regional level within Network Rail had started, and some phases of the programmes had already been rolled out, like technology introduction, and revised worksite protection arrangements and briefings.

We know from the work of Baxter and Sommerville (2011) that socio-technical system design (STSD) requires consideration of human, social, technical, and organisational factors when designing organisational systems, and that these aspects are better considered all together than separately. It would be true to say that studies 1 and 2 (see Chapters 5 and 6) showed some signs of this approach for the two national change programmes, during complex, dynamic change, and what this might mean regarding delivering successful change.

Findings from the research are summarised on the challenges identified in implementing the two national change programmes, with the study focusing on frontline staff perceptions around policy and process changes, particularly revisions to Standards, their levels of autonomy, and what the tools (e.g. means of control documents) and systems (e.g. e-permitting, planning pack production) have done to help improve workforce safety.

7.3 Methods

To capture respondents' attitudes and/or views, a questionnaire was developed for a survey, to support the investigation of the perceptions of frontline staff on policy and processes intended to improve workforce safety, viewed through the 'lens' of two specific Network Rail change programmes.

7.3.1 Questionnaire development and administration process

The following flowchart (see Figure 7.1) sets out the various steps in the process to construct and administer a questionnaire for the survey of frontline staff.

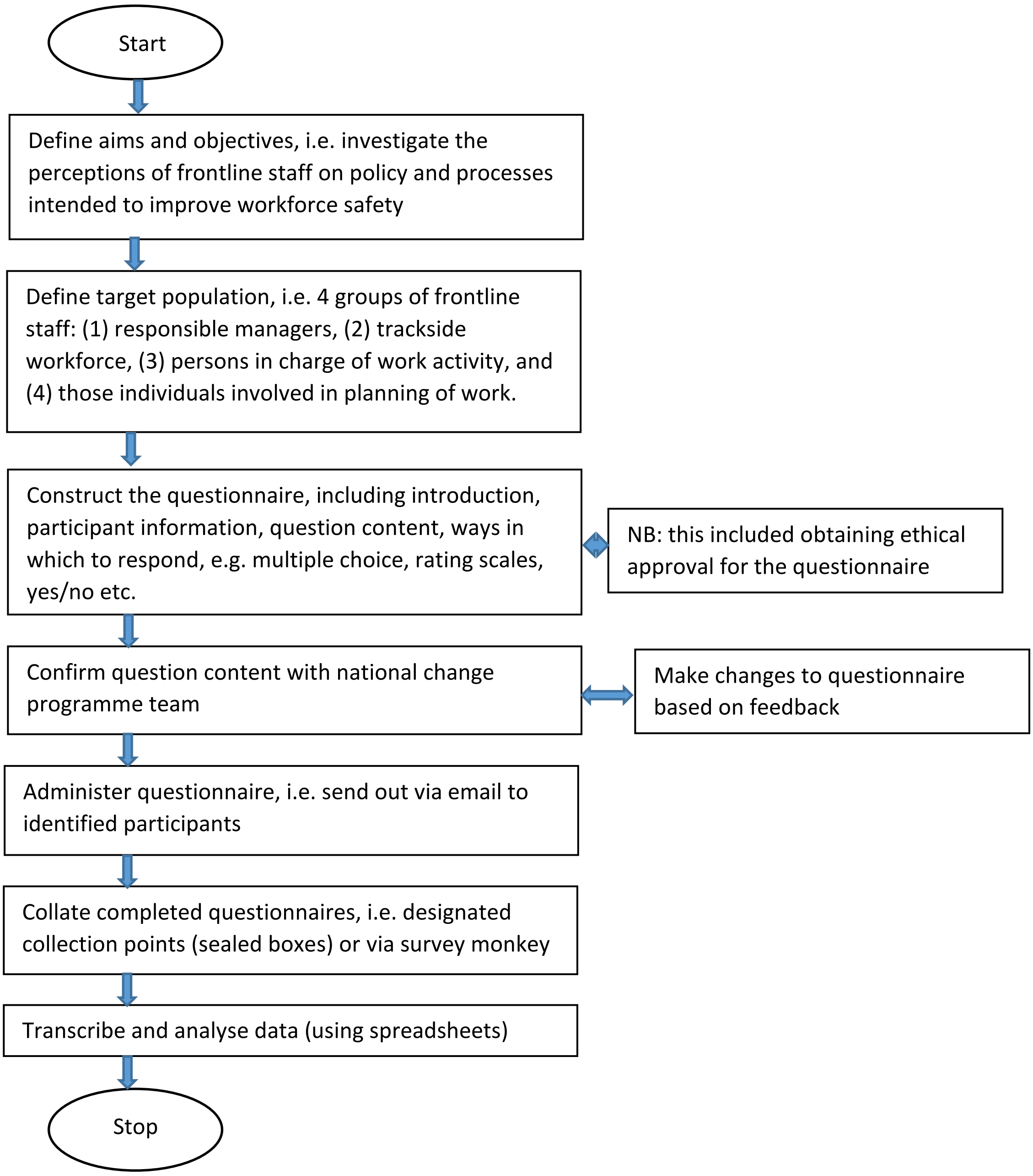


Figure 7.1 – Flowchart of the process for questionnaire development and administration

Some of the early work undertaken for the previous studies (Study 1 (Chapter 5) and Study 2 (Chapter 6)) provided an insight into the different functions and responsibilities – across track maintenance and construction project teams, and organisational levels – and was helpful in identifying potential survey participant groups, so that different perspectives could be gathered from those in the rail industry operating at the 'sharp end' in frontline roles.

7.3.1.1 Sampling, and participants

A questionnaire was developed and the survey work undertaken over a one-month period during 2018 with 4 groups of frontline staff: (1) responsible managers involved in ensuring the delivery of safe work (but **not** on the worksite), (2) the workforce involved in the execution of tasks on the rail infrastructure, (3) persons in charge of activity (individuals responsible for overseeing work on worksites), and (4) those individuals involved in the planning of work. The number of responses totalled 1355, having been sent to c. 3000 frontline staff across the 4 groups and reflects c. 4.5% of the national workforce involved in planning and/or delivering safe work in a 'normal' week (noting very high peaks in workload come over bank holidays and weekends, which the researcher chose to avoid).

There are more than 30,000 staff who might be considered 'frontline', including many in Network Rail's supply chain who are employees of those involved with 'projects'. The groups were purposefully selected for the survey to represent the four main areas of frontline (maintenance and construction) activity, i.e. managers, workforce, persons in charge and planners – and the ambition was to sample c. 10% across the overall population (i.e. 3000 staff), anticipating approximately half of that in replies (i.e. 1500 responses).

For this study, the researcher was able to use employee records – focused on job roles – and randomly selected 10% of each group to be targeted.

No attempt has been made to identify whether the participant group is a totally representative sample of their actual numbers, e.g. the 361 'workforce' participants who responded (out of the 1355 overall survey participants) are c. 2% of the total frontline staff employed in GB rail; this is because some participants may fulfil more than one role depending on their employer and workload. It is possible that questionnaires were completed by one individual but for two different groups due to the nature of their role(s) or are recorded as fulfilling two roles in employee listings but chose to only complete one response for one of their roles. An example is a responsible manager who may, on occasion, also undertake the role of a person in charge. In such instances, they were asked to respond according to the role they were completing the questionnaire for, i.e. one as a responsible manager, and one for a Person in Charge (PIC). The resulting returns were analysed statistically and across themes, and are reported further on in the chapter, below.

7.3.1.2 Survey distribution

The survey involved the use of a questionnaire, requiring self-completion. Respondents were asked to fill in the answers by themselves, or print off and complete, then return anonymously via an agreed collection point (sealed box), thus permitting large samples to be reached with relatively little effort.

The survey participants were approached directly via email with a link to an online 'survey monkey' questionnaire (also printable), and the responses were collated from those willing to participate and give feedback. The responses were not identifiable to them as individuals, only in their work group domain, e.g. responsible manager, planner etc.

Approval for the study was provided by the University of Nottingham's Faculty of Engineering Research Ethics Committee (UofN, FoE) in early 2018.

The survey consisted of a total of 36 questions. The question allocation to participants, the number of returns by each group, the % of replies vs target, and the percentage (%) of replies with supporting comments, is summarised in Table 7.1 below.

Table 7.1 – Breakdown of the participant group, reflecting question distribution, number of responses and the percentage (%) returned with supporting comments

Participant group	**Targeted questions (no.**	**Responses (no.)**	**% replies of population (target = 10%)**	**% replies with supporting comments**
(1) ***responsible managers*** involved in ensuring the delivery of safe work	7	285 of c. 3500 total population	8%	(174) 61%
(2) the ***workforce*** involved in the execution of tasks on the rail infrastructure	8	361 of c. 18,500 total population	2%	(136) 38%
(3) ***persons in charge of activity*** (individuals responsible for overseeing work on the worksites)	12	508 of c. 6000 total population	8.5%	(128) 25%
(4) those individuals involved in the ***planning*** of the work	9	201 of c. 2000 total population	10%	(153) 76%
Total	36	1355 of c. 30,000 total population	4.5%	(591) 44%

Consideration was given to how best to administer the questionnaire responses and the technology to be used for data collection, storage, and analyses. Thought was given to whether a 'single solution' was viable when some employees may not have ready access to IT systems and/or might prefer to respond in hard copy rather than using a tool like 'survey monkey'. Similarly, thought was given to question content, wording, and any rating scales or scoring ranges to be used.

7.3.1.3 Questionnaire development and content

The two national change programmes, affecting the frontline workforce, were used to frame the questions in the questionnaire for the survey work. It was assumed individuals would not be familiar with academic concepts and terminology (e.g. a socio-technical system, control structures etc.).

Therefore, questions were phrased using general terminology and concepts familiar to those in the rail industry (e.g. planning of safe work, responsibilities, Standards, briefings, compliance / non-compliance).

The questionnaire sent to survey frontline staff was developed jointly between the researcher and the Network Rail change team responsible for the planning and delivering safe work programme; they too had wanted to understand how the two national change programmes were 'landing' with frontline staff.

The researcher wanted to develop questions associated with the social and technical considerations of the change programmes. She was keen to understand frontline staff perceptions of these issues, particularly around the effects on workload and safe work pack production[38]. It was agreed with the change team that the researcher would write the bulk of the questions that they could then add to. Table 7.2 reflects the combined efforts to produce the questionnaire; the change team were keen to include questions 4, 5 and 6 for the workforce (highlighted for ease of reference), related to briefings and welfare facilities, all others were developed by the researcher.

Of the 36 questions posed, some were repeated across more than one participant groups (not the 'workforce' group though), for example around safe work packs and how often these are produced and authorised each week for cyclical work, non-cyclical work, or repeat work[39], and to get a feel for the different roles involved, and their respective volumes of work.

The questionnaire was developed whilst mindful that questions can be open or closed, or offer respondents multiple choices, or to choose a statement that mostly nearly describes their response to a statement or item.

Each of the four sets of questions that were designed to take cognisance of the specific role type, i.e. relevant to the tasks within the assigned participant group, and as related to the change programmes and organisational requirements.

[38] A safe work pack (SWP) provides information on how work is to be carried out safely and gives details on how to manage and control task, site, and operational risks. It is intended that it enables effective management and implementation of controls for the safety of people involved, or who might be affected by the work activities on or near the line, or which might affect the line. SWP refers to the documentation provided to the 'person in charge' (PIC) for the work they are to undertake; the pack is produced by a planner to provide clear information to allow the PIC to effectively use it to manage the risks to themselves and those working under their supervision.

[39] Cyclical, Non-Cyclical and Repeat work are all terms used by Network Rail to describe tasks planned for and undertaken , i.e. a cyclical maintenance task is an inspection or maintenance task which is performed to a frequency schedule specified in Network Rail standards. A Non-Cyclical Maintenance Task is a 'one off' work activity arising from an inspection, incident, fault or failure. Repeat work packs are for an activity that requires the same work activity to be undertaken more than once at the same location (e.g. multiple concurrent shifts within a track blockade or repeated visits) but not a frequency contained within a Network Rail standard.

Table 7.2 lists the questions used in the survey per participant group, and the types of answer choices available. The final column in the table explains why particular question types have been included, providing a rationale for the focus of the questions for each of the roles. For example, questions for the responsible manager are about workload and factors affecting this. These questions were designed to elicit their perceptions of how this is achieved since the revisions to Network Rail Standard '019'[40] were introduced. This is because changes to policy and processes under the two national change programmes were likely to increase the amount of paperwork the responsible manager would be seeing and having to approve. The survey sought to understand the scale and nature of this. Similarly, planners have responsibility for planning safe work and the production of safe work packs (SWP)[41]. The questions developed for them to respond to also focused on revisions to Standard '019' and workload, but also sought to understand if they were ably supported during periods of sickness or absence, or if they were expected to fulfil other roles in addition to their planner position.

As can be seen in Table 7.2, question response types varied, from simple yes / no responses to multiple options, Likert scale, or to give a scoring range when asked about a frequency of an activity in a typical week (0-25 plans signed, through to 100+ plans signed). Free-form text could be added, which further encouraged comments / reasons for responses given.

[40] Network Rail Standard '019' is the procedure related to the safety of people at work on or near the (railway) line.

[41] A safe work pack (SWP) provides information on how work is to be carried out safely and gives details on how to manage and control task, site, and operational risks. It is intended that it enables effective management and implementation of controls for the safety of people involved, or who might be affected by the work activities on or near the line, or which might affect the line. SWP refers to the documentation provided to the 'person in charge' (PIC) for the work they are to undertake; the pack is produced by a planner to provide clear information to allow the PIC to effectively use it to manage the risks to themselves and those working under their supervision.

Table 7.2 – Questions designed per participant group, and the response options available

Responsible Manager	Answer choices	Rationale for the question selection
1. Since the revised 019 standard came in have you had any challenges with your team's workload?	Strongly Agree / Agree / Neither Agree or Disagree / Disagree / Strongly Disagree	Changes to policy and processes under the two national change programmes were likely to increase the amount of paperwork the responsible manager would be seeing and having to approve, and thus it was important to understand the impact on their workload (i.e. the scale and nature of this)
2. Please quantify your additional workload	0%-19% / 20%-39% / 40%-59% / 60%-79% / 80%+	
3. What areas are causing the increase in the workload? - multiple answers can be given	Deconfliction / SWP Production / SWP verification / PIC involvement / Other (please specify)	
4. Have you considered any ways to reduce the workload, e.g. stopping doing other tasks, reducing the number of non-cyclical packs or implementing a LEAN project?	Yes / No / Other (please specify)	
5. On an average how many cyclical, repeat and non-cyclical safe work packs do you authorise on a weekly basis? Please enter the range.	0-24 / 25-49 / 50-74 / 75-99 / 100+	
6. To what extent do you feel your team are complying with the revised 019 v9 standard?	Fully / Partly / Not at all	To understand levels of compliance to the revised policy and processes – and potential reasons for non-compliance
7. Please mention any areas of non-compliance - multiple answers can be given	Pack Verification / Return and storing of SWPs / Review of returned packs / Other (please specify)	
Workforce	**Answer choices**	
1. Do you feel the revised safe work pack contains adequate details for you to feel safe on or near the line?	Yes / No / If No, do you feel confident your challenge would be accepted positively?	Changes to policy and processes under the two national change programmes meant a new approach to developing safe work packs and briefing of these when carry out tasks on the railway tracks; it was important to understand the perceptions of the workforce on the adequacy of the details provided by the change in approach
2. Do you feel the revised safe work pack contains adequate details for you to carry out your tasks safely?	Yes / No / Other (please specify)	
3. How often do you question the brief given to you by the PIC?	Never or Seldom / Often / Majority of the time / All the time	
4. How often does the PIC ask questions on the brief to you to confirm understanding of the contents?	Never or Seldom / Often / Majority of the time / All the time	These questions seek to understand how the national change programmes were 'landing' with frontline staff and the effect on safety behaviours, i.e. the impact of the revised track access standard since its publication, and the extent to which briefings had been undertaken and been considered effective
5. How often does the brief include risks not relevant to the work?	Never or Seldom / Often / Majority of the time / All the time	
6. How often does the brief include information about the welfare facilities?	Never or Seldom / Often / Majority of the time / All the time	
7. Have you seen an improvement in the method of working on or near the line (protection rather than warning)?	Yes / Stayed the same / No	Per 1 to 3 above
8. Which part of the safety brief do you think has improved the most?	Operational brief / Task Brief / None / Other (please specify)	Per 4 to 6 above

Key: questions required by Network Rail's change team responsible for the planning and delivering safe work programme

Person In Charge (PIC)	Answer choices	Rationale for the question selection
1. How often are you involved in the planning of the work that you are delivering?	Never or Seldom / Often / Majority of the time / All the time (please offer how it could also improve)	The researcher wanted to develop questions associated with the social and technical considerations of the change programmes, particularly the job changes for the person in charge, and the introduction of new interactions and work processes for safe work pack development, including changes to the briefings on site
2. Do you feel the safe work pack contains adequate details for you to brief your workforce to the best of your ability	Yes / No / If No, please specify	
3. How often do you receive a safe work pack at least a shift in advance?	Never or Seldom / Often / Majority of the time / All the time	
4. How often do you brief the specific site risks and tasks risks to your team?	Never or Seldom / Often / Majority of the time / All the time	
5. How often does your safe work pack contains any risks that is not relevant to the work?	Never or Seldom / Often / Majority of the time / All the time	
6. How often does your safe work pack contain the generic risks not relevant to the work?	Never or Seldom / Often / Majority of the time / All the time	
7. When handing back the site of work, who verifies that tools, equipment and personnel are safely removed and makes sure that the line is clear for safe passage of trains?	Signaller / PICOP / ES / PIC / SW Leader / COSS / Workforce / Other (please specify)	This is about understanding job roles since the process revisions were introduced and to ascertain if these were being followed
8. How comfortable would you be to verify a safe work pack electronically using a Network Rail computer / Ipad / tablet?	Confident / Confident after training / Paper-based safe work pack remains preference / Other (please specify)	Changes to policy and processes under the two national change programmes were going to lead to a change in work practice for the PIC, including the use of new technologies to plan work, and to check and verify safe work packs, hance these questions to understand the scale and nature of the change in practice
9. Since the revised 019 standard came in have you had any challenges with your workload?	Yes / No / If Yes, please specify	
10. On an average how many safe work packs do you verify each week? Please enter the range.	0 / 1-4 / 5-9 / 10-19 / 20+	
11. On an average how many complex safe work packs do you verify each week? Please enter the range.	0 / 1-4 / 5-9 / 10-19 / 20+	
12. When undertaking any work on or near the line who verifies that the work has been carried out in accordance with the relevant standards	Signaller / PICOP / ES / PIC / SW Leader / COSS / Workforce / Other (please specify)	This is about understanding job roles since the process revisions were introduced and to ascertain if these were being followed

Planner	**Answer choices**	**Rationale for the question selection**
1. Since the revised 019 standard came in have you had any challenges with your workload?	Yes / No / If No, please specify	Changes to policy and processes under the two national change programmes were likely to increase the amount of paperwork the planner would be producing, and thus it was important to understand the impact on their workload (i.e. the scale and nature of this)
2. Please quantify your additional workload	0%-19% / 20%-39% / 40%-59% / 60%-79% / 80%+	
3. What areas are causing the increase in the workload?	Deconfliction / SWP Production / SWP verification / PIC involvement / Other (please specify)	
4. Have you considered any ways to reduce the workload, e.g. stopping doing other tasks, reducing the number of non-cyclical packs or implementing a LEAN project?	Yes / No / Other (please specify)	
5. Do you produce all safe work packs for your section?	Yes / No / Other (please specify)	
6. On an average how many cyclical, repeat and non-cyclical safe work packs do you authorise on a weekly basis? Please enter the range.	0-24 / 25-49 / 50-74 / 75-99 / 100+	
7. Do you have cover for your annual leave, sickness etc.?	Yes / No / Partially	Given the likely increase in workload for the planner it was considered important to understand how their work was covered during periods of absence and if this brought about other pressures or a call to undertake other duties too given their skillset
8. Do you undertake other duties in addition to the role as planner?	Yes / No / If Yes, please specify	
9. As a planner, what percentage of PICs within your group do you feel would be able to use an IT based solution?	0%-19% / 20%-39% / 40%-59% / 60%-79% / 80%+	This was about capturing the 'confidence' levels of planners in their PICs, particularly the use of the new technologies introduced under the revised policy and processes

7.3.2 Method of analysis

Survey questions and answers, including free-form text, were entered into an excel spreadsheet, after the questionnaires were completed and returned by post, or were copied across from the 'survey monkey' system in a usable format.

The analyses work included details of the whole sample size, and analysis broken down by work groups (e.g. planner), geographical locations (e.g. 'x' Region), and business function (e.g. signalling maintenance). All answers were entered into the excel spreadsheet and functions were added to perform descriptive statistical analyses including frequency counts of question responses. Analysis was undertaken across the 36 questions, using the 1355 responses to generate a series of tables. The tables capture – per participant group – the percentage of answers to yes / no questions, and the comments connected to questions where choices were given, e.g. to mention a specific area of non-compliance such as returning and storing of all used safe work packs.

There were 591 separate comments offered; the majority being in relation to the questions put to the participants regarding: (a) the changes they perceive that have come about since Standard '019' was revised (including communications regarding the changes, end-user input to the Standard, and resulting technology introduction), (b) workload, (c) briefing content, and (d) safe work packs. These key words / phrases were captured in a spreadsheet with each one attributable to their participant group, and assigned to one of five main themes.

The main themes were developed to capture participant responses around social systems, system users, technical systems, systems integration, and future technology in a complex environment (akin to the Bostrom and Heinen (1977) model) – see Figure 7.2 below.

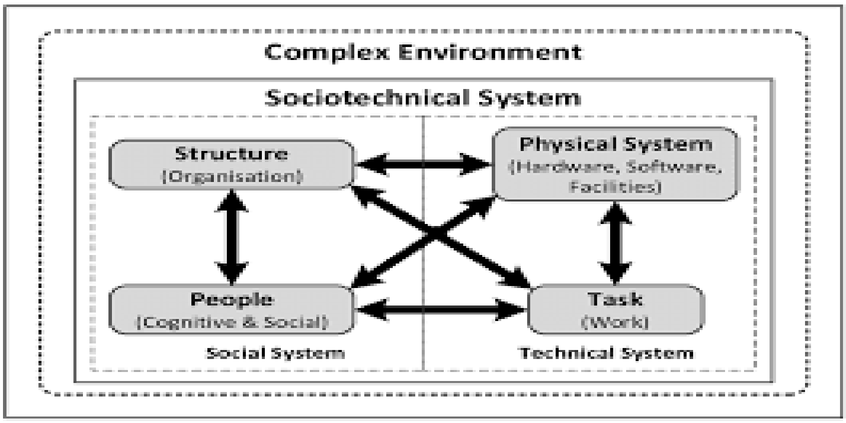


Figure 7.2 – Socio-Technical perspective on organisational work systems (Bostrom and Heinen, 1977)

The counts of content allowed for qualitative analysis identifying, for example, the 'social system' that reflects what the frontline staff were saying regarding job design, the organisational structure and changes to this, lack of employee engagement in the change programmes etc. Similarly, the 'technical system' construct emerged from the feedback from participants around new technology introduction and the lack of training and briefings to prepare for this, system access issues, IT connectivity in remote locations etc.

The coding process also afforded systematic comparison across the four participant groups, and the researcher has been able to critically analyse the perceptions of frontline staff about the two national change programmes, distinguishing between the initiatives, and particularly where there is a strength of feeling in a particular group, e.g. planners, and about a particular subject; for example, safe work pack volumes.

NB: it was established, as part of the process, that the researcher would critically analyse the results as part of the PhD; whilst the change team were interested in only some of the responses, i.e. the impact of the revised track access standard since its publication, and the extent to which briefings had been undertaken and been considered effective. The information deemed relevant by the Network Rail change programme team was made available to them immediately afterward the analyses was completed, ensuring anonymity to comply with the ethical requirements of this study.

7.4 Findings

A total of 1355 questionnaires were completed, and the responses captured per participant group are shown in Table 7.1, with an overall response rate of 4.5% versus the target of 10%.

The detail of the responses is summarised in a range of tables and charts below.

Table 7.3 presents the percentage number of respondents who selected each answer for each question asked specifically to each participant group, ***excluding*** common questions between the participant groups (these are, instead, addressed in Table 7.4).

Table 7.4 presents the comparative percentage response values for each participant group in response to the common questions. The final column provides the researcher's observations about some of the answers given.

Table 7.3 – Participant group's responses, ***excluding common questions***

Responsible Manager	**Response**
6. To what extent do you feel your team are complying with the revised 019 v9 standard?	Fully – 41% Partly – 50% Not at all – 4%
7. Please mention any areas of non-compliance - *multiple answers can be given*	Review of returned packs – 26% Safe Work Pack Verification – 58% Returning and storing Safe Work Packs – 51%
Workforce	**Response**
1. Do you feel the revised safe work pack contains adequate details for you to feel safe on or near the line?	Yes – 79% No – 21%
2. Do you feel the revised safe work pack contains adequate details for you to carry out your tasks safely?	Yes – 74% No – 24%
3. How often do you question the brief given to you by the PIC?	Never or seldom – 53% Often – 35% Majority of the time – 9% All the time – 3%
4. How often does the PIC ask questions on the brief to you to confirm understanding of the contents?	Never or seldom – 29% Often – 35% Majority of the time – 25% All the time – 11%
5. How often does the brief include risks not relevant to the work?	Never or seldom – 37% Often – 29% Majority of the time – 18% All the time – 16%
6. How often does the brief include information about the welfare facilities?	Never or seldom – 42% Often – 17% Majority of the time – 20% All the time – 21%
7. Have you seen an improvement in the method of working on or near the line (protection rather than warning)?	Yes – 13% No – 33% Stayed the same – 54%
8. Which part of the safety brief do you think has improved the most?	Operational brief – 11% Task Brief – 30% None – 59%
Person In Charge	**Response**
1. How often are you involved in the planning of the work that you are delivering?	Never or seldom – 61% Often – 19% Majority of the time – 12% All the time – 8%
2. Do you feel the safe work pack contains adequate details for you to brief your workforce to the best of your ability	Yes – 76% No – 24%
3. How often do you receive a safe work pack at least a shift in advance?	Never or seldom – 23% Often – 25% Majority of the time – 33% All the time – 19%
4. How often do you brief the specific site risks and tasks risks to your team?	Never or seldom – 19% Often – 18% Majority of the time – 25% All the time – 38%

5. How often does your safe work pack contain any risks that is not relevant to the work?	Never or seldom – 32% Often – 31% Majority of the time – 20% All the time – 17%
6. How often does your safe work pack contain the generic risks not relevant to the work?	Never or seldom – 30% Often – 29% Majority of the time – 21% All the time – 20%
7. When handing back the site of work, who verifies that tools, equipment and personnel are safely removed and makes sure that the line is clear for safe passage of trains?	PIC/SWL/COSS – 82% ES – 5% Workforce – 12% Signaller – 1%
8. How comfortable would you be to verify a safe work pack electronically using a Network Rail computer / Ipad / tablet?	Confident – 38% Confident after training – 38% Prefer paper-based pack – 24%
10. On an average how many safe work packs do you verify each week? Please enter the range.	0 – 12% 1-4 – 52% 5-9 – 26% 10-19 – 10%
11. On an average how many complex safe work packs do you verify each week? Please enter the range.	0 – 47% 1-4 – 41% 5-9 – 8% 10-19 – 4%
12. When undertaking any work on or near the line who verifies that the work has been carried out in accordance with the relevant standards	PIC/SWL/COSS – 83% Workforce – 17%
Planner	**Response**
5. Do you produce all safe work packs for your section?	Yes – 73% No – 27%
7. Do you have cover for your annual leave, sickness etc.?	Yes – 13% No – 60% Partially – 27%
8. Do you undertake other duties in addition to the role as planner?	Yes – 65% No – 35%
9. As a planner, what percentage of PICs within your group do you feel would be able to use an IT based solution?	0%-19% - 29% 20%-39% - 18% 40%-59% - 18% 60%-79% - 17% 80%+ - 18%

Table 7.4 – Participant group's responses ***for the common questions***

Common Questions	**Responsible Manager responses**	**Person In Charge responses**	**Planner responses**	**Observation**
Since the revised 019 standard came in have you had any challenges with your team's workload?	Strongly agree – 80% Agree – 17% Neither Agree or Disagree – 2% Disagree – 1%	Yes – 49% No – 51%	Yes – 86% No – 14%	49% of PICs answered 'yes' to this question; a similar number to those replying with a 'no' answer. The PICs perhaps seeing this differently to the others, i.e. 86% of planners saying 'yes' and 80% of responsible managers who 'strongly agree' that their workload has increased as a result of the revised '019' standard. This may be because they haven't seen a direct increase in their workload or because they feel the revised process hasn't added to their work, e.g. it has only changed the way in which they plan and undertake briefings
Please quantify your additional workload	0%-19% - 3% 20%-39% - 4% 40%-59% - 18% 6-%-79% - 37% 80%+ - 38%	n/a	0%-19% - 8% 20%-39% - 40% 40%-59% - 35% 6-%-79% - 12% 80%+ - 5%	There is a difference here in what the actual perceived increase in workload is for each work group despite both Responsible Managers and Planners believing they have had challenges. This may be explained by the revised verification process where the change to the process has added more directly on to the RM than it has to the Planner
What areas are causing the increase in the workload? - *multiple answers can be given*	Deconflicting work plans – 24% Safe work pack production – 67% Safe work pack verification for 88% Person In Charge involvement – 80%	n/a	Deconflicting work plans – 26% Safe work pack production – 68% Safe work pack verification for 83% Person In Charge involvement – 69%	There is a strong similarity in the responses between responsible managers and planners in their answers. This is probably due to the fact that they work jointly on these areas to resolve matters, i.e. deconfliction of the work plans where concerns are identified

Common Questions	Responsible Manager responses	Person In Charge responses	Planner responses	Observation
Have you considered any ways to reduce the workload, e.g. stopping doing other tasks, reducing the number of non-cyclical packs or implementing a LEAN project?	No – 42% Yes – 58%	n/a	No – 47% Yes – 53%	It is good that some suggestions were included in the free-form text offering comments as to ways the workload might be reduced, including some common threads like simplifying the review and verification processes, minimising how many non-cyclical packs are produced, and planning routine (cyclical and repeat work) in batches. However, of note is that a similar percentage (c. 40%) of responses across the RMs and Planners indicate that they had not considered ways to reduce workload, with some comments particularly from Planners suggesting that they didn't think they would be listened to.
On an average how many cyclical, repeat and non-cyclical safe work packs do you authorise on a weekly basis? Please enter the range.	In the frequency range 0-24 per week: Cyclical pack – 65% Repeat pack – 77% Non-cyclical pack – 51% In the frequency range 25-49 per week: Cyclical pack – 25% Repeat pack – 18% Non-cyclical pack – 34% In the frequency range 50-74 per week: Cyclical pack – 6% Repeat pack – 3% Non-cyclical pack – 12% In the frequency range 75+ per week: Cyclical pack - 4% Repeat pack - 2% Non-cyclical pack - 3%	n/a	In the frequency range 0-24 per week: Cyclical pack – 54% Repeat pack – 77% Non-cyclical pack – 54% In the frequency range 25-49 per week: Cyclical pack – 34% Repeat pack – 15% Non-cyclical pack – 31% In the frequency range 50-74 per week: Cyclical pack – 8% Repeat pack – 4% Non-cyclical pack – 10% In the frequency range 75+ per week Cyclical pack - 4% Repeat pack - 4% Non-cyclical pack – 5%	There are quite a few scores here, but generally they are largely consistent, except for the cyclical pack percentage responses between the RM and Planner for the 0-24 and 24-49 week range. This can, perhaps, be explained by how many get authorised by the respective roles in the required timeframes where it is often easier to review repeat packs than cyclical packs, and the RM is likely to spend more time on checking the planners work and their cyclical packs to avoid conflicting works.

Figure 7.3 shows four specific questions and their related responses that refer to the matter of briefings and welfare facilities which were put to the 'workforce' participant group; remembering that three of the questions (nos. 4, 5 and 6) were added by the national change team as the questionnaire was developed.

In terms of question 3, there is an even split between infrequent (never or seldom) and frequent (often / majority / all of the time) questioning of the brief (53%/47%) and this perhaps implies an issue of engagement and whether or not the 'workforce' feel they can / should question the brief. Some of the supporting comments in the responses given suggest that individuals don't necessarily feel they have a role to play in the brief except to listen, and others said they don't see it as their role or believe individuals are frightened to speak up.

> *"We know people don't feel the environment supports them to call things out, and 'speak up'."*
>
> *[Responsible Manager]*

Questions 4, 5 and 6 were designed to elicit employee perceptions on the impact of the revised track access standard since its publication, and the extent to which briefings had been undertaken and were 'landing' and/or considered effective. Question 4 indicates that the PIC in the majority of cases (71%) confirms understanding of the contents of their briefings, and usually (more often than not (58%)) includes relevant welfare facility information in these briefs (per question 6). More worrying, is that almost 30% believe a confirmation of understanding never or seldom happens. Interestingly though, question 5 then shows that the briefing material routinely includes risks that are not relevant to the work (63%) which might also explain why the 'workforce' respondents infrequently challenge the brief (per question 3). That said, perhaps the risks may genuinely not be relevant, or are real risks that the workforce doesn't appreciate as such.

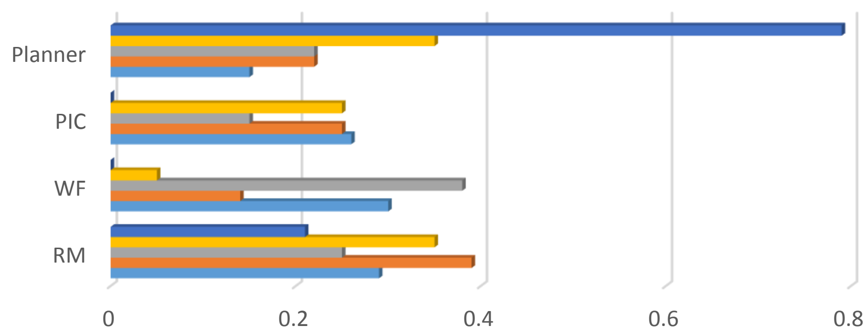
Figure 7.3 – 'Workforce' participant group responses specific to briefing and welfare facilities

The Bostrom and Heinen (1977) approach helpfully allows for a socio-technical perspective to be taken of the organisational work system, and as such their broad themes around people, organisation etc., were used to help guide the researcher when coding and analysing the survey responses. Table 7.5 reflects the relative frequencies that emerged from the key word / phrase count, related to one of the five main themes mapped to the source ones from Bostrom and Heinen. These came from the coding undertaken related to the 591 key words or phrases used in the free-form text fields of the survey responses.

Table 7.5 – Counts of content relative to each main theme linked to the organisational work system

Main theme	**Source: Bostrom and Heinen, 1977**	**No. of key words/phrases**
Social System	People	313
User-influenced design	Structure (Organisation)	57
Technical System	Physical System	80
System Integration	Task (Work)	85
Evolving Technologies	Physical System	56
Total		**591**

Figure 7.4, related to all of the comments received, shows that the planners (as a proportion of their responses) mostly comment on technology introduction, and offer their views on how work is planned, and information is accessed. Whereas the workforce marginally refers more to the social system than the other groups, and the Planner much less so than the other groups. Similarly, the responsible manager makes more comments related to user-influenced design than the workforce. The workforce goes on to refer to technical systems more than the other groups, but they are largely silent on system integration matters, and do not comment at all on the systems in place.



	RM	WF	PIC	Planner
Evolving Technologies	0.21	0	0	0.79
System Integration	0.35	0.05	0.25	0.35
Technical System	0.25	0.38	0.15	0.22
User-influenced design	0.39	0.14	0.25	0.22
Social System	0.29	0.3	0.26	0.15

Evolving Technologies System Integration Technical System
User-influenced design Social System

Figure 7.4 – Rate of participant group comments

Importantly, this quantitative analysis complements the points that are made in the qualitative analysis undertaken and reported on in Table 7.6 below.

The table summarises the main findings from the survey outcomes, and reports on some of the comments made and feedback proffered.

Not unexpectedly, it was the more junior roles (the trackside workforce, and persons in charge of work activity) who provided the least number of comments in proportion to their overall participation (e.g. 136 of 361 (38%) of the workforce responses included comments, compared to 153 of 201 (76%) individuals involved in the planning of the work) – see Table 7.1 above. Of note also is that 11 of the 36 questions allowed for yes / no responses and, as such, whilst comment was still invited, it was possibly not felt necessary by the survey participants having answered in absolute / unequivocal terms, i.e. either yes or no.

The main themes to emerge from the survey help paint a picture of the participants perceptions of the current policy and processes intended to improve workforce safety, and further categorisation is included in the initial column of Table 7.6 to bring the key words / phrases to life. For example, engagement, workload demands, technology roll out etc., that relate to comments made by survey participants.

Table 7.6 – summary of emerging themes and main findings

Emerging themes	Main findings	Comment
1. Social system: engagement, job design, pace of change, and compliance	1. The survey shows that 313 of the 591 returns included comments related to the social system and had a number of responses indicating that people had not been engaged in the change programmes and found their ability to comply with Standards and processes encumbered by not understanding their part in the process, and subsequent worries around Standards compliance. A participant said: ***"….I am concerned about being Standards led, leaving no room for experience or risk based decision making" [Person in Charge]*** 19 free text comments directly point to the need for better communications, although many more infer this too. Across all participant groups a total of 37 comments were made regarding the pace of change, particularly the need for changes to be rolled out in phases, and as separate work packages as part of the necessary job changes that were required. ***"…..we should have delivered the standards change first at a local level, not everything done all at once. This would have allowed us to check we were compliant with the revised processes and undertaking tasks as required. The Centre could then have revised the technology if changes were needed."*** **[Responsible Manager]**	When questioned about policy and process change (including specifically Standard '019') there were 145 (of the 313 comments) that related to concerns about workforce engagement, including worries about the overly ambitious programme plans and people not being involved in the changes
2. User-Influenced Design Workload demands, end-user involvement	2. Notable increases in workload are reported across three of the four participant groups, i.e. responsible managers, persons in charge, and planners all report workload increases. The exception being the workforce participants where 54% report that their method of working has largely stayed the same. A little over 50% of the participants registering workload increases also report they have considered ways to reduce their workload burden, but 22 of 57 participants have also included comments, saying that they felt unable to influence changes (predominantly at the more junior level). ***"When you are designing a system, you need to have the people in the room that are actually going to use it, but we don't seem to operate like that."*** **[Responsible Manager]**	The issues emerging from the research, especially from the 57 comments put forward, reveal complicated work processes often because of multiple users and interfaces, which have increased workload demands. There was also a reported lack of end-user involvement in the change programmes.
3. Technical System: Technology roll out, system access and interfaces	3. The responses related to tools for planning work, using IT based solutions, indicate that 39% of Persons In Charge (PICs) participating in the survey would be confident ***after*** training in using new electronic systems. 80 free text comments reinforce the point that new technologies introduced as part of the two national change programmes were complex, with many indicating that, in computerising processes, the human experience was overlooked, particularly regarding initial training during technology roll out.	The single biggest factor for technical systems, identified from 30 of 80 comments, was the issue of access to systems. There were also 12 items of feedback about increased workloads brought about by information exchanges and additional checks required by revised work processes.

Emerging themes	Main findings	Comment
4. System Integration System requirements and interfaces	4. There are 85 free form comments related to the actual task / job of work and the integration of new arrangements with existing ones. They indicate that Network Rail did not allow the system requirements to evolve, and 30% of these suggested that the changes were too prescriptive, did not reflect work in practice, and thus were having an impact on workload and workflows. 79% of workforce respondents feel the revised safe work pack contains adequate details for them to feel safe when working on track, and a similar percentage (74%) say the same about carrying out their tasks safely. However, what this also shows is that over 20% feel that they don't feel safe on track or when carrying out work. This is perhaps a reflection on how the safe work planning system was rolled out and operated, and/or the overly complicated process involving interfaces and a number of safety roles (e.g. safe work leader (SWL), Controller of Site Safety (COSS) and Person In Charge (PIC)).	Of note is that questions put to both responsible managers and the planners elicited that a lot of their work can involve the production of repeat safe work packs. 21 of the comments proffered by survey participants indicate that a lot of the planning involves cyclical or repeat work, but issues like this were not discussed across teams to make the supporting tools far simpler.
5. Evolving Technologies: artificial intelligence, cloud computing, computer supported cooperative working	5. There were 56 key words / phrases used to suggest that technology users either need new skills to make best use of the tools being made available / issued to them, or that the training they have had gets updated at sufficient intervals as the planning tools are further developed and rolled out. 26 'planners' who provided supporting comments suggest that had they and their colleagues been given the choice they would have been willing to support trials of IT based solutions, especially if their work could be made easier, but much of the feedback indicates that survey participants felt the tools and associated workflows and processes currently add to their burden not lessen it.	There were 18 comments directed at the way in which the new technologies were set to evolve, with concerns raised regarding future job roles, particularly the possibility of organisational changes and the likelihood of more systems being introduced to support intelligence gathering,

The following sections provide a more detailed analysis of the views expressed by the frontline staff, grouped according to the five themes that emerged. Commentary on the findings is provided, particularly on the implications of the pace of change and the challenges of user-influenced design in the context of a railway system where there are rapidly evolving technologies, and a need to consider the skills workers will need to engage with them are discussed.

7.4.1 Views on the social system, including staff engagement

Eight sub-themes were identified in the 313 comments relating to the social system and 'people' aspects of the change. Figure 7.5 shows the number of responses given by members of each participant group for each sub-theme. For example, mention was made of: *"engagement with frontline staff"*, *"insufficient attention to actual work practice"*, and *"issues with communication"*.

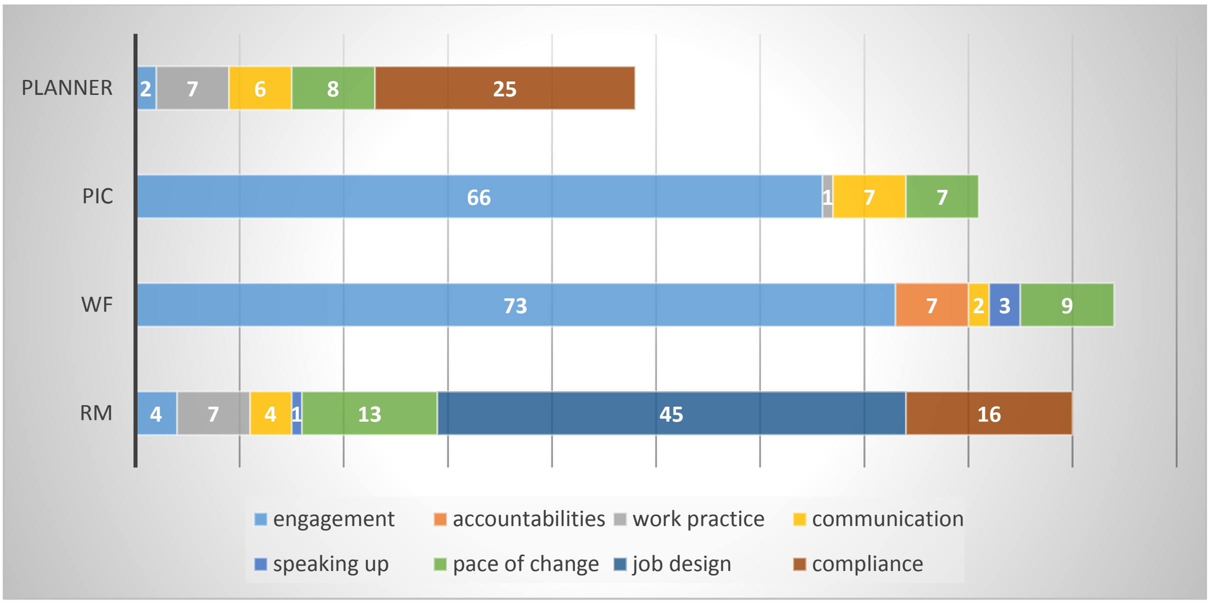


Figure 7.5 – Count of comments on the social system, including staff engagement

An earlier study (Study 1, Chapter 5) had found that leaders and employees need better skills and abilities to manage change in the GB Rail socio-technical system. Both in the previous study, and this current research, it was identified that regular engagement is needed with those affected by change, to ensure a smooth transformation. Two quotes from the survey responses bring to life the concerns expressed:

> *"People flourish when they are well informed, involved, listened to, and treated well. That has not been the case with the change programmes so far."*
>
> *[Responsible Manager]*

> *"The direction from seniors is one way, making their expectations clear. They do less listening and understanding of what it takes to deliver change safely."*
>
> *[Responsible Manager]*

45 (or 26%) of 174 'responsible manager' comments in the free-text fields indicate that things like job design factors meant a number of structural changes were needed at the outset, and that subsequent changes took far too long to implement. Fifty percent (50%) of 'Responsible manager' participants responding to their survey question no. 6 (see Table 7.3) said they felt only partial compliance to Standards was possible by them and their teams.

16 'responsible managers', but also 25 'planners', identified in their comments that there were fears regarding broader compliance issues with rules and procedures, some mentioning *"significant risk exposure"* primarily around the introduction of new planning requirements and systems on such a large scale, and without an appreciation of how things are done in practice.

> *"Short cutting procedures is coming – the new processes have too many steps to follow, too much paperwork to fill out."*
>
> *[Planner]*

> *"I wonder about the extent to which change is possible within an already complex system."*
>
> *[Person in Charge]*

These concerns were also recognised by other respondents in the survey work, but at a more junior level, where 148 comments were provided by 'workforce' and 'Person in Charge' participants, indicating that the lack of communications and/or engagement in the programmes made it difficult to understand their part in delivering the planned changes, with a further 7 'workforce' participants specifically suggesting accountabilities and responsibilities could become blurred.

7.4.2 Views on user-influenced design, and workload demands

Two specific themes were identified in 57 comments relating to people aspects of change, i.e. end-user involvement in policy and process revisions, and what these mean in terms of the change to work practices, workload demands, and individual and team capability (see figure 7.6) below.

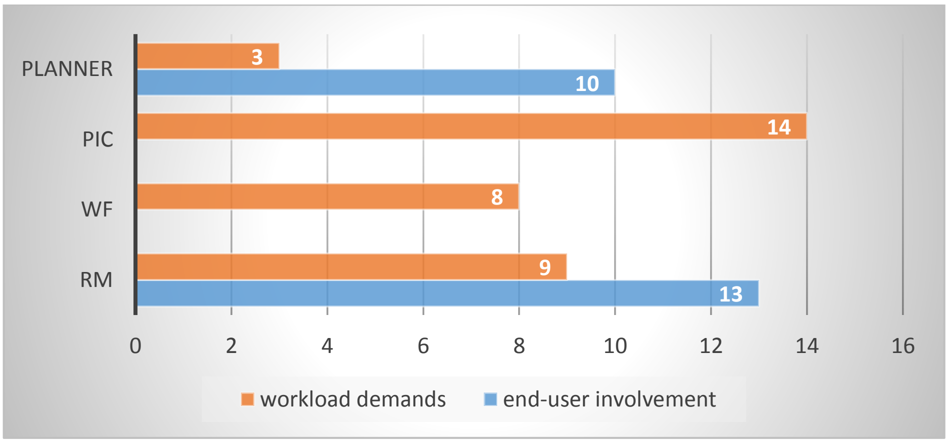


Figure 7.6 – Count of comments on user-influenced design, and workload demands

Survey results indicate that 79% (seventy-nine per cent) of ‘workforce’ respondents believed there were genuine efforts to improve safety (see Table 7.3), but the comments suggest that some of those on the frontline clearly felt the changes were often attempted too quickly without the necessary levels of end-user involvement, and one said specifically there was an over-reliance on ‘luck’ when it comes to safety.

> *“So many near miss incidents tell us that luck is what saved us.”*
>
> *[Workforce]*

The survey showed that 97% (ninety seven percent) of ‘responsible managers’, 49% (forty nine percent) of ‘PICs’, and 86% (eighty six percent) of ‘planners’, agree to some extent or other (e.g. strongly agree or agree) that there are issues around their workload increase since the revisions to Standard ‘019’, with comments made about:

> *“…..having little involvement in the design of the system to support changes.”*
>
> *[Planner]*

61% (sixty one percent) of ‘Persons In Charge’ indicate that they are never or seldom involved in the planning of the work they are responsible for delivering; this is contrary to the requirements of the revised process, and yet 78% (seventy eight percent) go on to say they believe the safe work pack contains adequate details for them to brief their workforce when on site. What also emerged around workload was the seeming reluctance to consider ways to reduce the burden; it was primarily ‘responsible managers’ (58% (fifty eight percent) of those responding) who felt they could try to change things (e.g. *“stop doing other things”,* or *“reduce the number of non-cyclical packs”*). 22 of 57 participants across the ‘workforce’ and ‘PIC’ roles, however, advise in their comments they did not feel they had sufficient input to be able to influence matters, with 53% of the ‘workforce’ group survey responses indicating individuals never or seldom challenge or question the brief given to them about their work, albeit this is countered by 35% (or 123 people) reporting they ‘often’ question the brief from their PIC.

There were 6 ‘responsible managers’ and 3 ‘planners’ who used words like *“marginalised*” and *“disengaged”,* with some indicating they do not want to be involved in the changes being brought about.

Three ‘responsible managers’ offering their thoughts on user-influenced design and suggested changes are about *“hearts and minds”* and *“requiring better consultation”*, but two separately said that *“better data”* was needed to help inform and back up the planned changes rather than repeat the anecdotes and ‘war stories’ they so often hear replayed.

7.4.3 Views on the technical system

Three sub-themes were identified in the 80 comments relating to technology introduction, system access, and the interfaces and information exchanges required due to revised work processes. See figure 7.7 below.

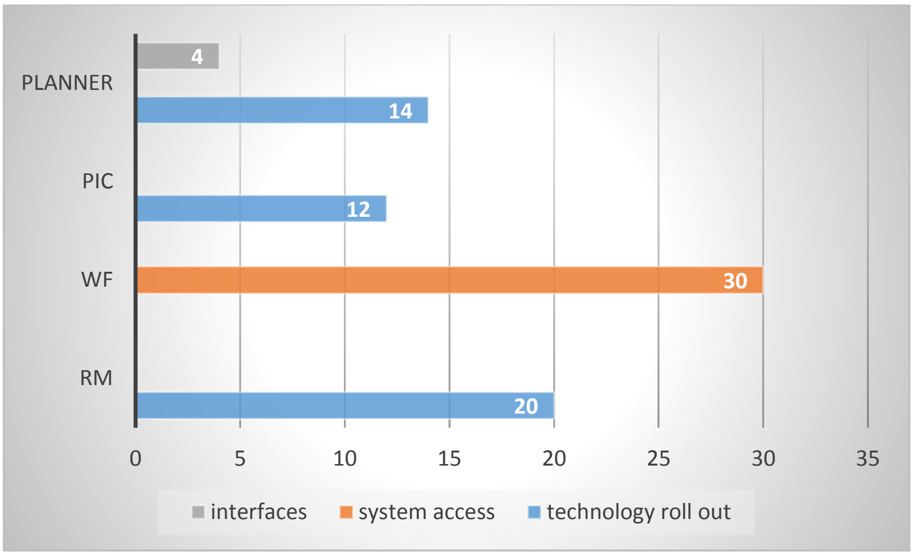


Figure 7.7 – Count of comments on the technical system

Earlier studies (Study 1, in Chapter 5, and Study 2, in Chapter 6) indicate that when a new system has been introduced in the past in Network Rail, there has been an assumption that people have been rather daunted by it and/or reluctant to use it. This certainly seemed to be the case when the Planning and Delivering Safe Work planning tool was initially introduced, but also reinforced through this study and the survey feedback when mention was made about *"….not preparing people for change through briefings and training"*. That said, the questionnaire responses indicated that 38% (thirty eight percent) of the 'Persons in Charge' said they would be confident to use electronic systems / tools for planning work, and an equal number (also 38%) would be confident ***after*** training (per Table 7.3).

Interestingly, the problem of user take-up and usability of the new systems, reported by 4 'planners' offering their views, seems to have started to shift over time with them also saying that there was probably more concern currently around user expectations of both the technical system and its outputs (e.g. responsiveness / speed of processing data), particularly since some have now had time to use the tools, and practice what they've been taught in training.

When asked specifically if the 'workforce' themselves had seen an improvement in the method of working on or near the line (i.e. since the revised Standard's introduction, the technology for planning, and changes to protection systems on sites), 33% (thirty three percent) of this participant group said they had seen no improvement, and 54% (fifty four percent) reported things as having stayed the same.

Feedback regarding system access to the new planning tools indicated (in 30 from a total of 80 responses) that there are still issues of getting access to the new (planning) systems (logons, IT availability, and connectivity).

Twelve respondents – eight 'responsible managers' and four 'planners' – indicated that they thought the technical systems developed do not reflect the work in practice, for example around complex information flow(s), and multiple user roles within the workflow (e.g. planner, person in charge, authoriser, supervisor, responsible manager).

"We've set ourselves up to fail even before we start the real process of change if we have tools and systems that bear no relation to how we plan and deliver work……"

[Responsible Manager]

Finally, specific mention of non-compliance arose around changes to work practices since the technology roll out, and 115 (58% (fifty eight percent)) 'responsible managers' indicate safe work pack verification requirements are where their concerns lie, and 102 individuals think 'return and storage' of used safe work packs is also an area where non-compliance exists. The point being here that the revised '019' Standard is explicit in the hierarchical controls over the pack's sign off and subsequent returns for record-keeping purposes, and supporting comments suggest this is a known problem which individuals are struggling to address.

7.4.4 Views on system integration

Three sub-themes were identified in the 85 free-form comments relating to the actual task / job of work and the systems used in support of planning and delivering safe work – see Figure 7.8 below. These comments were often provided in relation to specific questions in the survey around safe work pack production and content, and the findings indicate three main issues to emerge: systems integration, requirements, and interfaces.

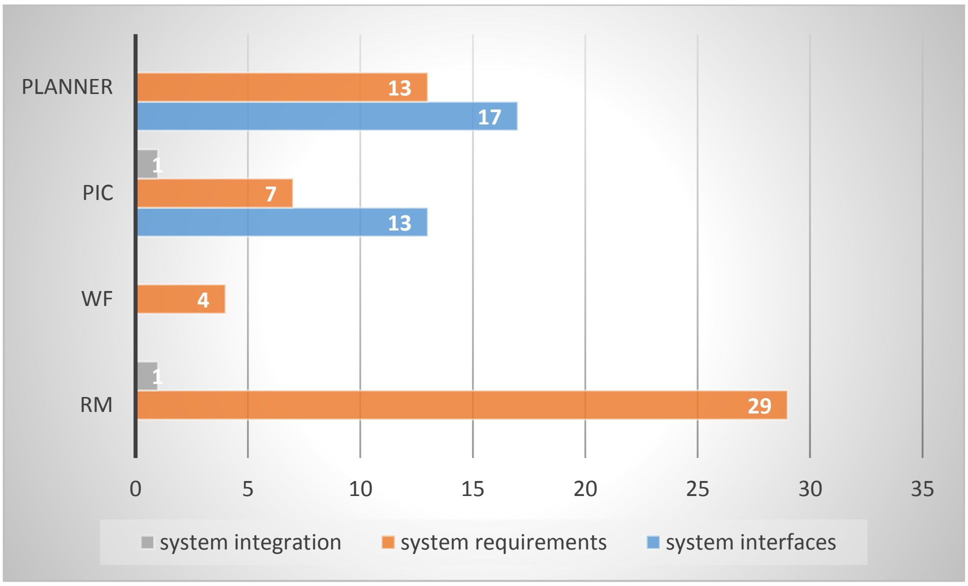


Figure 7.8 – Count of comments on system integration

The survey work shows that integration of current systems with new systems proved problematic for Network Rail and its supply chain with the two national change programmes. Several examples were cited by survey respondents, including the fact that established work processes could be disrupted by the new systems introduction.

As a result, 24% (twenty four percent) of PICs responding to the questionnaire said they would prefer to use traditional paper-based systems over the new planning tool, whilst the remaining 76% (seventy six percent) indicated they would use the tools.

Of note is that 21 individuals across the four participant groups indicated that they ought to have been invited to help develop the system requirements, which might have helped make the planning process simpler.

Further survey feedback from 13 ‘persons in charge’ and 17 ‘planners’, highlighted that managing large amounts of information and interfaces is also a major issue for them and frontline workers. More than two-thirds of these 30 respondents flagged concerns including the volume of emails, text messages, file transfers, and safe work planning packs, in addition to the number of Standards, rules and procedures they must refer to.

> *“Our supervisors are the critical performance link. They need developing and to be freed up from the burden of paperwork and reporting, so they can properly support change implementation.”*
>
> *[Person in Charge]*

9 of the ‘responsible managers’ indicated that *“information overload”* (a term popularised by Toffler, 1971) was an issue for individuals and teams, with some citing it as affecting decision making, and their worries that it was getting made worse by the complexity of the changes and the lack of specificity in system requirements:

> *“We blame poor quality processes and procedures all the time, but we lack risk-based thinking and decision making, so that might explain why people feel overloaded and overwhelmed.”*
>
> *[Responsible Manager]*

7.4.5 Views on evolving technologies

There were 56 free-form comments relating to technologies and technical systems, particularly around their development / evolution, and the feedback suggests that technology users need new skills or refresher training to use the planning tools as they are further developed and rolled out into Network Rail’s business.

47% (forty seven percent) of the ‘planners’ answering their survey question (no. 9) collectively felt up to forty percent of their PICs were not yet able to use IT-based solutions. Content analysis of 18 ‘planner’ comments, using free-form text fields, suggested that early developments of the technologies for planning and delivering safe work did not consider that group working requires a critical mass of people to participate, and an understanding of the respective job roles (i.e. the responsible managers, person in charge etc.). They thought the next evolution of the technology must address this concern, without which some PICs would continue to prefer paper-based systems.

26 comments from ‘planners’ suggested many would be willing to participate in ‘trials’ of new / evolving technologies if invited, and indicated they thought new skills or refresher training would at least be needed by everyone involved in ‘019’ compliance in future.

Nine ‘responsible managers’ expressed frustrations that those setting Standards and revising processes as part of the two national change programmes had a poor appreciation of what happens on the ground and seemed to care very little about introducing technology to those that may be less familiar with smart phones, iPads, and use of Apps. A few comments were directed at *“youngsters”* or *“our apprentices”* using technology, and the inference here is that perhaps older workers were either being left behind or not engaged in the changes.

Given that 83% of ‘planners’ and 88% of ‘responsible managers’ responding to the survey (see Table 7.3) indicated that safe work pack verification was the main reason for their workload increase, it is disappointing to note that despite introducing new technologies, and their evolution, the tools and associated workflows were not being made easier, thus changes only added to the workload burden not lightened it.

7.5 Discussion

Examples from the work of others (Baxter and Sommerville, 2011; Oosthuizen and Pretorius, 2016) suggests that developing complex socio-technical systems (STS) often means integrating new technologies into existing systems, and that work can come to be more complex because of the various interactions involved (individuals, within and across teams, and between people and technology).

This research and its findings, including both the qualitative analysis of the free-form text and the descriptive statistics from the study, highlight some of the difficulties in relation to the integration of social (people, organisation, and job design) and technical (tasks, information, and technology) components, as the two change programmes have been progressively rolled out.

7.5.1 The social system

The literature often talks about change (whether organisational change, programme change, technology change) as a process which can result in uncertainty for affected employees (Schweiger and DeNisi, 1991; Callan, 1993; Shaw *et al*, 1993), and with the potential to evoke stress reactions and other negative consequences due to the dynamic environment. Grote (2015), however, suggests that uncertainty – in some circumstances – can be a positive thing, getting the right balance between a stable and flexible system, matched by controls and accountabilities for those involved.

In either case, the literature suggests uncertainty around change needs to be managed as a threat or an opportunity, and crucially there is a need for the provision of information during such periods to keep those impacted informed so they can establish a sense or understanding of their role in the change.

The majority of the 591 comments provided indicate issues around the social system; this study with the survey results and feedback from participants has highlighted concerns about employee adaptation due to the scale of the changes required to underlying processes, the organisation (social system), and new technology introduction. The work has certainly reinforced the importance of effectual change management programmes, including the need to communicate plans, reasons for change, and develop processes with clear accountabilities.

Direct reference has been made to the lack of information and poor communications around the change programmes, which created dysfunctional outcomes when Standards were revised, and new roles, job design, and work practices were introduced.

To move things forward, this could mean setting up teams across all levels of engineering and national functions in Network Rail to bridge the gap between designing, developing, and maintaining systems, and then going on to actually operate them. Certainly, from the survey carried out, it is evident more collaboration and participation is needed from frontline staff and subject matter experts to support changes that can then be well designed and can be effectively implemented. Involving users in systems (and process) design is well established (Eason, 1982; Damodaran, 1996), and some key principles are outlined in an ISO ergonomics-related publication (ISO, 2010). However, Harris and Weistroffer (2009) report that design decisions are often made at a strategic level, and in practice users may have little influence on fundamental aspects of design and technical functions.

The survey also revealed that GB rail workers are becoming increasingly familiar with technology such as smart phones and apps that are issued to them for work, therefore their user experience and expectations of how they interact with technology has changed in the years since the new technologies, as part of the two change programmes, were first introduced. This presents a challenge for technology and innovation designers to try and address system user requirements and adaption to newly emerging data, especially as simple customisation is not always possible on bigger software applications used in the workplace, already recognised by Maguire (2014), often because of security restrictions or capabilities of the operating environment / platform.

7.5.2 The technical system

As identified in Chapter 2, setting out the background to the two national change programmes, the Network Rail Executive were keen to use technological solutions to aid decision-making, plan safe work, and provide e-diagrams for site access to rail locations. However, developing such systems and tools perhaps requires an understanding of 'work as described', 'the work as done', 'work as prescribed', and 'the work as disclosed' if safety thinking and safety practices are to be analogous (Hollnagel *et al*, 2013).

This study has revealed a techno-centric approach to system design and technology integration as the two change programmes have been introduced. It shows how there has been insufficient consideration of the complex relationships between the organisation, the frontline staff expected to adopt and deliver the changes and work to revised processes, and the technologies that support these processes (Norman, 1993).

Integration with other systems also needed tighter control – for example, the comments made by 'planners' reveal problems with employee access to track diagrams, primarily because the requirements and dependencies were not understood at the design and subsequent development stage(s). Whilst developing technologies such as new work planning tools, artificial intelligence, information integration, and cloud computing are evolving and becoming part of 'business as usual' (BAU) in GB rail, they are still relatively new and not commonplace in everyday tasks associated with frontline rail infrastructure activity (Network Rail, 2021).

The survey shows that there is still a need to have users feeling empowered to seek technical support when faced with system problems (rather than find workarounds), recognising that individuals currently say they find themselves restricted by their job design and complex interfaces, impinging on their decision making and/or feeling of autonomy.

7.6 Study limitations

As acknowledged previously, there are more than 30,000 staff who might be considered 'frontline' working on the rail infrastructure or in support of it, including Network Rail's supply chain, but it was not realistic to survey them all and expect a 100% return. Instead, the 4.5% that did respond have provided a good insight into what the issues and concerns are with implementing change at the 'sharp end' and the impact the programmes have had in improving workforce safety.

It was possible, and acknowledged as part of the survey process, that participants could complete more than one questionnaire where they fulfil more than one role. An example is a responsible manager who may, on occasion, also undertake the role of a person in charge. In such instances, they were asked to respond according to the role they were completing the questionnaire for, i.e. one as a responsible manager, and one for a Person in Charge (PIC). However, there is the potential that their experience of completing the questionnaire once for one role might have affected how they complete this for another role. It is not possible to know how many completed more than one questionnaire because of the anonymised approach, but it is a feasible limitation when interpreting the study results.

7.7 Conclusions

Like many researchers that have gone before, there are no illusions here about the problems of introducing socio-technical system design methods and approaches, or how long it takes for change to come about in an organisation. However, this study has investigated the impact of complex change on those most expected to deliver it, along with the effect on improving workforce safety through revised work processes and new technology introduction.

The findings from this study are valuable in understanding the range of attitudes, aspirations, and perceived constraints towards change, but also the opportunities that exist to improve matters. The research clearly highlights the difficulties to date in bringing about the intended organisational and behavioural changes envisaged, and brings awareness to real-world situations that businesses face, and where the human factors / ergonomics field can help in future developments.

The results indicate that Network Rail and its supply chain working on the GB rail infrastructure had numerous considerations regarding the different components of the system whilst implementing the two national change programmes, including policy and process change implications. Introducing new technology and partially automating planning processes did not come down to the manipulation of a single variable where multiple factors were at play. For example, the tools and equipment needed for work, technology introduction, systems integration, and possible information flows, also meant transforming people's practices (and requiring them to adapt in novel ways (Flores *et al*, 1988)).

Sadly, some of these important features were missed, like job design and process change without securing acceptance of the changes, and issues of compliance arose (and continue) since revisions to Standards were introduced. The findings also show that as individuals have evolved their experiences in using technology, their confidence in, and adoption of, new systems is growing, and so issues of usability, accessibility and system responsiveness have become bigger concerns as capability and expectations have developed.

The work undertaken here has been supported by a longitudinal (observational) study that has tracked the Network Rail BCR and PDSW national change programme's progress over time; see Study 5 (Chapter 9). As is evident here, and in the further work, the magnitude of the changes being brought about, and the likelihood that the pace of change will increase, means that the affected GB rail organisations will need appropriate methods to monitor the timings and progress of their programmes' implementation. They will need systems and risk management processes that provide the assurance that is needed in demonstrating that the change programmes have realised their intended benefits, particularly improvements in workforce safety.

8. Study 4 – Evaluation of systems analysis tools (i.e. STPA with bow ties) and their suitability as prospective analysis tools for industry to use

8.1 Chapter overview

Putting controls in place to manage or mitigate risk and selecting the right tools to be effective when needed has long been part of the safety management systems of safety-critical industries, including aviation, rail, and the oil and gas sectors. Organisations invest significant effort (time, money, and resources) to understand hazards associated with their high-risk operations, seeking to prevent losses, and using formal techniques to assist in risk identification and control processes (Senge, 1990).

Some of the formal techniques have been around for some time, e.g. Event Tree Analysis, Root Cause Analysis, and Hazard and Operability Studies (HAZOPs), whilst there are other techniques that are now also coming into regular use, e.g. STAMP (the Systems Theoretic Accident Modelling and Process model) (Leveson, 2011), and FRAM (Functional Resonance Analysis Method) (Hollnagel, 2012a).

Network Rail decided back in 2013 to use the technique of bow tie analysis – noting this had been used in other sectors – as the basis for barrier management (see 2.3.2.1 in Chapter 2). They were influenced by the technique's popularity in other safety-critical domains and were keen to use the readily available software tools to provide a visual representation of the bow tie analysis elements / outcomes. However, there still seems to be some doubt in the literature whether bow tie analysis offers anything more than a linear event-driven model; with the likes of Leveson (2011), Hollnagel (2012a), and Perrow (1984) suggesting the approach to be inadequate for understanding dynamic complex socio-technical systems, or the ways they can lead to loss events (McLeod and Bowie, 2018).

This study sought to challenge some of these assumptions, and an evaluation of systems analysis tools was undertaken, reviewing the bow-tie analysis technique used by Network Rail along with the STPA method, as part of STAMP. Consideration was given to these two different techniques / analysis methods, and whether they may be suitable as prospective analysis tools for industry to use to support future interventions in change programmes.

8.2 Introduction

The findings of studies 1, 2 and 3 revealed that the GB rail socio technical system is complex, and getting change implemented either 'as prescribed' or 'as imagined' is not without its difficulties. The introduction of new technologies and the pace of change in GB rail often result in regular organisational restructurings, and the move to greater decentralisation has created potential conflicts between stability and flexibility as autonomy and risk-based decision making are pushed down through the hierarchical levels of command (and control).

As the earlier studies also describe, change frequently introduces new or different roles, communication channels, relationships, power structures, sources of decision making and collaborations to consider.

How these are achieved, to support organisational learning from a risk management and safety-driven design perspective, requires a socio-technical systems approach, with systems analysis methods that are effective, prospective (as well as reactive if required) and ultimately useable in real-world settings / contexts.

In the railways, and other domains such as aviation, nuclear, and healthcare, incidents and accident analysis form an integral part of safety management systems, and because of systems errors and the impact of these, organisations seek to draw lessons using some form of an analysis method (Wienen *et al*, 2017).

Having a framework in place for analyses makes it easier to compare different events and draw conclusions about what is found, however there are numerous systematic accident analysis (SAA) methods available and selecting the appropriate method for the incident or accident, to suit their intended audience, can be less than straightforward (Underwood and Waterson, 2013).

From a review of the available research literature around systematic accident analysis (SAA) it soon becomes apparent that there are differing views on the effectiveness of current approaches to accident analysis methods and models, and it is suggested that there are number of factors which may affect the adoption and usage of SAA methods (Carayon *et al*, 2015; Underwood and Waterson, 2013; Wienen *et al*, 2017). Indeed, it is posited that the use of an analysis technique is affected not only by its features but also by the characteristics of the users, the tasks they carry out and the technical, organisational, and physical environments in which the method is used (Thomas and Bevan, 1996).

For example, the Rail Accident Investigation Branch (RAIB) use several methods or combinations thereof for their incident and accident investigations (e.g. fault tree analysis, and AcciMaps), and also use different reporting mechanisms to reflect the severity of the events and how these are shared, ready for lessons to be learnt, e.g. investigation reports, safety digests, class investigations into a specific topic etc.) (RAIB, 2015).

Underwood and Waterson (2013) also concur with the view of Salmon *et al* (2012), that the systems approach is the dominant model in accident analysis, requiring systems to be studied as a whole rather than separate elements.

The earlier literature review in Chapter 3 found that the systems approach is the foundation for the range of SAA methods and models in use, e.g. STAMP (Leveson, 2011), Functional Resonance Analysis Method (FRAM) (Hollnagel, 2012a), and AcciMap (Rasmussen, 1997), and it is argued that the cause-effect accident models are unable to sufficiently explain the non-linear complexity of today's socio-technical system accidents (Hollnagel, 2004).

Analysis techniques such as the more traditional Fault Tree Analysis are best suited to describing what happened in an accident, but not necessarily how complex system behaviour contributed to it (Underwood and Waterson, 2013). That said, different methods can suit different situations, thus an evaluation of two specific systems analysis tools (i.e. STPA with bow ties) to determine if they are suitable to use for prospective analysis.

8.3 Study design

For the purposes of this study (no. 4), a detailed evaluation and review of the bow tie technique and STAMP was undertaken to identify their suitability for prospective analysis.

The approach taken was to evaluate each method from a range of document sources, management, and employee information and direct observation or participation. In the case of both the bow ties and STAMP, an evaluation of the techniques as a prospective approach to hazard analysis was carried out to gain a better perspective on how such hazards are controlled in real-world settings.

To develop a detailed and reliable picture of the actual use of the bow-tie methodology in Network Rail, research was undertaken that involved the review of organisational processes for risk management, and accessing published Network Rail policies, standards and local procedures and manuals associated with undertaking activities. The study also included the researcher sitting in and observing several bow-tie workshops; these involved a mixture of participants with risk management expertise, and/or safety practitioner experience, although attendance was noticeably sporadic. Very few frontline managers or track workers were invited to participate in the workshops. Two interviews were also undertaken, with individuals considered 'experts' on bow tie production and analyses; these interviews were used to inform the researcher about Network Rail's approach to the use of bow ties, after the company took the decision to use the bow tie technique in 2013.

The researcher, along with a (then) colleague, also attended a week-long STAMP workshop in Manchester (UK) in April 2019, led by Dr John Thomas of MIT, to understand the model and STPA approach, and how this might be applied in practice, i.e. a complex system such as Network Rail.

Approval for the study was provided by the University of Nottingham's Faculty of Engineering Research Ethics Committee (UofN, FoE), including the two specific interviews undertaken in relation to Network Rail's bow-tie approach.

Individuals participating in the observed workshops, and the interviews undertaken, were made aware of the researchers work, and were asked to participate in the knowledge that their comments would be captured and potentially used but clearly anonymised.

8.4 Bow-tie evaluation

Network Rail decided to use the bow-tie method primarily as a risk evaluation tool to analyse and demonstrate causal relationships in high-risk scenarios, and to graphically portray how risks are being managed such that resource can be focused in the most efficient way.

Figure 8.1 reflects the approach Network Rail has taken to building their bow ties. The actual scale of them when completed can, however, be very large (i.e. several feet wide) and complex (see Figure 8.2 as a screenshot of one area focused on a typical 'top event' e.g. a train passing over an unsupported track system).

The actual process for bow tie development as observed by the researcher, and subsequently evaluated, is described in section 8.4.1 below.

In summary, workshop participants start by looking at the top risk event - or something that is likely to cause harm. They then visualise the things that might cause the top risk event, or threats, and the consequences of it happening. Finally, they identify the controls to be put in place to mitigate the risks and show who is responsible and accountable for those controls. The bow ties provide a visual representation of the analyses and enable those viewing them to see a clear picture of risk, with a view to managing them proactively.

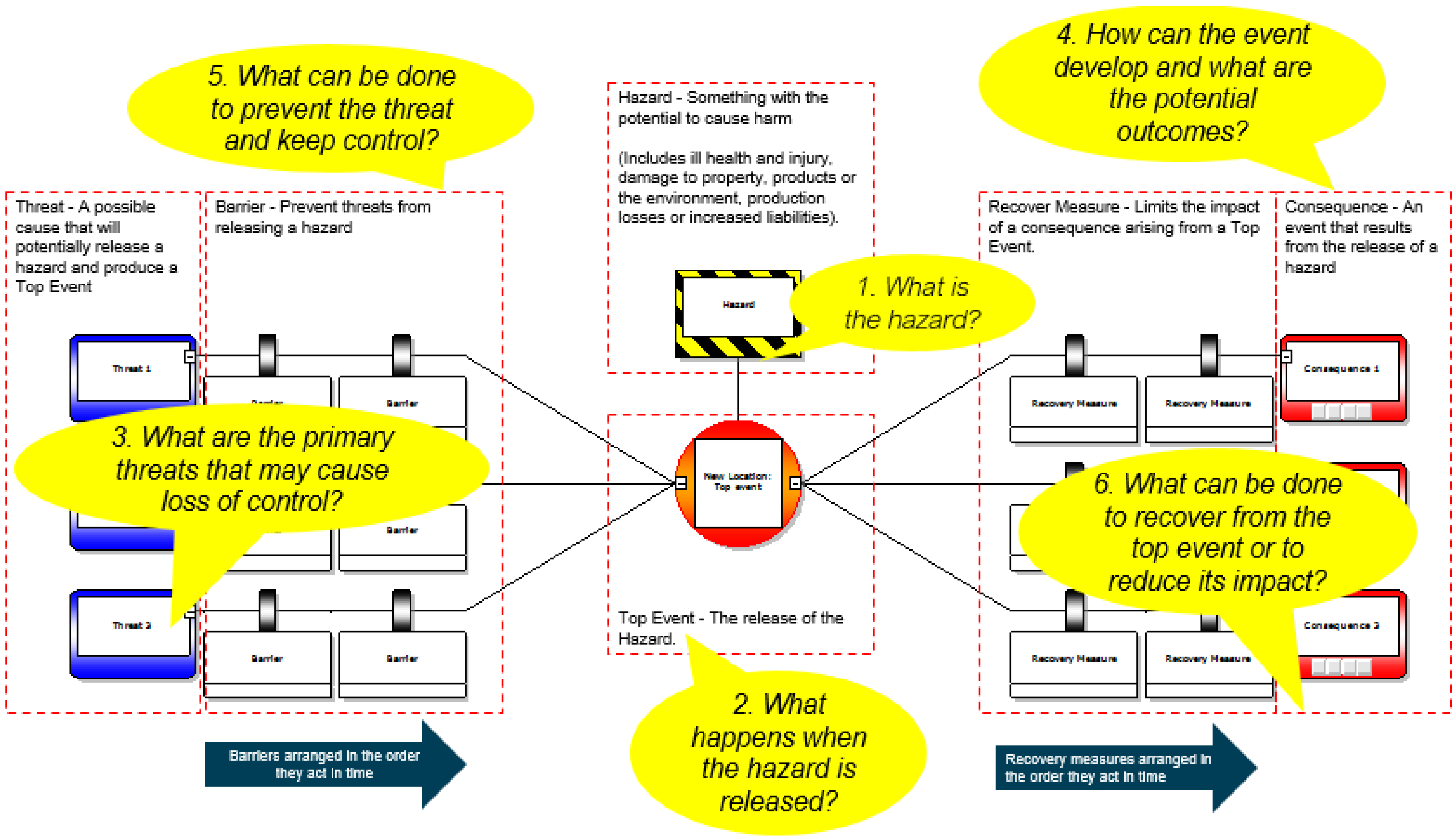


Figure 8.1 – Network Rail bow-tie template Steps 1 to 6 (adapted from Network Rail, 2016)

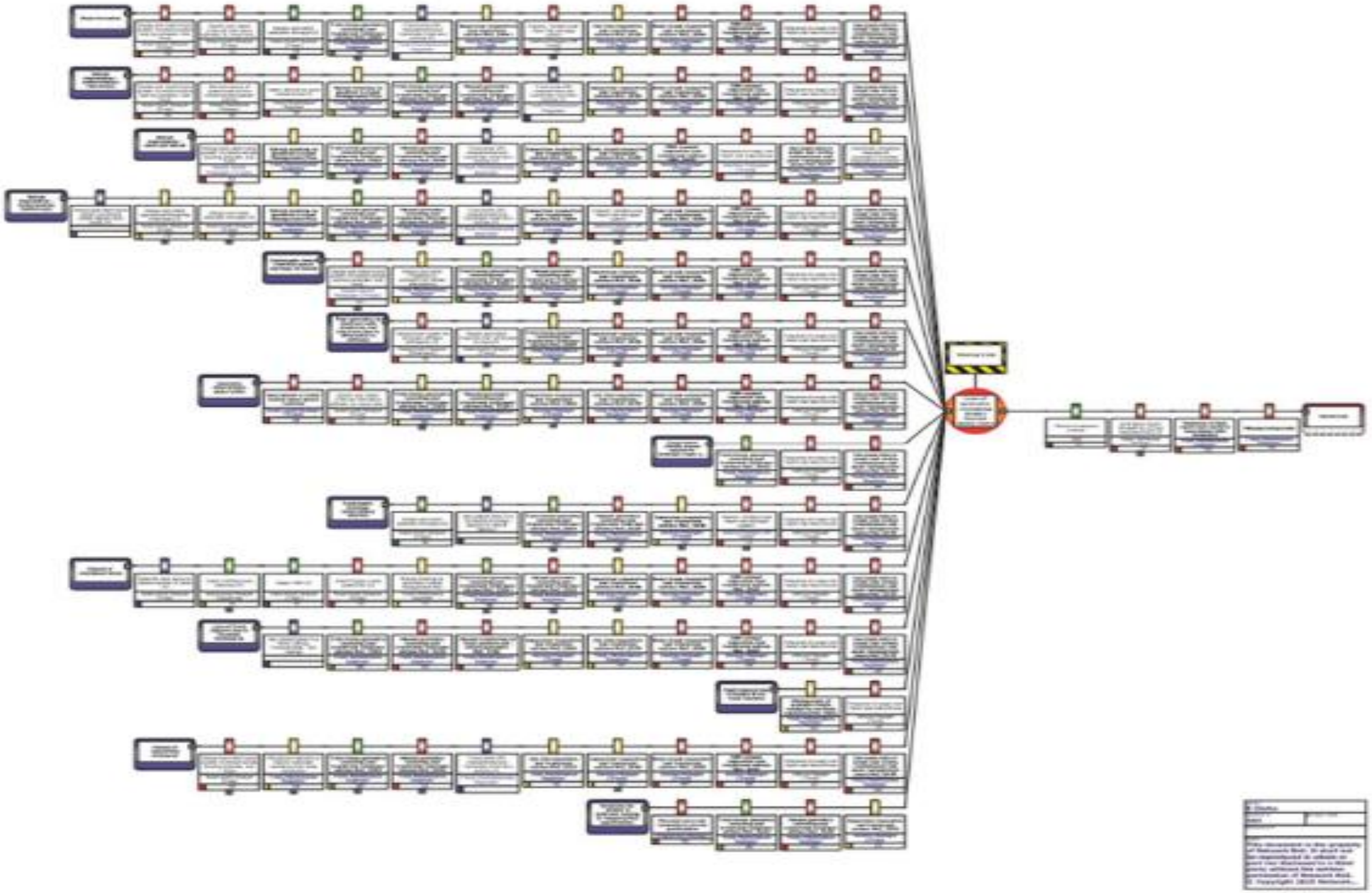


Figure 8.2 – Screenshot of a Network Rail bow-tie completed for a top event, i.e. a train passing over an unsupported track system (adapted from Network Rail, 2016)

8.4.1 Bow Tie Method

A series of workshops, developing bow ties, were held during late 2014 and continued during 2015, some of which the researcher was able to directly observe. For the purposes of this study the bow tie example to be referenced is that associated with operating trains over the plain line track system with a series of threats identified, including loss of track geometry, broken rail, insecure fastenings, and the wheel / rail interface.

Figure 8.3 shows the Hazard in the yellow/black hatched box, the Top Event in the red circle, four threats in blue boxes to the left, and the three potential consequences in red boxes to the right.

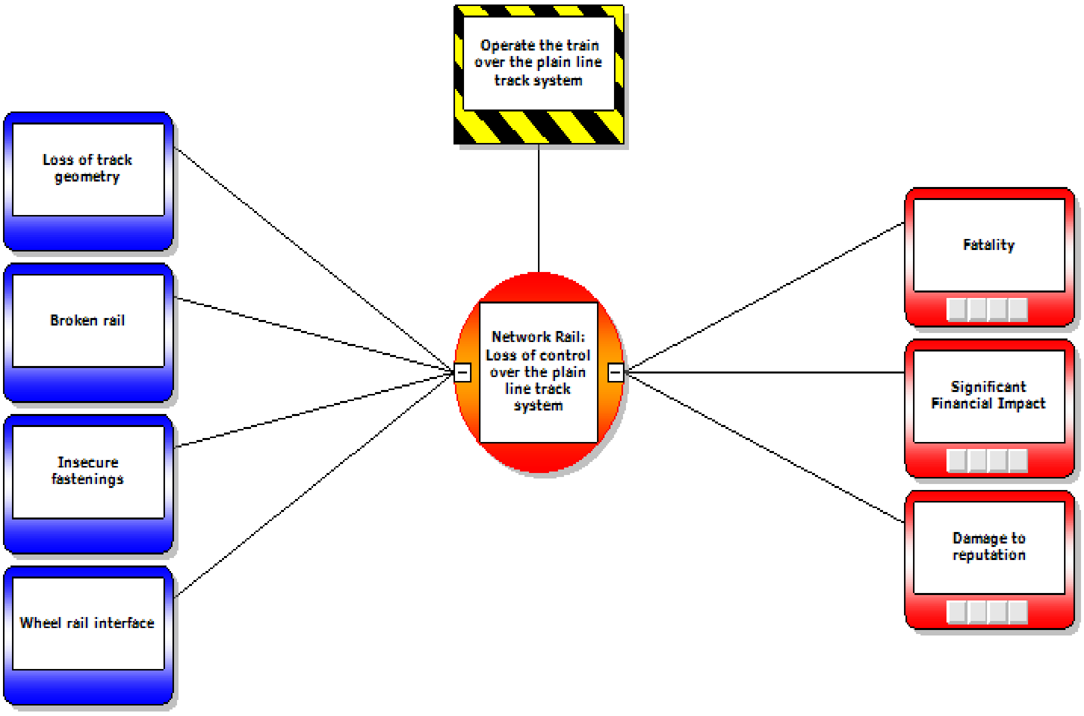


Figure 8.3 – Plain Line Track Bow Tie – part a (Network Rail, 2014)

Network Rail's approach to bow tie development was to use as a series of steps during the second workshop – facilitated by someone different to the first workshop (due to logistics) – to then identify barriers for each threat. Each barrier (for example, a visual inspection) was to be independent of other barriers and threats on the same line of the bow tie diagram, this was to create a clear delineation and allow for each barrier to be defined and represented rather than conflated with similar barriers (e.g. ultrasonic inspection). Furthermore, each barrier was required to represent a prevention or mitigation barrier, not both, with one designed to keep control and prevent the threat, and one limiting the impact of a consequence arising from a top event.

During the second workshop it was also observed how participants should identify the consequences in the bow tie model with the various potential outcomes of the event. This approach was to enable assessment of the barriers' effectiveness against the differing outcomes and allowed multiple examples of an outcome-type to be included too.

Of note is that consequences were not typically independent, and several outcomes could occur together or one after the other, e.g. a derailment causing a fatality, and a derailment causing infrastructure damage.

Finally, in the third workshop observed, facilitated by the person from the first workshop, time was taken to group the barriers, i.e. those that are co-dependent – see example below in Figure 8.4. The example here is an inspection which is not enough, on its own, to stop a threat – and so it needs combining with an action.

This workshop also ranked each barrier using a set of definitions provided to the participants, ranging from unacceptable, average, good, and very good (and which also had colour coding: red, amber, bright green and dark green to denote the ranking).

For each barrier, accountability was also assigned, i.e. the person ultimately answerable for the correct and thorough application of the process / control. For example, a track quality supervisor.

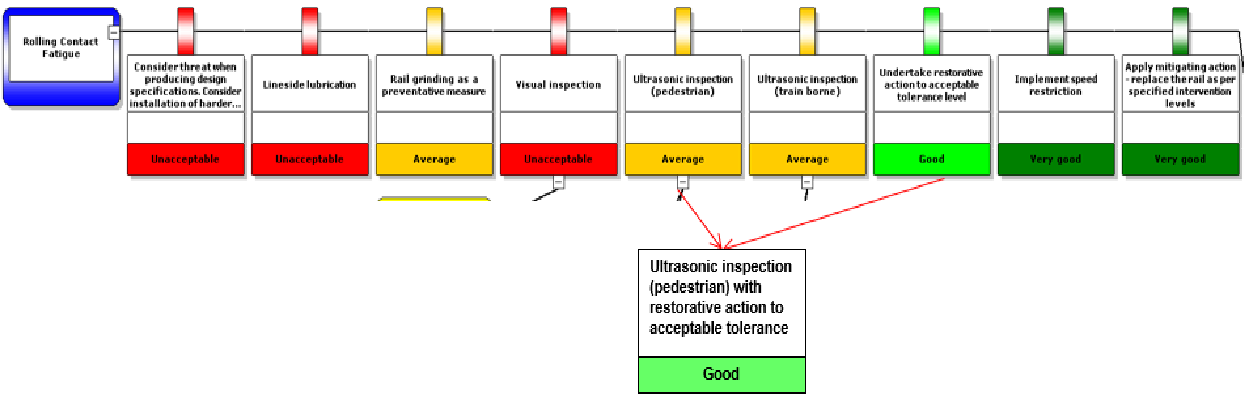


Figure 8.4 – Plain Line Track Bow Tie – part b (Network Rail, 2014)

8.4.2 Plain Line Track Method

The plain line track bow tie formed part of national trials that were undertaken by Network Rail to test the principles and framework of the Business-Critical Rules programme (previously described in Chapter 2, and a feature of Studies 1, 2 and 3).

The trials started in 2014 (a little later than planned) and included the suite of documents associated with the intended changes, i.e. the plain line track rules and some other related rules involving maintenance, risk management and fair culture, besides (critical and baseline) tolerances and limits, Means of Control (MOC) and Role-Based Manuals, to help trial participants understand the link between a risk and the process followed to manage that risk (see Chapter 2 where these are explained in more detail). The intention was to identify where problems might exist with aspects of process design and where work systems needed to be made more certain as a result, or more flexibility afforded, depending on the conditions.

The trials were specifically limited to creating and then applying (at a local level) the bow tie analyses for plain line track and were focused on:

- broken rails;
- loss of geometry (gauge) beyond safety limits;
- loss of geometry (top and twist) beyond safety limits; and
- loss of geometry (alignment) beyond safety limits

A range of data was collated by the national change team, including how many tolerances and limits were able to be challenged informed by the bow tie analysis, and how many critical limits hold good in all circumstances. The intention of the trial was not to generate change for change's sake but to give individuals freedom to evolve the controls system with a risk-based framework in support, and for the national change team to test the principles of bow tie analysis and business critical rules application before a move to full implementation. Of note is that only a selection of rules were chosen for the trial, not *all* rules, and a local change process was developed by Network Rail – that the researcher was able to review – intended to assist trial participants in identifying new derogations or variations required and formally recording these after appropriate authorisation.

Benefits and issues arising from the trials were captured during a series of post-implementation reviews related to the wider BCR programme (see Study 5, Chapter 9), but specifically a review was also undertaken by independent consultants brought in by Network Rail to identify where the bow ties were also likely to be scale-able, and adaptable to suit specific projects too. The researcher was able to discuss the post-implementation reviews, and the consultant's findings, with two interviewees known to have expertise and input to bow-tie development in Network Rail.

Background information was also supplied to the researcher by the Network Rail change team responsible for the business-critical rules programme and the associated plain line track trial. This included a controlled copy of the Role Based Manual for a Track Maintenance Engineer, and an uncontrolled copy of the procedure on how the bow ties were intended to be developed.

Related briefing and presentation materials were also given to the researcher on the agreement that these would be collated and analysed as part of this study and quoted as source material if required.

This range of published documents and information, alongside observation of three workshops, has resulted in a series of findings that are reported below.

8.5 STAMP / STPA evaluation

System Theoretic Process Analysis (STPA) is a hazard assessment tool derived from Systems-Theoretic Accident Models and Processes (STAMP) and is a hazard analysis method developed at the Massachusetts Institute of Technology (MIT) for modern complex safety-critical systems (Leveson, 2004).

Whilst much has been written about traditional techniques and methods to analyse variations and deviations at an individual component failure level, faults, and combinations thereof (e.g. Fault Tree Analysis), more complex safety-critical systems – such as nuclear, aviation, rail, space, oil and gas – can exhibit unsafe and undesirable behaviour that does not involve any component failures, or was never anticipated by failure-based analysis. For example, components may operate exactly as designed and may perform their intended function perfectly at the component level, while their interactions can lead to unexpected or unsafe system level behaviour. This is reported as occurring when engineering assumptions are incorrect, requirements are incomplete or otherwise flawed, components behave in conflicting or otherwise unanticipated ways, and/or when human interactions are not fully understood or anticipated (Thomas, 2013).

STPA uses a model called a control structure to determine how controls, feedback, and other interactions between failed or non-failed parts can lead to incidents / accidents. The STAMP workshop showed how STPA treats safety as a dynamic control problem rather than a failure prevention problem, and the emphasis is on enforcing constraints on system behaviour rather than preventing individual failures.

With the above in mind, having already recognised a 'systems thinking' approach would be needed to better understand Network Rail's two national change programmes, STAMP / STPA was selected as a potential prospective analysis tool.

The intention of the researcher was to apply the STPA method to design a safety-driven concept of Network Rail's future organisation structure, looking at how teams / individuals might interact with each other (rather than the more usual deterministic safety assessment focused on component level interfaces, e.g. the train with the signalling system).

The researcher and her colleague agreed they would specifically evaluate the Systems-Theoretic Process Analysis (STPA) method to analyse the design of the organisation structure proposed by Network Rail, intended to deliver better safety and performance through greater decentralisation and a transformation programme (referred to as 'Putting Passengers First').

Four basic steps of STPA were followed (See Figure 8.5), with more than 80 hours of collective effort spent over 9 separate sessions, that allowed for:

- The purpose of the analysis to be defined; i.e. considering the scope of the system to be analysed and the system boundary, (safety, performance etc.).
- A model of the system to be built around the control structure (e.g. relationships, interactions, feedback control loops etc.).
- An analyses of control actions in the control structure, with unsafe control actions able to be used to create functional requirements and constraints for the system.
- The identification of loss scenarios and the reasons why unsafe control might occur, e.g. because of design errors, or safe control actions are not followed or executed properly.

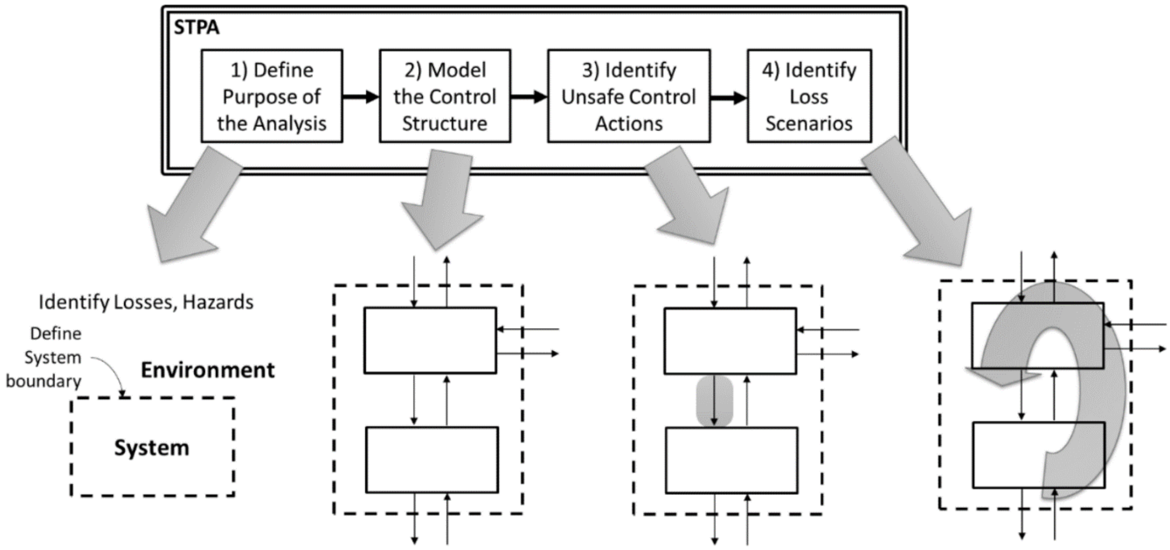


Figure 8.5 – Overview of the basic STPA method. Source: Dr, John Thomas, MIT (2019)[42]

The following is a detailed overview of the approach taken for each of the four steps, outlining key stages as part of the STPA method as applied by the researcher.

It should be noted that examples using the STPA method are given, not *all* possible losses, hazards, or system constraints.

The examples were developed based on readily available information, drawing on the experience and knowledge of the researcher and her colleague around current systems and the environment, and the ability of the researcher to complete the STPA within a reasonable timeframe, i.e. no more than 10 working days, given her own, and her colleagues, other diary commitments.

[42] Nb: the use of figures in this study is with the permission of Dr John Thomas having attended his workshop in 2019 in Manchester; he advocates that the STPA method should be shared and applied in real-world situations

8.5.1 STPA Method

8.5.1.1 Step 1 of the STPA Method

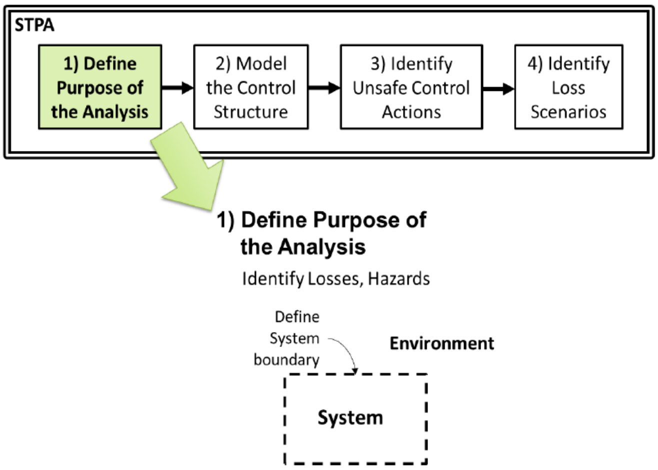


Figure 8.6 – STPA Step 1: Defining the purpose of the analysis

For this study the purpose of the analysis was defined as: ***the identification of hazards and how these relate to an organisation re-design to achieve a new future state / structure in Network Rail***

The system boundary was defined as: ***company management, its operational design and documentation, and the implementation and assurance of operations processes.***

Outside of this system boundary there are other things that cannot be directly controlled, e.g. the external environment such as government, regulations, funding etc. These were acknowledged to exist by the researcher and her colleague.

Having identified the system boundary, the next step for the study was to define the system-level hazards by identifying system states or conditions that will lead to a loss in worst-case environmental conditions. The STPA method is quite prescriptive in defining certain elements, e.g. what is a hazard and what is a system, and so these were duly considered when identifying system-level hazards.

Consideration was given to how the hazards might lead to a loss in a worst-case situation, and therefore the twelve identified were very much thought to be the most significant ones which require to be prevented as part of the process of organisational re-design. They specifically refer to factors thought to be able to be controlled or managed by the system designers and operators.

The process of STPA also allows for potential sub-hazards to be identified per hazard, and so the researcher decided to select just one specific hazard (i.e. Hazard 1) to work through to give an indication of the types of sub-hazards that need to be considered – see Table 8.4 in the results section (8.4.2.1) below.

Once the system-level hazards were identified, the STPA method requires the identification of system-level constraints that must be enforced, such that each constraint should be traceable to one or more hazards, and each hazard is traceable to one or more losses.

The method suggests the traceability need not be one-to-one; a single constraint might be used to prevent more than one hazard, multiple constraints may be related to a single hazard, and each hazard could lead to one or more losses.

The STPA methodology further requires the identification of potential sub-system level elements, in this case, sub-constraints. The researcher and her colleague agreed to select two constraints (i.e. System Constraints 7 and 12) to work through – see Tables 8.6 and 8.7 in the results section (8.4.2.1) below.

8.5.1.2 Step 2 of the STPA Method

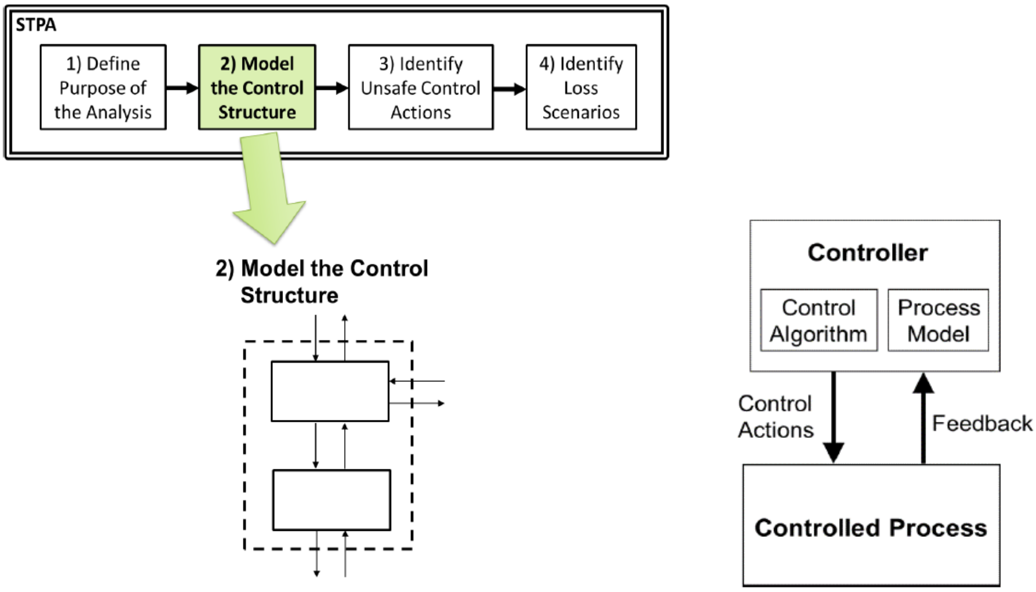


Figure 8.7 – STPA Step 2: Modelling the control structure

At step 2 it was important to understand that a controller, in the context of the STPA method, may provide control actions to control some process and to enforce constraints on the behaviour of the controlled process. The control algorithm represents the controller's decision-making process, and then the control actions to provide.

Controllers also have process models that represent the controller's internal beliefs used to make decisions. Process models may include beliefs about the process being controlled or other relevant aspects of the system or environment.

All downward arrows represent control actions (commands) while the upward arrows represent feedback.

The generic control loop can be used to explain and anticipate human interactions that can lead to losses. For humans, the process model is usually called a mental model and the control algorithms may be called operating procedures or decision-making rules.

Of course, most systems typically have several overlapping and interacting control loops, and this was a consideration for the researcher as modelling of the control structure was undertaken.

8.5.1.3 Step 3 of the STPA Method

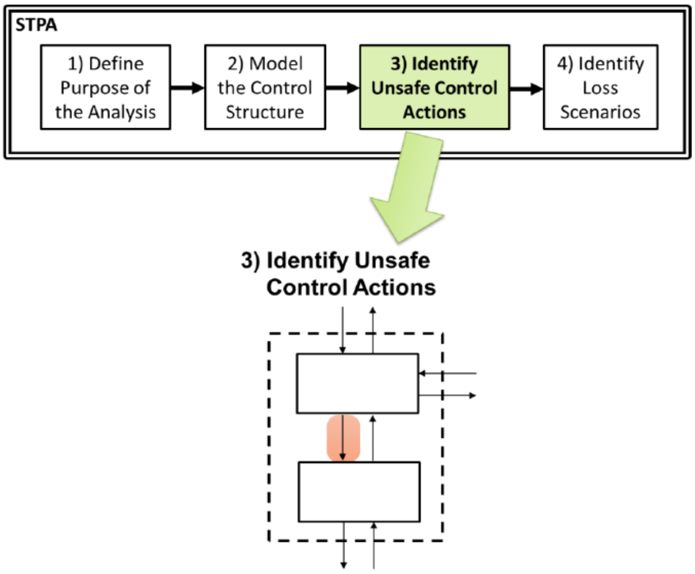


Figure 8.8 – STPA Step 3: Identifying Unsafe Control Actions (UCAs)

Next, the researcher moved to step 3, to identify unsafe control actions (UCAs), in the knowledge that the STPA method says there are four ways a control action can be unsafe:

1. not providing a control action, and causes a hazard;
2. providing a control action, and causes a hazard;
3. providing a control action too early, too late or out of order / sequence;
4. stopping a control action too soon, or applies it for too long.

Once the UCAs were identified, they can be translated into constraints on the behaviour of each controller. See Table 8.11 in the results section below.

8.5.1.4 Step 4 of the STPA Method

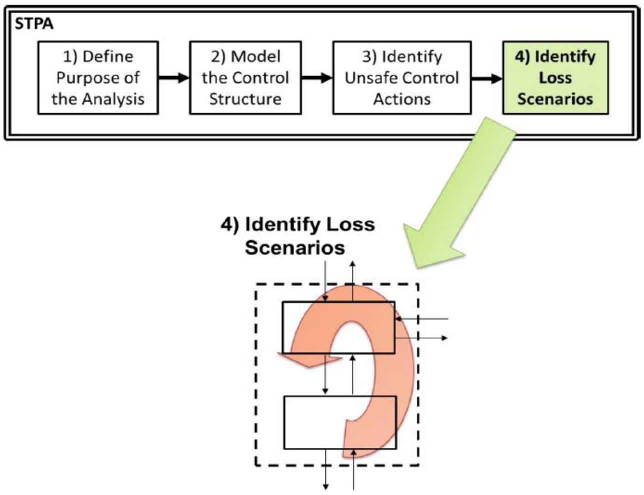
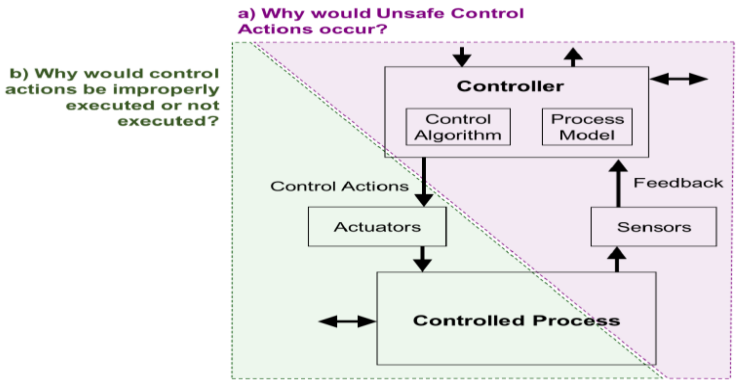


Figure 8.9 – STPA Step 4: Identifying loss scenarios

Having identified unsafe control actions (UCAs), step 4 required the identification of loss scenarios, considering (a) why would UCAs occur, and (b) why would control actions be improperly executed or not executed, leading to hazards?



Note: the figure includes sensors and actuators. Up to this point in applying the STPA method, the researcher has considered the control actions and feedback that may exist, but not yet examined how the feedback is measured or detected (e.g. with sensors) or how the control actions are executed (e.g. with actuators).

Figure 8.10 – Identifying scenarios that lead to Unsafe Control Actions

Different scenarios were created by the researcher by starting with a UCA and working backward to explain what could cause the controller to provide (or not provide) that control action. Consideration was given to the factors shown below in Figure 8.11, starting with the unsafe controller behaviour that caused the UCA.

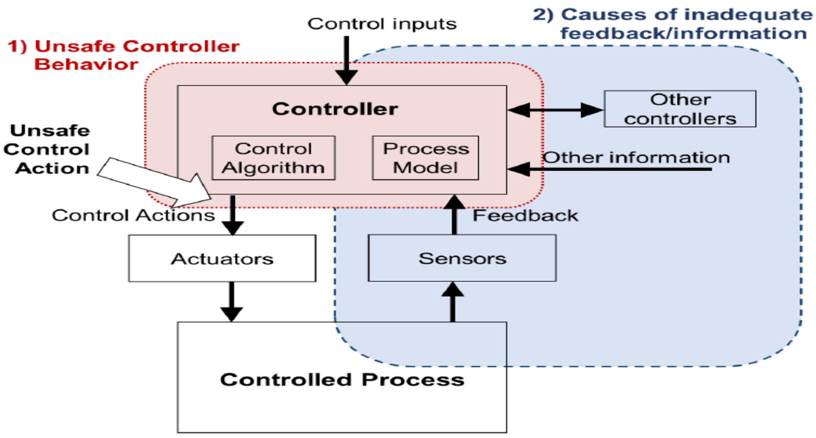


Figure 8.11 – Scenarios that lead to unsafe controller behaviour and unsafe control actions

Consideration was given to the reasons why a controller might provide (or not provide) a control action that is unsafe.

For physical controllers it was recognised that a UCA may occur due to a failure related to the controller. For example, the controller may not provide the command because the controller fails, because the power fails etc. An inadequate control algorithm can also cause a UCA. A control algorithm specifies how control actions are selected based on the controller's process model, previous control inputs and outputs, and other factors. For human controllers, the control algorithm is sometimes called decision-making and it may be shaped by different factors like training, procedures, and experience.

Unsafe control inputs from other controllers was also another factor considered that can cause UCAs. These are usually found during Step 3 above when identifying Unsafe Control Actions for other controllers.

8.6 Findings

8.6.1 Reflections on the bow tie approach and the subsequent Plain Line Track trial undertaken by Network Rail

During the past 5 years Network Rail has developed more than one hundred bow tie diagrams covering a range of hazards across different asset types, and involving a number of individuals, primarily from central (rather than Route-based) teams with a knowledge of risk management or safety practitioner experience. The workshops to develop these, however, were facilitated by different individuals with a variety of backgrounds, leading to the potential for inconsistency in approach, i.e. minutiae for some looking to a component level, and general with others (e.g. the overall rail system). It is possible this was intentional, to gain different perspectives of a system, but there's no evidence in the defined process for producing bow ties (Network Rail, 2017) of any preferred approach.

The observation of the bow tie workshops identified very early on that participants had to agree that each threat was a top event in its own right, i.e. something that caused it in the first place, and over a series of three workshops observed by the researcher (a total of 18 hours), the attendees sought to gradually build up a bow tie around each threat to understand what causes them, and how to prevent them occurring.

The 100 or so risk bow ties produced to-date by Network Rail have been used to support the updating of national standards across the organisation and have enhanced the methods for enabling local change to accommodate risk-based maintenance regimes for various asset types. They have brought about an awareness of numerous threats and consequences, and show that multiple barriers are required to prevent, or help recover from, events. The process has meant fostering discussion on a range of potential hazards, and the processes and people involved in loss prevention, requiring input from many people (Network Rail, 2020).

There were undoubted benefits in Network Rail seeking to bring awareness and visibility of the controls that one might expect to be in place and are relied upon to protect against losses. Using Means of Control manuals as part of the national trials across Network Rail – with the different types of controls made visible and available – were a significant step on the risk management journey. The independent review commissioned by Network Rail also confirmed the bow ties were positively received when used to graphically demonstrate complex risk scenarios, making it easier to communicate these to staff.

Several benefits were reported and presented by the BCR Programme Team to the Network Rail Executive (Network Rail, 2016) as having emerged from the initial trials that started in 2014 (albeit that the trials were curtailed early due to issues of non-compliance with the new BCR material and an ability of some teams to adapt the Means of Control locally to how their delivery unit works). The three main benefits listed were:

1. ***A clear and visible connection between the risks inherent in Plain Line Track assets and the controls put in place to manage those risks.*** *NB: previously Network Rail would state that x, y, or z needed to be done without saying why it was a requirement. Under the change framework, using the bow ties, it was intended there would be a link back to the risk that each control was designed to deal with. That said, there is the assumption here that all risks can be identified and prevented in advance – a systemic method would help see this differently.*

2. ***An explicit identification of the critical limits[43] which hold good in all circumstances, and are to be followed at all times, so nobody is in doubt that they are to be complied with.*** *NB: the Network Rail standards had previously lacked this clarity, and there had been less important requirements that had the potential to assume as much prominence as the most important ones.*

[43] These are limits set for rail assets that must be complied with at all times, e.g. track gauge must equal 'x', the rail temperature must not to exceed 'y'.

3. ***The change framework, as part of the bow tie process, permits risk assessment of alternative Means of Control, with implementation of these allowed under written authority.*** *NB: this means, alongside the critical limits which apply everywhere, that Network Rail could (in theory) apply appropriate controls locally that have been risk assessed and 'owned' by the teams in the delivery units, but this proved problematic in some locations due to pre-existing issues with non-compliance, and large backlogs of work.*

However, it became evident during the workshops observed by the researcher that there was insufficient knowledge of all the processes and hazards under control. This could have been addressed by suitably informed operational knowledge and experience had greater thought been given to attendees, and advanced preparations. Those observed in the workshops seemed to refer to and describe extant processes, i.e. 'work as intended' rather than the 'work as done' seen through the lens of a frontline practitioner (Hollnagel *et al*, 2006).

The emphasis in the workshops was on referencing known standards and risks, and the capability to comply. There was also no suggestion that perhaps the bow ties could be developed in anything other than the prescribed way by Network Rail, for example starting with consequences and working back through the bow ties. This might have allowed for some greater staff reflection – perhaps because of a particular concern around the consequences arising from a loss of control – and to help identify and critically judge how work is carried out. Such an approach might also then have created an opportunity to establish leading rather than lagging indicators and avoid relying on indications that point towards a failure to control risk (SPE, 2014).

How the bow ties are developed, e.g. a combination of fault and event trees[44], and whether barriers are in series and/or consequential are really important to understand (CAA, 2015). It was observed by the researcher that some individuals seemed to struggle to ascertain the difference between one barrier failing and resulting in a top event, versus all the barriers needing to fail for the top event to occur. This appears to have arisen from people taking their cue from the graphical representation of the bow tie and the descriptions of links between parts, not then necessarily also factoring in the possibility of concurrence (i.e. things happening simultaneously), or a stable system suddenly becoming unstable (e.g. incorrect performance of a safety critical task which could increase the risk of a top event or increase the severity of its consequences).

Whilst proprietary tools were available to prepare the bow ties during the workshops it seemed easier for some participants to have these drawn by hand on whiteboards. This often meant limiting what was captured and/or a tendency to have very few mitigations (to the right of the bow tie), almost always leading to a series of controls in a traditional linear way, albeit that these are not in a particular order, they are just presented this way.

[44] A Bow Tie diagram is created by combining two established risk analysis tools, the fault tree, and the event tree. Fault trees picture all possibilities that lead to an event. Event trees work inversely, starting with a single event and modelling all its consequences.

It was certainly noticeable how the barriers to the left of the diagram (seeking to prevent threats from releasing a hazard) are significant in their number, compared to the right side of the diagram where there are very few barriers (i.e. recovery controls, limiting the impact of a consequence arising from a top event). A few examples are detailed below in Table 8.1, where an unequal amount of the barriers is focused on prevention, and less so on the response after an event.

Table 8.1 – Example of bow ties, comparing prevention vs recovery controls

Bow Tie (by asset type)	Barriers (prevention)	Barriers (recovery controls)
Broken Rail	76	7
Track buckle	55	12
Loss of Geometry (excluding gauge)	110	10
Loss of Geometry (gauge)	33	4
Unsupported track system	125	4

It is possible few mitigations were identified as the workshop attendees were satisfied that they had identified enough or at least sufficient acceptable ones. This is not untypical of other bow ties seen in use in other safety-critical sectors (CAA, 2015), i.e. where there are 'stopping rules' when it is considered there is no practical benefit in going further, but does beg the question on how far an organisation should go in assuring itself that both the preventative barriers and mitigations can stop a top event from occurring and leading to the consequences.

There was certainly a lot of pace injected into two of the three workshops observed, seemingly because of the imperative to deliver the wider change programme benefits and drive the rapid development of the diagrams; this meant the criticality scores of each barrier[45] did not necessarily factor in any potential for flexibility, complexity or variability (e.g. local conditions, like limited clearances in some locations on the track or across bridges), nor was there much of an attempt to understand what people actually do beyond assigning responsibility to each barrier. Ideally, time would have been given to consider *all* engineered and procedural solutions, and how they are applied in practice, without which it means that the barriers that are included are not necessarily reflective of the risks and controls needed to be in place.

One might argue that the slightly unmanageable approach by Network Rail to creating such a large number of bow ties in quite short order resulted in the workshop participants identifying a not insignificant number of plans, processes and tools, that were inappropriately classified as controls. This led to unnecessarily complex bow ties being created, and potentially had the effect of reducing the attention required to implement the controls to manage, mitigate or prevent adverse events, as there wasn't enough time allocated to talk about any item in sufficient detail. Furthermore, prospective measures, such as monitoring, audit, and assurance, were not appraised for their own effectiveness at detecting weaknesses in operations and maintenance, and so left Network Rail vulnerable should these safeguards not be working well too.

[45] Network Rail use a 4x4 matrix to identify a criticality score across two criteria (i.e. Inherent strength – a relative measure of the control strength based on the bias between an engineered versus procedural solution, and then its application – a relative measure to determine how well the control is used in practice.

Clearly the bow tie technique can support prospective analysis if the view taken is that the organisation's resilience comes from the predictability of threats. Predictability in this context does not mean foretelling when an event will occur, but that its occurrence is foreseeable (HSE, 2008).

During the Plain Line Track-related bow tie workshops there were some participants who could clearly draw on learning from their experiences. This included making use of specific performance and incident data and sharing their knowledge of past events. This helped with identifying the primary barriers that can target direct threats. A second element was in the identification of symptomatic events, and emerging trends (for example, replacing foot patrols on track with trolley patrols, reducing the number of slips, trips and falls, but also removing risks like working without protection, and benefiting from the use of trolleys to carry tools to do additional work, like minor repairs. The information came via safety 'experts' who proffered incident and near-miss data, such as the Precursor Indicator Model (PIM) that is produced by the Rail Safety and Standards Board (RSSB) as a quantified risk model for understanding train accident risk[46].

What was not in evidence, however, was the practical realities of predicting threats and decay / failure modes related to controls, and how and when these occur. The absence of track workers and their supervisors or managers in the workshops meant this information and knowledge was missing from the bow tie development work and analysis. For example, very little, if any, cognisance was taken during the bow tie workshops of the human factors associated with supporting and applying the control measures. Operational pressures, assumptions, non-compliance, and human error can all erode the effectiveness of the control measures, and yet this was not a feature of the workshops. There was nothing to indicate in the supporting materials how controls could be sustained or indeed how the bow ties would go on to be updated over time considering adverse events and organisational learning.

8.6.2 Reflections on the use of the STPA method

8.6.2.1 Procedure to complete Step 1

A total of 24 hours was spent on working through Step 1. This included 4 hours to re-read the STPA workbook that was provided as part of the workshop, and several hours to review the tools that might be available in support, e.g. software to capture the hazards, and before the losses, hazards and constraints were actually identified.

Defining the purpose of the analysis specifically required four elements for consideration, i.e. identify losses, system-level hazards, system-level constraints, and (if necessary) a refinement of the hazards.

[46] Network Rail also has a Horizon Scanning Group that assists with identifying any items (technology, events, practices and trends) external to the business that could pose a risk to its safety or sustainable development objectives. This was not in place at the time of the early bow tie workshops.

Using the STPA method as part of this study, and the framework of losses, hazards, and controls, 8 unacceptable losses, and 12 hazards related to these losses were identified. Taking just one hazard alone, there were then 9 sub hazards, and numerous system constraints and sub constraints that emerged.

(a) Identifying losses

The following losses listed in Table 8.2 are those identified by the researcher and her colleague, through the lens of them being users / stakeholders within the system boundary. These are not intended to be comprehensive but instead give a flavour for the types of loss considered. The researcher has NOT sought to reference individual components or specific causes, e.g. "human error" or "brake failure".

Table 8.2 – Identified losses

L1	Loss of life or injury to people
L2	Loss of or damage to infrastructure or assets
L3	Loss of operational capability / performance
L4	Loss of customer / passenger satisfaction
L5	Financial loss
L6	Reputation loss
L7	Environmental / sustainability loss
L8	Loss of employee engagement / wellbeing

(b) Hazards

The following system-level hazards are those identified by the researcher and her colleague through the lens of them being users / stakeholders within the system boundary (see Table 8.3 below).

Other system-level hazards undoubtedly exist as regards Network Rail's structural change and drive for decentralisation but have not been included here because STPA is an iterative method, and the hazards did not need to be set in stone at this point. Later STPA steps can uncover new hazards and the method allows for the list to be revisited and revised.

Table 8.3 – System-level hazards

		Link to Loss(es)			
H1	Change(s) lead to organisational uncertainty	L8			
H2	Organisational culture; cover up and blame rather than identifying and solving problems	L2	L3	L8	
H3	Inefficient workflow with breakdowns and non value-added steps	L1	L2	L3	L8
H4	Inability to control the intensity and/or pace of change	L1	L2	L3	L8
H5	People don't have information and/or authority to solve problems when and where they occur	L1	L2	L3	
H6	Lack of knowledge and focus on objectives (e.g. customer service, putting passengers first etc.)	L4	L6		
H7	Delays or capability in decision-making	L1	L2	L3	
H8	Systems are ill-defined or reinforce wrong behaviours	L1	L2	L3	L8
H9	Lack of ownership ("It's not my job") or a shared vision (e.g. agreed set of priorities)	L8	L2	L7	
H10	Fragmented work with little regard for good of the whole (misaligned goals)	L4	L5	L6	L7
H11	Mistrust between workers and management (leading to change resistance)	L6	L8		
H12	Silo mentality and functional 'turf battles'	L1	L2	L3	L8

(c) Potential sub-hazards

Potential sub-hazards can be identified per hazard, and so the researcher selected just one specific hazard (i.e. Hazard 1) to work through to give an indication of the types of sub-hazards that need to be considered.

Table 8.4 – Potential sub-hazards related to Hazard 1: 'Change(s) lead to organisational uncertainty'

H1.1	Trade Union support is insufficient to allow for changes to proceed
H1.2	Insufficient employee uptake for new roles
H1.3	Uncontrolled communications lead to 'tittle tattle' and misinformation
H1.4	Different cues for organisation drift and resilience (personnel, meetings, relationships)
H1.5	Duplication and re-work, competitive and localised solutions
H1.6	Multiple (sub-optimal) solutions for common problems
H1.7	Need for decentralised specialist expertise requires more capacity (staff)
H1.8	Lack of co-ordination and control
H1.9	Strong requirements and principles hard to articulate / message attrition happens quickly

(d) System constraints

The following system-level constraints are those identified by the researcher and her colleague that seek to specify system conditions or behaviours that need to be satisfied to prevent hazards (and ultimately prevent losses). Consideration was given to how these constraints might already exist or be required to be developed, informed by the researchers working knowledge of Network Rail's management, its operational design and documentation, and current implementation and assurance of its operations processes.

Table 8.5 – System constraints

		Link to Loss(es)			
SC1	The programme need to manage organisational change uncertainty	L8			
SC2	A behaviour change programme to manage uncertainty and maintain shared corporate objectives is embedded in the transformation plans	L2	L3	L8	
SC3	Clear process / work flows provided and processes made LEAN	L1	L2	L3	L8
SC4	Clear plans for the roll out and implementation of new technologies, factoring in pace of change and including user-experience design input	L1	L2	L3	L8
SC5	Clear disposition of current accountabilities and responsibilities is undertaken prior to the change(s)	L1	L2	L3	
SC6	Clearly defined / articulated vision, mission and objectives	L4	L6		
SC7	The organisation design has considered competence / capabilities for decision-making within agreed accountabilities	L1	L2	L3	
SC8	Systems are well defined and provide clear line of sight on expected behaviours	L1	L2	L3	L8
SC9	Clear goals, milestones and priorities	L8			
SC10	Work is planned / structured around agreed goals, and a systems view is taken to deliver a safe, performing and reliable railway	L4	L5	L6	L7
SC11	Well-consulted, engaged, Union(s) and Workforce, with people-centred implementation plans	L6	L8		
SC12	Organisation design removes silos and moves to a matrix structure that does not introduce more silos	L1	L2	L3	L8
SC13	Matrix introduces duplication and interface management issues	L1	L2	L3	L8

(e) Potential sub-constraints

The researcher and her colleague agreed to select two constraints (i.e. System Constraints 7 and 12) to work through – see Tables 8.6 and 8.7 below.

These were chosen over other possible system constraints on the basis that they offered two different types of sub-constraint but were linked to similar loss(es), and were likely to lead to similar, subsequent, controls, e.g. clear lines of accountability / responsibility needing to defined within the organisation structure.

Table 8.6 – Potential sub-constraint linked to System Constraint 7: 'The organisation design has considered competence / capabilities for decision-making within agreed accountabilities'

SC7.1	Sufficient information available to enable the workforce to make risk-based decisions
SC7.2	Sufficient level of training available to develop decision-making competence / capability
SC7.3	Clear lines of accountability / responsibility defined within the organisation structure
SC7.4	Sufficient specialist expertise available

Table 8.7 – Potential sub-constraint linked to System Constraint 12: 'Organisation design removes silos and moves to a matrix structure that does not introduce more silos'

SC12.1	Design controls prevent unsafe changes and detect if they occur
SC12.2	All planned changes are evaluated, including temporary ones, for potential impact on safety
SC12.3	Individuals understand the organisation and why it was designed the way it was
SC12.4	Clear lines of accountability / responsibility defined within the organisation structure

8.6.2.2 Procedure to complete Step 2

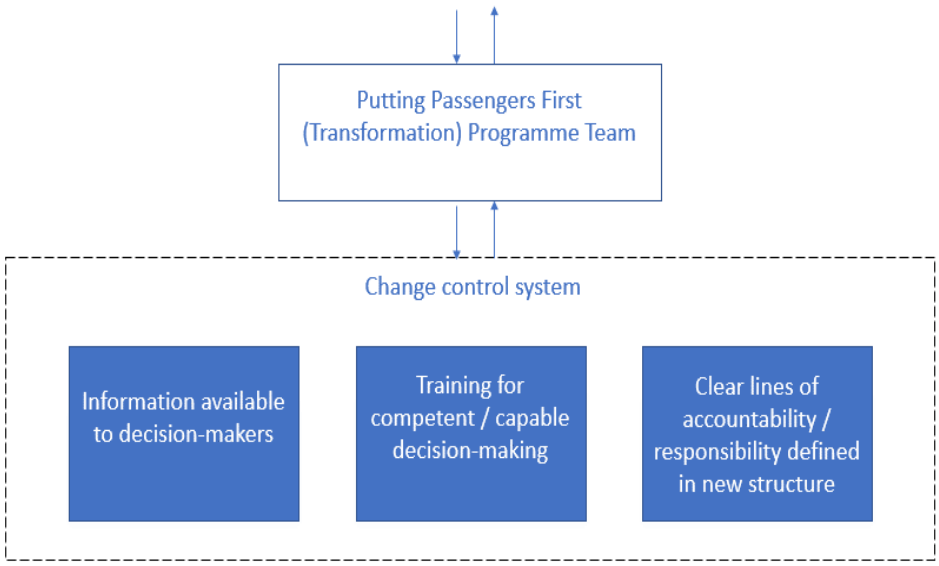
Completing the various stages of step 2 took a further 12 hours of collective effort.

To start this second step in the process the researcher identified the basic subsystems needed to enforce the previously identified system constraints, and prevent the hazards identified earlier.

Figure 8.12 presents the initial control structure, providing an example of these sub-systems. It should be noted that in this case, as the STPA method was being applied early before design development was finished, some information was not necessarily known, and the control structure might be considered incomplete. Therefore, the analysis started with an incomplete control structure with a view that the STPA method would later help identify potentially missing feedback, controls, and other gaps so the control structure could be refined in parallel with organisation design development.

The bare minimum was applied to begin with, i.e. at least one controller, control action, and controlled process. However, it is accepted that STPA will be easier and more efficient if relevant information is not intentionally missing from the control structure.

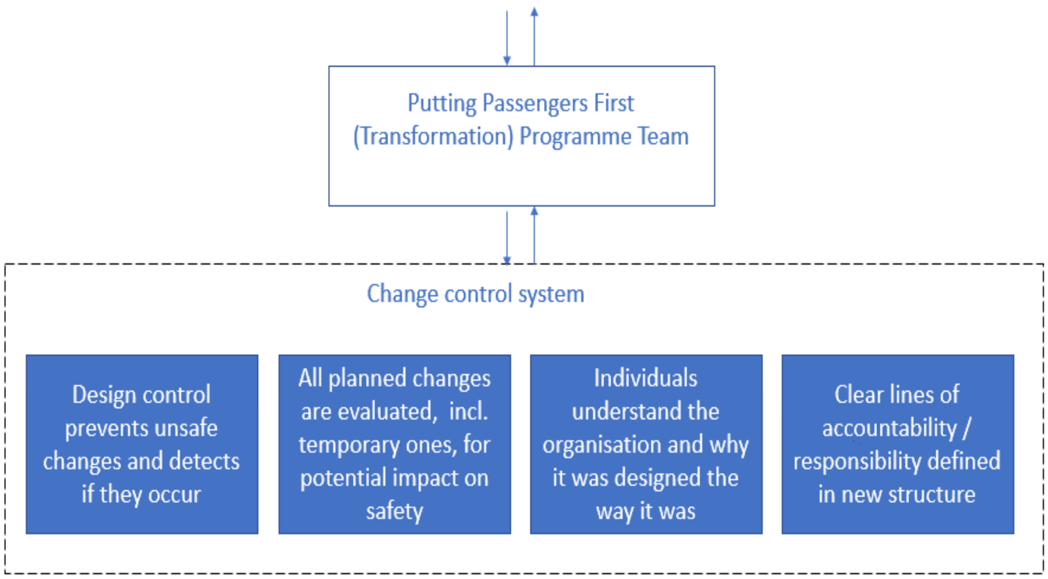
In example 1 below (system constraint (SC7)), hazards and constraints were derived, related to delays in or capability of decision-making. It was considered that these constraints could be enforced by information being available to decision-makers, training for decision-makers and/or clear lines of accountability / responsibility defined within the organisation structure.



System constraint SC7:
The organisation design has considered competence / capabilities for decision-making within agreed accountabilities

Figure 8.12 – Control Structure with Subsystem(s) related to decision-making

In example 2 below (Figure 8.13), using system constraint (SC12), hazards and constraints were also derived, this time related to organisation design. These constraints could be enforced by design controls, the evaluation of planned changes, an understanding of the organisation and why it was designed as it was, and/or clear lines of accountability / responsibility defined within the organisation structure.



System constraint SC12:
Organisation design removes silos and moves to a matrix structure that does not introduce more silos

Figure 8.13 – Control Structure with Subsystem(s) related to organisation design

Having identified the subsystem(s) the STPA process allows for the refinement of the control structure by defining how they will be controlled. For the purposes of this evaluation of the method, the researcher decided to refine the training for competent / capable decision-making subsystem.

Consideration was given to whether the training subsystem will be controlled directly by the transformation team only. For example, will a training strategy, standards or other teams exist that can also control the training process? In this case, as STPA was being applied during early concept development, then the hazards and the constraints above could be used to guide these decisions. Later, you might decide to include a requirement for mandatory training for key safety roles where risk-based decision making is a core requirement or agree to change the training function to be able to respond to evolving or emerging business needs.

The process meant carefully 'zooming in' to add more detail to the control structure (see Figure 8.14), however at this stage – to keep things deliberately simple – no direct control or feedback links were made between the Programme Team and Training standards.

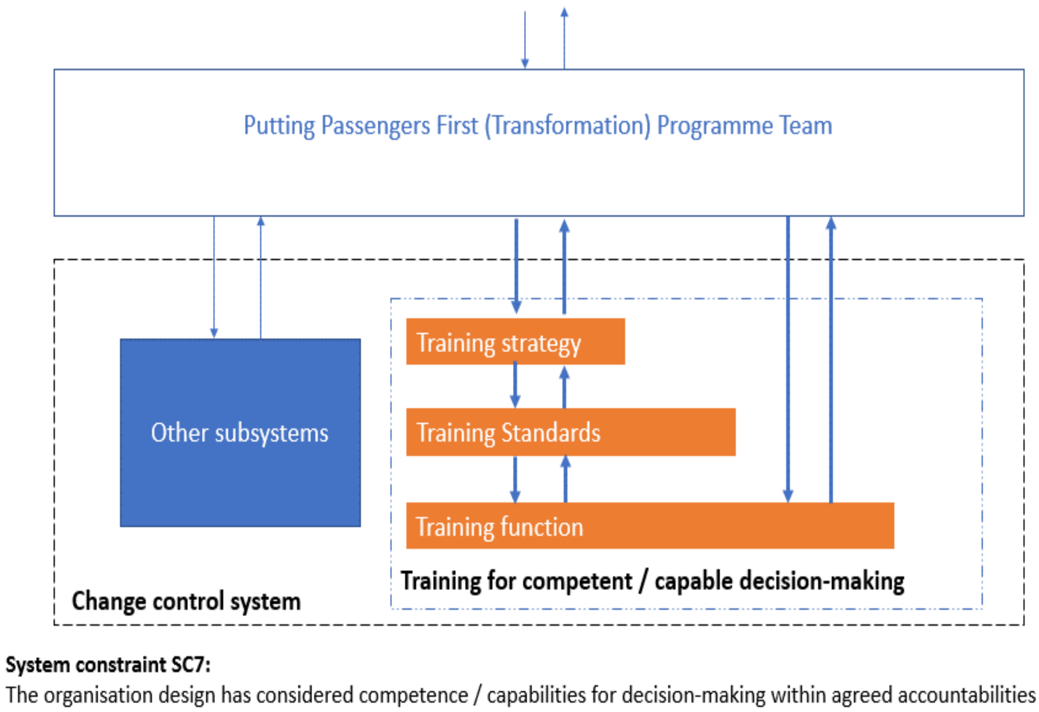


Figure 8.14 – Refined Control Structure with Subsystem Controllers related to decision-making

During this second step, once the controllers were identified, then responsibilities could be assigned (see Table 8.8). These responsibilities are a refinement of the safety constraints, i.e. what does each entity need to do so that together the safety constraints will be enforced? For example, the training strategy might set out the requirements for who training in decision-making should be applied to, while the transformation team may be responsible for deciding when the training is to be applied, (e.g. only to new starters in safety critical roles).

Table 8.8 – Responsibilities assigned related to training for decision-making

		Link to Sub-constraints	
Training Strategy			
R1	Sets out requirements for who should be trained in decision-making	SC7.3	
R2	Training strategy - who controls and delivers what? How is coordination and consistency achieved?	SC7.3	
Training Standards			
R3	Determines what needs to be trained, e.g. risk-based decision making in emergency scenarios	SC7.2	
R4	Sets and enforces mandatory training for risk-based decision making	SC7.2	
R5	Provides stewardship of decision-making competence / capabilities	SC7.2	SC7.3
R6	Agreement on who owns the training standards	SC7.2	
Training Function			
R7	Decides how to deliver the training, e.g. face-to-face, e-learning etc.	SC7.2	
R8	Provides sufficient quantity / quality of trainers to deliver training in risk-based decision-making	SC7.2	
R9	Alignment of Regions (unique) requirements - local to them	SC7.1	SC7.3
Transformation team			
R10	Designs organisation structure to provide clear lines of accountability for decision making	SC7.3	
R11	Assigns resposibilities for decision making throughout and at all levels of the control structure	SC7.3	
R12	Ensures tools / systems available to enable the workforce to make informed risk-based decisions	SC7.1	

Next, the control actions for each controller were to be defined based on the identified responsibilities. For example, the transformation team will need the capability to describe the organisation accountabilities and responsibilities to satisfy responsibility R10. They will need a way to assign responsibilities throughout and for all levels of decision-making to satisfy responsibility R11. They may need to design and/or procure new tools and systems to satisfy responsibility R12.

Figure 8.15 shows a revised control structure with labelled control actions based on the responsibilities described for system constraint SC7, i.e. the organisation design has considered competence / capabilities for decision-making within agreed accountabilities.

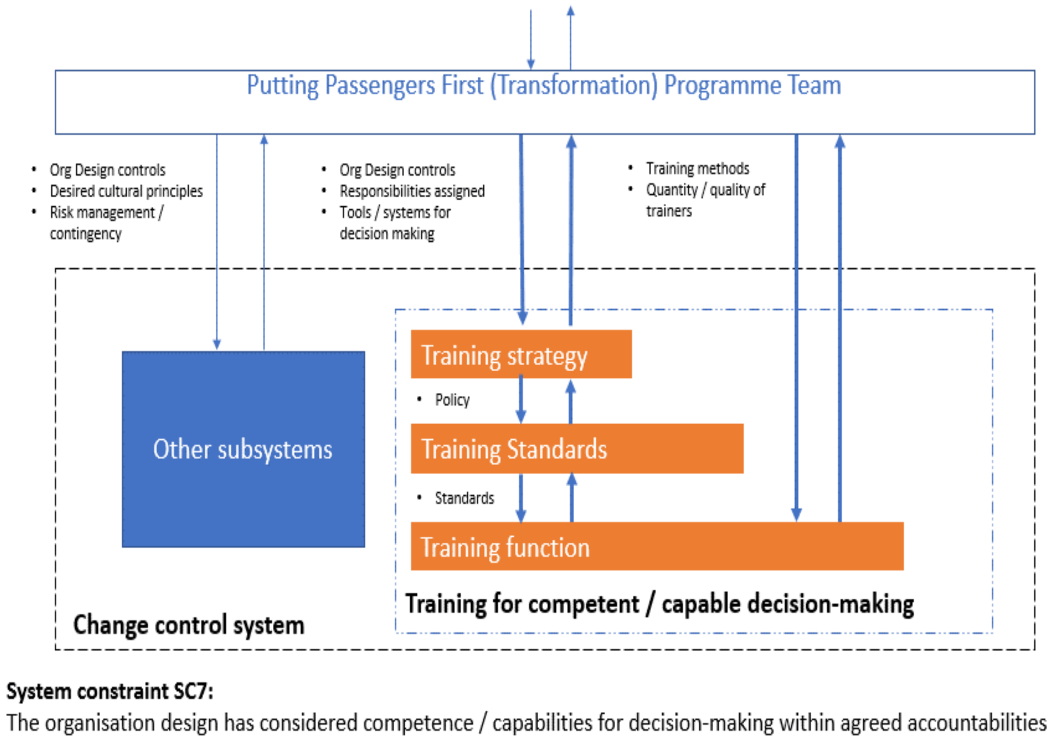


Figure 8.15 – A refined control structure after the allocation of processes to subsystems related to decision-making

Finally, as part of step 2, having identified and labelled the controllers and control actions, the next stage was to address feedback. The feedback is derived from the control actions and responsibilities by first identifying the process models that controllers will need to make decisions. Then, feedback and other information needed to form accurate process models can be identified.

For example, assigned responsibility R8 specifies a requirement for sufficient quantity / quality of trainers to deliver training in risk-based decision making. To do this, the transformation team will need to know that training is set to take place (i.e. information that should be included in the competence management system). Considerations included: what feedback is needed to capture that the training has been completed? Perhaps employee details of their training / test results could be used. Similarly, assigned responsibility R1 specifies that the Training Strategy sets out the requirements for who should be trained in decision-making. To do this, it was thought that the transformation team would need to know that the training is set to take place (again, information that should be in the competence management system). Table 8.9 shows some worked examples produced by the researcher, reflecting how feedback can be derived from the responsibilities.

Table 8.9 – Feedback based on assigned responsibilities

Responsibilities	Process Model	Feedback
Provides sufficient quantity / quality of trainers to deliver training in risk-based decision-making - SC7.2	Training is planned in the system (Oracle)	Record of completed training
Responsibilities	Process Model	Feedback
Sets out requirements for who should be trained in decision-making - SC7.3	Training is planned in the system (Oracle)	Record of completed training

The iterative approach using the STPA method allows for the control structure to be refined by using the responsibilities to "zoom in" and add additional details. For example, training strategy sets out the requirements for who should be trained (responsibility R1). This could be done by setting up a working group to establish key safety roles as a primary focus for the risk-based decision-making training. Assigned responsibility R5 indicates that the Standard will provide stewardship of decision-making competence / capability. The Training Standard will need to specify who needs to be trained, including mandatory content and enforce this through an assurance regime. Two controls within the Standards setting process could be used to control these processes: a content development group, and an assurance team.

The researcher also considered other potential feedback, such as system capacity for training (e.g. the number of available places in a training school) and feedback on competency levels from recording systems. However, this and other considerations would be appropriate in a deeper application of the STPA method, but time did not permit this during the study.

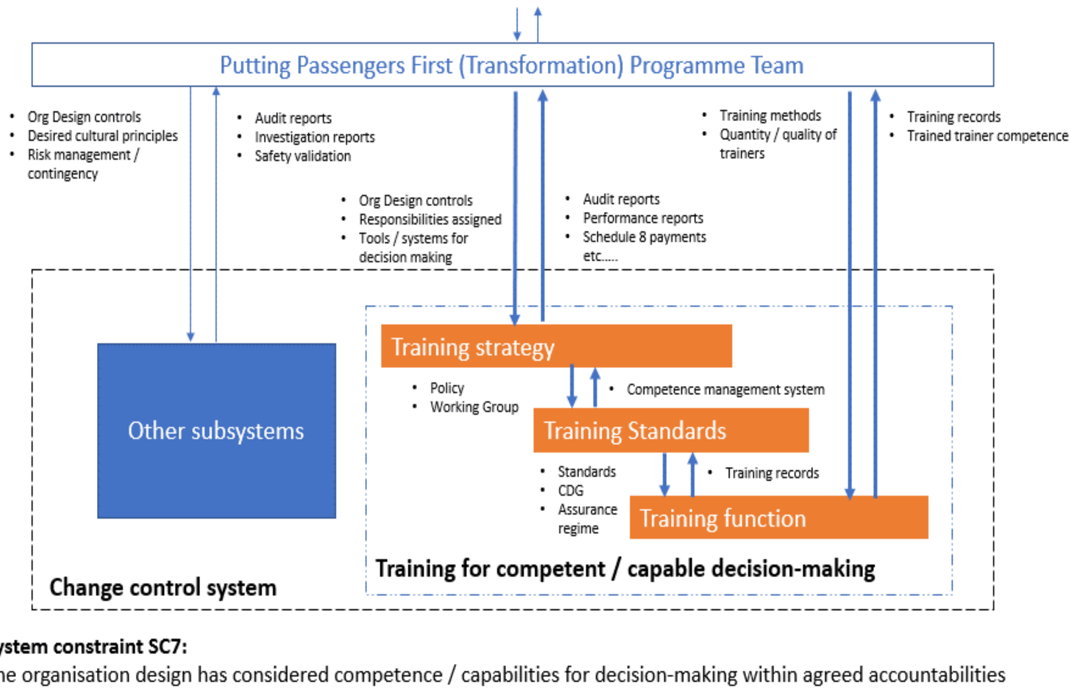


Figure 8.16 – Example of a control structure after refinement based on the assigned responsibilities related to decision-making

8.6.2.3 Procedure to complete Step 3

Step 3 took a total of 8 hours of the researcher's time along with that of her colleague. Much of this was spent on revisiting and checking back on the original hazards and constraints from Steps 1 and 2. Time was also taken to identify unsafe control actions (UCAs), in the knowledge that the STPA method says there are four ways a control action can be unsafe (see Table 8.10). These afford the potential for further analyses and can suggest process improvements encompassing both technology and human elements.

Table 8.10 – Worked example identifying Unsafe Control Actions (UCAs) related to Training Strategy

Control Action	**1. Not providing causes hazard**	**2. Providing causes hazard**	**3. Too early, too late, out of order / sequence**	**4. Stopped too soon, applied too long**
Working Group (to establish key safety roles to receive training in risk-based decision making)	UCA1 - Training Strategy does not provide a requirement for a working group to be set up (H7)	UCA 2 - Training Strategy does set up a Working Group but with insufficient authority (H5)	UCA4 - Training Strategy sets up the working group too late to affect change(s) (H3, H4, H8)	N/A
		UCA3 - Training Strategy does set up a Working Group but with insufficient focus on company objectives (H6)		

Once the UCAs were identified, they can be translated into constraints on the behaviour of each controller. For example, when analysing Training Strategy control actions, the researcher determined that the Training Strategy providing a working group, but with insufficient authority, could lead to a hazard. Therefore, the Training Strategy must not provide the Working Group control action in that context. In general, each UCA can be inverted (upturned) to define constraints for each controller. Each UCA can also be traced back to a hazard.

Table 8.11 – Worked example of Unsafe Control Actions (UCAs) linked to controller constraints

Unsafe Control Actions	Controller Constraints
UCA1 - Training Strategy does not provide a requirement for a working group to be set up (H7)	C1 - Training Strategy must provide a requirement for a working group to be set up (UCA1)
UCA2 - Training Strategy does set up a Working Group but with insufficient authority (H5)	C2 - Training Strategy must set up a working group with sufficient authority (UCA2)
UCA3 - Training Strategy does set up a Working Group but with insufficient focus on company objectives (H6)	C3 - Training Strategy must set up a working group with sufficient focus on objectives (PPF etc.) (UCA3)
UCA4 - Training Strategy sets up the working group too late to affect change(s) (H3, H4, H8)	C4 - Training Strategy must set up a working group in a timely manner to allow it to affect changes (UCA4)

8.6.2.4 Procedure to complete Step 4

Step 4, going through the loss scenarios, took 4 hours.

Process model flaws occur when a controller's process model does not match reality ('work as imagined' versus 'work as done' (Hollnagel *et al*, 2006). Below in Table 8.12 is a worked example of how the scenarios might be derived from UCA1 identified as part of Step 3.

Table 8.12 – Developing scenarios derived from an Unsafe Control Action

UCA1 - Training Strategy does not provide a requirement for a working group to be set up (H7) • ***Controller process model (belief) that could cause the UCA:*** Controller (Training Strategy) believes the working group is already established under a different process or believes that the working group is unnecessary because the existing arrangements/meetings fulfil this role. • ***Controller receives correct feedback but interprets it incorrectly:*** Training Strategy believes working group has been established and training requirements are captured in the competence management system, or there is a belief that risks are being controlled. ***Scenario 1a for UCA1*** - The Training Strategy team does not provide a requirement for a working group to be set up (UCA1) because the team incorrectly believes there is already a working group in place. This flawed process model will occur if the competence management system provides feedback that competences are captured; the received feedback may indicate some training is happening, even though it was not the working group that specified this. ***Scenario 1b for UCA1*** - The Training Strategy team does not provide a requirement for a working group to be set up (UCA1) because the team incorrectly believes that the working group is unnecessary because the existing arrangements/meetings fulfil this role. This flawed process model will occur if the competence management system provides feedback that competences are being captured, and the received feedback – perhaps through assurance processes – indicates that training is happening, even though it was not the working group that specified this.

Where the scenarios identify feedback or information (or lack thereof) that can cause a UCA, the researcher then needed to examine where the feedback/information comes from to explain what could cause those problems. Feedback comes from the controlled process (usually via sensors) and other information may come from other processes, other controllers, or other sources in the system or the environment.

Hazards can clearly be caused by UCAs, but they can also be caused without a UCA if control actions are improperly executed or not executed. To create these scenarios, the researcher had to consider factors that affect the control path as well as factors that affect the controlled process – see Figure 8.17 below.

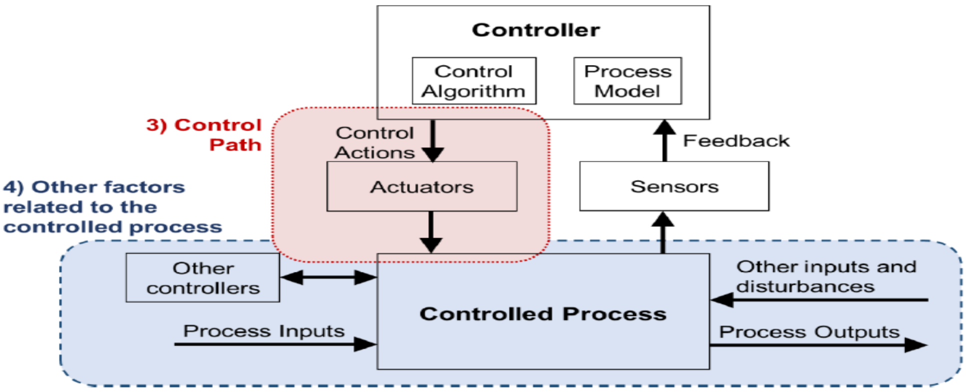


Figure 8.17 – Control loop illustrating the control path and other factors that can also affect the controlled process

To create the possible range of scenarios[47], the researcher and her colleague started with a control action, identified what improper execution or no execution means, and identified how the control path could contribute to that behaviour, including the various stages of control and the environmental context, e.g. objectives, policies, standards etc. – see Table 8.13.

The researcher understood from the STPA process that even if control actions are transferred or applied to the controlled process, they may not be effective or they may be overridden by other controllers. Also, that these scenarios could be caused by a multitude of factors, e.g. process inputs that are missing or inadequate, external or environmental disturbances, potentially conflicting commands received from other controllers, degradation or changes to the process or the environment over time.

Table 8.13 – Control path

Control Action:	Training Strategy sets requirement for a working group to be established
No execution:	Working group doesn't get set up
Improper execution:	Insufficient authority given to working group
Scenario 1:	Working group is established but does not understand their authority
Scenario 2:	Working group is established but exceeds their authority
Scenario 3:	Working group is established but they fail to communicate the requirements for training in risk-based decision-making

8.7 Summary of results

It should be noted that once the scenarios were identified as part of step 4, the evaluation went no further due to time constraints. That said, process evaluation and observations of the STPA method as an effective tool took 8 hours of collective effort to review, and a further 16 hours were spent on testing various tools available for capturing hazards etc. (i.e. SafetyHat, A-STPA, and XSTAMP), although none of these were actually finally used in practice to capture the results for this research due to their complexity.

STAMP / STPA / CAST related papers were also identified as part of the literature review and 8 hours of reading was undertaken in support of this study.

Through practical application of the method, it was found that System-Theoretic Process Analysis (STPA) supports a safety-driven design process where hazard analysis can be used to influence and shape early design decisions, and importantly be iterated and refined as the design evolves. It was used to see if it can specifically support risk analysis / hazard analysis of existing systems, and the study revealed both its benefits but also limitations in these areas, particularly when defining scenarios in which the safety constraints could be violated.

[47] Scenarios with control actions that are sent but improperly received or not received may be caused by delays in communication (including control actions sent but received in a different order), transmission errors, or lost communications. Similarly, scenarios with an improper actuator response or no response may be caused by actuator failures, inaccuracies in actuator operation, actuator errors or misbehaviours, other commands received by the actuator (including potentially conflicting commands from other controllers), degradation or changes to the actuator over time, or other problems.

The simple premise of STPA is that it starts from a basic control structure and assigned responsibilities for safety-critical actions; it has the same goal as fault trees or any other hazard analysis approach, but as was demonstrated from the study it can look at more than component failures and has the potential to find more types of accident scenarios through the systematic evaluation of unsafe control actions.

The following sections reflect the researcher's observations about the use of the tool in its real-world application, and the findings demonstrate the value of the exercise when the method and outcomes are discussed by like-minded subject matter experts, particularly around the co-creation of the analysis, as well as the future utility as a hazard analysis method in Network Rail and other possible settings / industries.

8.7.1 The supporting tools are hard to use

Presenting the analysis having applied the STPA method to a given issue / design is difficult. It is hard to present a useful summary because the complexity of the analysis needs to match the complexity of the system under consideration.

Tools like XSTAMP that are available online to download / purchase provide structure but are hard to use, slow and constraining (noting it took several hours to populate XSTAMP with just a few example losses and hazards and were not ultimately used to capture results for this research). Plain text lists of processes and procedures is simplest and quickest when put into a spreadsheet, as was done for this study, but it also proved difficult to track and interrogate without drop down tables and lots of pivot tables. There was also no easy way to produce the control structures and other diagrams without spending a lot of time at a whiteboard and then more time using Visio (or similar) to sharpen these up into something useable and visible.

One obvious point to emerge from the study is the need to start with lots of questions about your intended operations and engineering developments, and work towards getting answers, not just start with the method and try to fill in the details around the framework. For example, when it came to the organisation re-design for Network Rail that was used as the basis for analysis, it would have been helpful to have had existing and proposed organisation charts, relevant design and operational documentation, job / role details, company procedures, and access to relevant risks from the risk register (NB: from a total of 220,000 risks currently captured in Network Rail's system).

8.7.2 A significant value of the exercise is in the discussion and co-creation of the analysis

It was evident during the study, and the 80 hours in applying the STPA method, that no single person has the information required to generate the analysis to the detail required. A superficial analysis using structured introspection and individual knowledge elicitation is possible, but simply writing down what is already known would not get you to the deep insights possible using a blended team, where co-creation allowed for ideas and thoughts to emerge, be debated, and either accepted or discarded.

8.7.3 You need to get into the detail

It was evident from the different stages the researcher and her colleague went through that the power of the approach is not fully unleashed until you get down to the engineering or operational design of inputs, process, and outputs. For this you need a deep understanding of the people, process, and technology elements of the system. A superficial understanding may help to direct further research or questioning, but it does not generate valuable insight. Exceptions might be if you are able to have:

- Human and procedural requirements that help generate **technology requirements** *(this was evident from Step 1 when identifying system and sub-system constraints such as the need for competence recording systems);*
- Process (task) and technology constraints generate **human skill, experience, and know-how requirements** (delivered through recruitment, training, and practice) *(again, evident from Step 1 and having appropriate accountabilities/responsibilities defined, clear decision-making pathways etc.);*
- Technology and HF limitations set **requirements for the processes to be followed** (e.g., sequencing, pace, etc) *(this became evident during Step 2 when modelling the control structure, but also at Step 3 when identifying the unsafe control actions and controller constraints, such as wanting to set up a working group with sufficient authority to act).*

8.7.4 STPA for business process engineering has limited utility

The concept of a control structure is fundamental. The analysis does not work without the structured control loop of control actions and feedback between a controller and a controlled process. For a person pressing a brake in a car, the laws of physics on the engineered system design provide a clear set of opportunities and constraints for what is likely to happen in particular conditions. In a social system where the controller is a person in a leadership or supervisory position, and the controlled process is a method of working (other people doing goal-based activities), the constraints are extremely difficult to model and predict. The gap between ‘work as imagined’ and ‘work as done’ can be huge in these situations so the value is probably to ‘stress test’ the assumptions of what would be required by the individual controller of the business process. An example, identified in this research, was related to training and the assumption that people (as part of the controlled process) undertake tasks based on standards of competence specified by others (i.e. the controller), but individuals may no longer hold the competence or it has lapsed, and without recourse to the intended business process or its owner the control action is potentially unsafe.

8.7.5 Modelling human performance requires tight constraints

Electromechanical devices are complicated but work as designed, software is extremely complex but has algorithms that can be evaluated, human performance on the other hand is difficult to model due to a range of factors (Stein, 1998).

These include:

- Individual differences in people with equivalent training, experience, and tools;
- Situation and contextual factors increasing variability in situational awareness and response; and
- Strategies, tactics, motivation, and risk perception as moderators of action and performance.

Given the above, and what is said in the available literature, the researcher feels that using the STPA method requires you to constrain the analysis within well-defined system boundaries (e.g. only a part of an organisation such as a department rather than an entire business unit or whole company), or to take a more holistic and abstract view of predetermined goals (e.g. the system safety engineering analysis of a new organisational structure, rather than the entire operating structure).

8.7.6 STPA can help with a gap analysis of organisation design options

Successful analysis requires clearly stated goals, requirements, and constraints so that assumptions and control structures can be evaluated. Applying the STPA method to an organisation change, at a programme level, proved to be too vague and if the researcher were to repeat the evaluation of STPA as a predictive tool she would go deeper into the technical safety evaluation (for example, understanding assets and system interfaces and associated job roles as new technologies are introduced) to make this more than a superficial exploration of factors that could impact the performance of any system.

8.7.7 Clear documentation, structured processes and detailed compliance processes are required

The analysis of a well-defined sociotechnical system that works as designed is (by definition) exceedingly difficult to complete. Detailed interviews to elicit how organisational controls work are required, and the gaps between the reported process and what happens in practice may be significant.

For example, the researcher and her colleague found job descriptions pretty much useless, and even where safety responsibilities are mapped out (e.g. as a key safety post) there were likely gaps, deviations and conflicting/competing demands, pressures and requirements that really need to be understood for the STPA method to be used effectively.

8.8 Discussion

8.8.1 Bow Ties

Whilst the technique of Bow Tie Analysis has seen steady take up within or across sectors, often in safety-critical domains, there appears to be little in the way of standardisation or recognised best practice about how to conduct and implement this barrier-type method in organisations (CIEHF, 2020). Yes, there is guidance available through a review of the literature, and internet searches, but it is mostly broad principles for barrier management, and very little mention is made of human factors (CIEHF, 2016).

Network Rail took its lead from others when it decided to adopt the Bow Tie approach back in 2013, e.g. Royal Dutch Shell. However, even when it came to practical implementation, Network Rail did not adopt a particularly structured approach – primarily because of the sheer volume of workshops and 'hazards' it decided to address – and this resulted in an inconsistent picture of plausible accident scenarios that could exist around a certain hazard. The Network Rail workshops that were observed quickly jumped into identifying the range of barriers based on what the attendees considered to be critical barriers, but some participants got into far too much detail, and struggled thereafter to identify the ways in which control measures fail because of the overly complex structure of the bow ties that emerged.

Workforce engagement was almost non-existent as the bow ties were developed; it was only the Plain Line Track trials that served to engage the frontline personnel as to their responsibilities for barrier function. It was very evident, however, from these trials, that it is the workers at the 'sharp end' who know why particular pieces of equipment or processes are needed to function as barriers or to assure barriers and make the case for change through the 'Means of Control' process (Network Rail, 2016).

Had the bow ties been developed to serve as a far more prospective risk assessment technique to be used by Network Rail they might have secured more interest and 'buy in' from the Routes tasked with identifying and managing controls at a more local level. There was certainly widespread interest in their use in Network Rail, as there is across health care and other sectors, but as others have also found, the practicalities and rigour required to identify a 'barrier' capable of preventing accidents without an appreciation of how these barriers can be degraded, or what needs to be in place to prevent such degradation, remains a challenge (McLeod and Bowie, 2018). Also, ensuring barriers are as effective as they can reasonably be, is an area that other sectors have also found themselves wrestling with (Society of Petroleum Engineers, 2014), and so they have also had to develop supporting / leading indications directly derived from operational and reliability criteria around resourcing levels, competency records, work banks, defect reporting / tracking systems and maintenance backlogs. Such information is similarly available to those in Network Rail, but it needs a concerted effort, and commitment, to deliver the level of training, support, and assurance resources required for the Route businesses to be capable of carrying out bow tie analysis to a consistent standard without recourse to consultants.

8.8.2 STPA

Although the STPA method captured the complex system of controls and feedback inherent in Network Rail's change processes, and demonstrates the potential to help redesign them, both the researcher and her colleague found the methodology to be time consuming due to the large amount of information generated, even for just a small sample, and the obvious shift from linear causality thinking.

Using the STPA method allowed for several potential improvements to be identified in any future use of the tool. For example, in the case of Network Rail's organisation change, modelling the organisation design and decentralised structure would be necessary to manage classic systems risks (e.g. management of the infrastructure assets) where optimising individual components (e.g. in the local route) does not lead to overall system optimisation.

This would require the identification of changes to accountabilities, responsibilities and job descriptions, e.g. are new roles created and is there a removal of existing roles? Does this change or leave gaps in safety accountability? Would there be new interactions and reporting lines as a result?

It is also felt that there would be a need to review the organogram as a control structure, understanding if new silos are created, or there are other opportunities for reduced controls and feedback. Also, if the organisation change is assumed to be agile then there is a need to review the process for managing reverberations, future changes, and reactionary forces. For example, who has overall oversight and accountability for change management as it evolves? Who is planning and designing future change? How is change informed by monitoring and measuring intended outcomes / outputs?

If the implications on operations (and business as usual) are to be understood then the organisational change activity would need to be reviewed equivalent to any engineering development[48], i.e. understand the relationship between development and operations – see Figure 8.18– and the necessary control actions (constraints, requirements and procedures) and feedback mechanisms (reports) that go on to inform the controlled process(es).

Figure 8.18 – The relationship between engineering development and operations

[48] Engineering development examples might include introducing new technology (e.g. signalling equipment) or increasing track capacity, or replacement / additional assets on the rail infrastructure

This study and analyses have helped to identify that a simplified process for hazard analysis of organisation design to manage system safety risk is required, noting the process is also derived from the available literature and experience of the researcher in risk analysis and risk management, and therefore the relevance / application of bow ties is also shown (where appropriate).

It is proposed that the process would use STPA as a framework but also guide preparations before application. See Table 8.14 below.

Table 8.14 – Simplified process for hazard analysis and related STPA step(s)

Simplified process	**Related STPA step(s)**
1. Define the goals / boundaries: a. Identify system hazards, constraints, and requirements (drawing on any extant bow ties and corporate risk registers to inform where issues might already exist)	Step 1 – being clear on the purpose of the analysis and the context (system boundary) in which the losses, hazards and constraints apply (known knowns, and foreseen ones)
2. Model the control structure: a. Describe roles and responsibilities (Job Descriptions, Standards, Procedures) b. Describe the processes for feedback	Step 2 – it is important to recognise that control loops developed here may often overlap or have human interactions, thus the operating procedures and decision-making rules need to be captured
3. Review the gaps between requirements (1a) and role-based controls (2a)	Repeat Steps 1 and 2 as appropriate to further identify any potential gaps
4. Identify risks: a. Individual risks b. Collaboration and co-ordination problems c. System resilience and emergent properties due to scale (e.g. time and space)	Step 3 – this is about understanding the consequences of having unsafe control actions, and the implications of not managing risks, doing something that imports risk, or not going far enough to manage or mitigate risk
5. Identify common causes of risk, e.g.: a. Co-ordination issues b. Goal conflicts and trade-offs c. Ideal vs Real (imagined vs done) d. Information needs and flows e. Key controls (top down) and feedback mechanisms (bottom up)	The identification of the common causes of risk seems to be missing from the STPA process, albeit that Steps 3 and 4 suggests the link between the control actions and the controllers should be understood, and that potential scenarios are identified. Experience of bow tie analysis is relevant here.
6. Recommend risk mitigation activities: a. Structural design weakness b. Standards and policy c. Controls for identification and corrective action d. Realistic assessment that not all requirements are safety-critical	This simplified process goes further and recommends that risks are understood in distinct categories (per 5a-e) and that how these are mitigated fall into just four areas of activity (per 6a-d). This is more analogous to the approach used in bow tie analyses and affords an opportunity to graphically portray a range of scenarios and where loss events may occur and their potential severity.

8.9 Study limitations

The evaluation of the bow tie technique used by Network Rail was necessarily limited to attendance at workshops facilitated during late 2014 / early 2015 to observe developments as part of the intended Plain Line Track trial that was to be rolled out nationally. Whilst many further workshops were held related to other assets, it became necessary for the researcher to address elements of the wider national change programmes – and the bow ties as part of this – in interview and survey work carried out as part of Studies 1 and 2 (Chapters 5 and 6), in addition to desk-top reviews of materials available as part of the longitudinal work carried out as part of Study 5 (Chapter 9).

Also, as regards the STPA method, it should be noted that once the scenarios were identified as part of step 4, the evaluation went no further, although an obvious next step would have been to use the scenarios to create additional requirements, identify mitigations, and drive the organisation architecture. More time would also have allowed for recommendations and new design decisions to be made (as STPA was used during the development phase in this instance), the evaluation / revisit of previous decisions, identification of any gaps, and the development of leading indicators of risk during operations.

8.10 Conclusions

Both the bow tie analysis technique and STPA can be used either as stand-alone or complementary tools for prospective risk assessment and analyses. If applied exclusively or mutually, they could help industry to undertake prospective analysis, using the tools in a range of settings / contexts.

The approach to bow tie analysis, i.e. understanding barriers, failure mechanisms, controls and additional safeguards it can generate, means the model could be used in support of or on the back of the STPA method to serve as a prospective analysis tool, seeking to evaluate the quality of controls proposed to ensure they will have the capability of providing the intended protection(s), besides affording the opportunity to explore where the controls might fail.

The STPA method was found to be similarly effective and goes to the heart of systems-thinking and analysis. It allows practitioners to find inadequate controls in a design, and the approach is typically used to help capture requirements flaws, software errors, and/or human errors.

When performed properly both bow tie analysis and the application of the STPA method can provide a deeper understanding of controls expected to protect against loss, but also expose how they might fail. Importantly, practical implementation – whether using one or both methods – requires sufficient resources to support and manage the process of analyses, particularly given the time-consuming nature of these when done thoroughly. It is acknowledged that they are both labour intensive approaches, and should be used where the value of the prospective technique can be justified (e.g. time, cost, resource) and can be offset against the occurrence of top events with the potential to cause loss of life, damage to property, environmental harm, or reputational damage.

If used, it is suggested that risk identification is done using STPA to extract a set of risk scenarios related to different asset types and organisation structures in Network Rail. Following on from this would be an evaluation of these risk scenarios performed by using the bow tie technique. A key feature of both methods is really having a thorough working knowledge / understanding of the organisation, or design, or changes that are to be analysed – this requires actual workforce involvement so that ‘work as done’ is put into context and workarounds and trade-offs are factored in. Training should, therefore, be a pre-requisite before undertaking the analyses – both for participants and practitioners – to ensure high quality, reliable, outcomes.

9. Study 5 – To undertake a longitudinal (observational) study to understand the extent to which a 'systems approach' has been applied to two Network Rail national change programmes

9.1 Chapter overview

Implementation of Network Rail's two national change programmes, to improve workforce safety, previously described in earlier chapters, was tracked during the period 2014-2020 whilst the researcher was conducting this part-time PhD.

Undertaking the longitudinal (observational) study has allowed for the various stages of the programme's implementation, pauses and changes to be monitored over an extended period, revealing the differences in how end-users and subject matter experts have been involved, and how the changes have been managed and evaluated. Unplanned events, such as two track worker fatalities at Margam (RAIB, 2020), and the Covid-19 pandemic, have also impacted on the change programmes, and these are also included in this study.

The research has identified how lessons were learned and addressed as the programmes were rolled out; there were various reviews and opportunities taken to denote delivery of the changes that the researcher was able to observe. However, there were also lengthy periods when the programmes were running without Executive-level intervention, and much effort and time were spent before it became apparent that the programmes were not delivering their intended benefits and outcomes. It took a while for some elements of activity (e.g. technology roll out) to be paused and re-started, seemingly due to a lack of a clear understanding of how individual's and team's actions, decisions, and technological factors needed to be better connected, and the 'systems approach' applied in practice.

The challenge, therefore, remains for Network Rail as to how it can deeply embed changes to its systems and processes as these programmes progress in a new 'guise' – especially when pressures remain on safety and performance, and the organisation faces further disturbances with the release of 'The Williams-Shapps Plan for Rail' (DfT, 2021), and the call to end the fragmentation of the past 25 years, bringing the network under single national leadership and requiring wide-ranging structural changes across GB Rail.

The results identify some important points for Network Rail to consider for the implementation of change across its business and the wider rail sector, and how a framework might be adopted by Network Rail that supports organisational learning and a systems approach to safety-driven design.

9.2 Introduction

Implementation of Network Rail's two national change programmes, to improve workforce safety, began in 2012 and over a period of 6 years from 2014 their progress was tracked by the researcher as part of this longitudinal (observational) study.

Unfortunately for Network Rail, due to a range of factors, the change programme's phased roll outs and implementation have been thwarted at different stages, and they gradually morphed into other activities by the time this study concluded in late 2020.

By example, during 2020, Network Rail re-started the Business-Critical Rules (BCR) programme as a 'business as usual' activity, and whilst the company remains committed to replacing the existing standards framework with a simplified, risk-based control framework, it has taken the decision to move the development stages into new localised programmes within its five Regions.

A change of emphasis means that the risk-related bow ties that were developed as part of the BCR programme (and tracked as part of this study) are now to also be used to aid the review and challenge of pre-existing Standards, rather than write new Standards or further develop the 'Means of Control' documents the bow ties were intended to support.

In a similar vein, the initial introduction of the Planning and Delivering Safe Work (PDSW) programme, particularly the planning technology and revisions to the supporting '019' Standard[49], led to concerns (from local management as well as the change programme team) regarding the process being open to interpretation, and thereby potentially a level of risk not originally foreseen. The decision latitude afforded, whilst always intended to a degree, also had the potential to let things go too far and meant instances of non-compliance because some took this autonomy to mean they could change things like critical limits for track assets to suit local needs (but which was not actually permissible as part of the process). As a result, learning from this initial phase also led to programme changes, and this longitudinal study was able to observe the re-launch of the initiative in November 2016, along with further revisions to the process introduced in July 2017 (i.e. protection of staff from a range of risks, not just trains) and again in 2020 (a re-badged programme re-titled to 'Planning for Work' (P4W) with greater focus on frontline communications and briefings).

Mumford (1987) helpfully showed that in the pursuit of delivering change the focus is often only on the technological solution, neglecting social aspects and thus failing to achieve a successful outcome. 'Systems thinking' and a 'systems approach' can, however, be used to blend the social and technical sub-systems when introducing new technology or processes (Trist, 1981; Senge 1990; and Sterman, 2003) and could be used as tools to support effective change – as identified in paragraphs 3.1.1 and 3.1 2 of the literature review and also reflected in earlier studies reported on in Chapters 5, 6 and 7.

[49] NR/L2/OHS/019 is a Network Rail Standard entitled "Safety of Personnel at Work on or near the Line". Version 9 was introduced on 3rd July 2017, with the (then) expectation of full adoption on railway worksites by 23rd September 2017.

Clegg also recognised that many organisations lack an integrated approach to organisational and technical change, and he suggests that users do not have much of an influence on system development (Clegg 2000).

Clegg developed a list with nineteen principles across three groups (meta-principles (philosophy / vision), content principles (e.g. task allocations), and process principles (e.g. expertise and skills)). These were not designed as a blueprint to be strictly adhered to, but more of an aid to be used alongside methods and tools that support different types of socio-technical activity.

It is Clegg's principles that have, therefore, been used as part of this study to helpfully understand the extent to which a 'systems approach' has been applied to two specific national change programmes, and which were tracked over time.

Specific objectives were established to achieve this aim:

- Undertake a longitudinal (observational) study that includes:
    - Observation of change programme boards;
    - Gather, and analyse, incident report recommendations;
    - Identify unplanned events that might influence change implementation; and
    - Understand and describe change over time, and the impact on the study of such changes.
- Use Clegg's nineteen principles for system design to understand the extent of systems thinking and the systems approach applied to Network Rail's two national change programmes.
- Use the findings from the study and associated analyses to inform the development of a potential framework that supports organisational learning and a systems approach to safety-driven design.

9.3 Methods

A longitudinal (observational) study to track progress of the two national change programmes was developed to observe programme board reviews, gather, and analyse incident report recommendations, and identify and learn from examination of unplanned events that might influence change implementation.

9.3.1 Longitudinal (observational) study

The longitudinal (observational) study began in December 2014 and continued until December 2020 – a period of 6 years – and afforded the researcher 12 separate occasions to measure, and collect descriptive detail, regarding programme progress and/or change(s). The study ran alongside the studies that are reported elsewhere in earlier chapters related to interviews, survey work, and the review of systems analysis methods.

As identified in the earlier literature review (Chapter 3), and in studies 1 to 3 (Chapters 5 to 7), proponents of socio-technical levels of control, such as Rasmussen (1997) and Leveson (2004), offer helpful structures for dividing complex organisations or industries into hierarchical levels with control processes operating at the interfaces. With this in mind, a simple study approach was developed for the longitudinal (observational) study – see Figure 9.1 below.

Thought was given as to the scope and purpose of analysis, i.e. the two national change programmes under review, and then what the control structure was for these (e.g. regulators, company standards and reports, programme management, physical operations, systems and processes).

Observational work was undertaken throughout in the form of attending programme board meetings and reviewing incident reports and their recommendations, along with Network Rail's response to unplanned events that occurred.

Approval for the study was provided by the University of Nottingham's Faculty of Engineering Research Ethics Committee (UofN, FoE).

Identified two national change programmes as focus

Undertook process analysis and review of research method over time, and identified two unforeseen events: 1. Two track worker fatalities at Margam in July 2017 2. GB Rail response to Covid-19 during 2020

Study to help inform development of a framework for organisational learning

December 2014 to December 2016	**December 2016 to December 2020**	**January 2021**
• Research selection • Identified research and evaluation methods • Obtained ethics approval • Reviewed change programme remits • Started observational study across various levels of Network Rail's structure	• Observational study continues • Parallel studies run alongside, including interviews, a survey, and a review of system analysis methods • Attended a total of 12 programme boards at 6-monthly intervals • Reviewed incident and accident report recommendations from 2017 to 2020 • Reviewed lessons learnt reports for the two national change programmes	• Drew all the observational study outcomes together • Used Clegg's 19 principles for system design to evaluate the systems approach and identify where opportunities may have been missed • Completed data analysis • Drew conclusions

Figure 9.1 – Longitudinal (observational) study approach and its timeline

9.3.1.1 Observation of change programme boards

Changes in the two national programme-specific change boards were observed over a six-year period, at 6-monthly intervals, (e.g. looking at milestones, programme risks and issues, system and process change requirements and funding implications). The researcher has also reviewed internal organisational reports on the lessons that have been learned in relation to these BCR and PDSW change programmes.

Changes in the programme boards have also been noted (e.g. their constitution, changes in personnel, programme sponsors, and required governance arrangements).

The effectiveness of these various communications (downward reference channels, providing the information necessary, and the upward measuring channels, providing feedback) is a key feature of this study.

9.3.1.2 Incident report recommendations

Following incidents and accidents there are a range of reviews, analyses, and reporting undertaken across the rail sector including Network Rail, and potentially the ORR and the Rail Accident Investigation Branch (RAIB) – depending on the severity.

This study has focused on those incident reports, safety digests and class investigation(s) that have recommendations in relation to workforce safety and the subsequent handling of these, i.e. how they are considered, and where appropriate acted upon.

The data has been reviewed going back over the past 5 years and has focused on RAIB reports (published since 2017) as it is these that are in the wider public domain and investigations and reviews are usually undertaken because of more major incidents / accidents.

The reports reviewed each make a number of recommendations related to worker safety, often in relation to work procedures and more broadly around issues of compliance with these, and the communication of work activity plans. Particular attention is paid to those recommendations made specifically in connection with several strategic challenges including clarity around roles and responsibilities, consistency around planning and delivering safe work (and systems), making greater use of technology to reduce risk, and improving monitoring, supervision and assurance (including the use and application of standards and procedures).

9.3.1.3 Identify unplanned events that might influence change implementation

During the longitudinal (observational) study, two unplanned events occurred that were thought significant that they could / would influence the implementation of the two national change programmes, and thus are included in this study.

The first event was the fatalities of two track workers at Margam, near Port Talbot, in July 2018, which resulted in a RAIB investigation and report (RAIB, 2020), and a series of recommendations that are later referred to in the 'Findings' section below. The second event was the Covid-19 pandemic, and the GB Rail industry response to this, including the implications for Network Rail, and the effects on the two national change programmes in relation to workforce safety.

Various sources of data were called upon for these events / situations, including Network Rail (internal) and RAIB investigation reports related to Margam, as well as progress updates on the recommendations made. Similarly, there were daily briefings and meeting minutes that were produced capturing the rail industry's response to the pandemic and the researcher was given direct access to the meeting outputs and action summaries.

9.3.2 Method of analysis of the longitudinal (observational) study

The longitudinal study through programme board observations, review of incident report recommendations, and analyses of reports and meeting minutes related to the unplanned events, allowed the researcher to understand the primary aims of the change initiatives, but also how these needed to adapt and evolve over time due to various factors – social, technical, operational, and financial.

Clegg's nineteen principles for system design were then used to understand the extent of systems thinking and the systems approach applied to Network Rail's two national change programmes – see Table 9.1. Outputs from the analyses of incident report recommendations, and observations and review of various data sources related to unplanned events that emerged during the longitudinal study are also included in the findings.

The research has helped to inform the development of a framework that supports a systems thinking approach to organisational change; one which is able to handle growing complexity and support learning from a risk management and safety-driven design perspective.

9.4 Findings

9.4.1 Longitudinal (observational) study, including change programme boards

The longitudinal (observational) study has allowed the researcher to document the key points and history of the two national change programmes from their inception in timelines covering the relevant periods of study – see Figures 9.2 and 9.3. Of note is that the observational study and thereby the tracking of the change programmes necessitated slightly different methods for capturing progress. This is evident in the arrowed sections in the timeline which reflect key moments in the respective programmes, and there are 'call outs' which highlight some of these differences but also where there are similarities.

As part of the longitudinal study and observations of the two change programme boards, Clegg's nineteen principles were used to evaluate the systems approach – see Table 9.1– reflecting the details about change design and implementation. The evidence found through programme progress reviews, programme board attendance, observations of workshops etc., is described in detail, with a supporting summary of the main learning points, including the most relevant text highlighted in bold, and examples given below that (not in bold).

Figure 9.2 - Business Critical Rules (BCR) timeline (2012 to 2016)

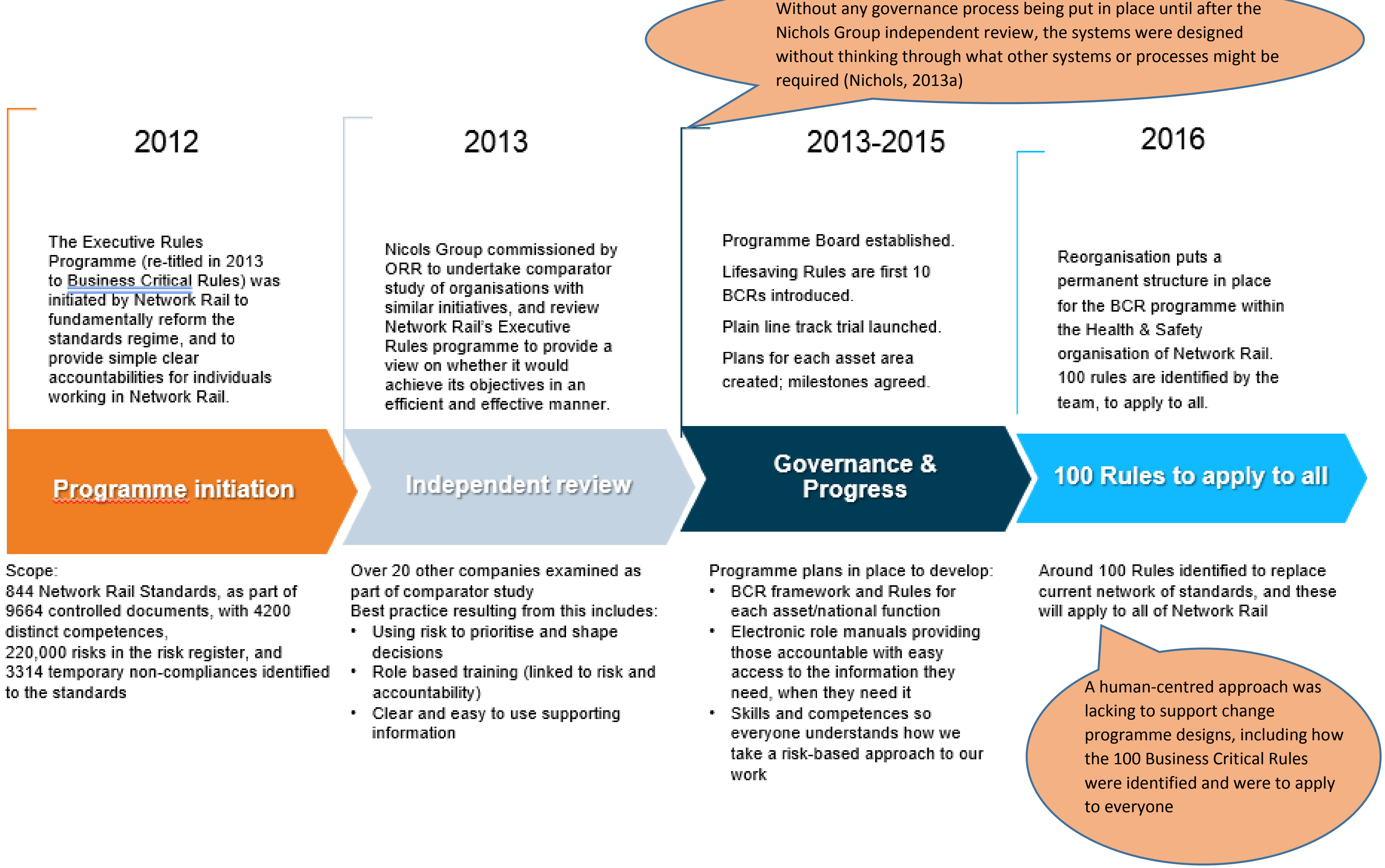


Figure 9.2 (continued) - Business Critical Rules (BCR) timeline (2017 onwards)

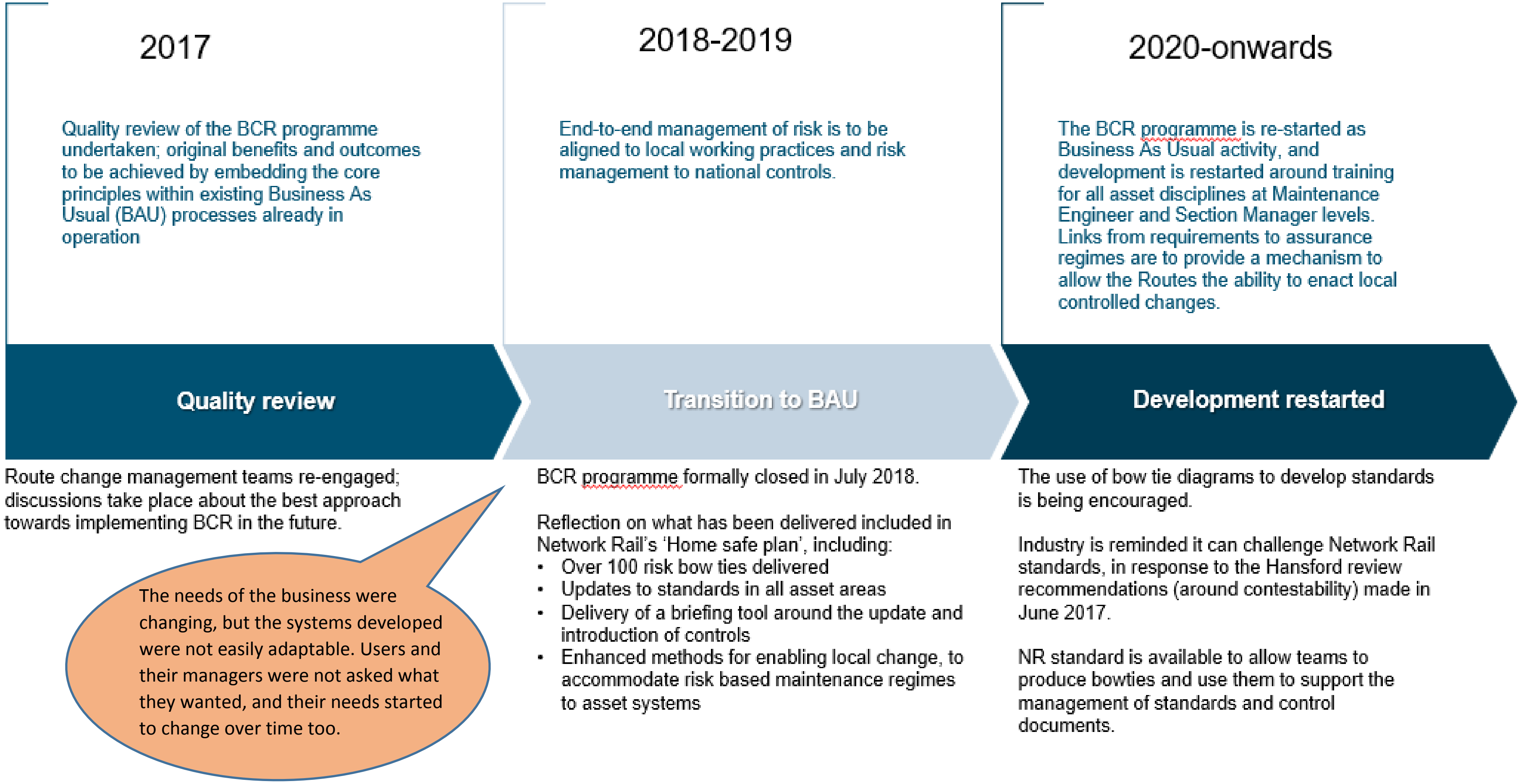


Figure 9.3 – Planning and Delivering Safe Work (PDSW) timeline (2014-2016)

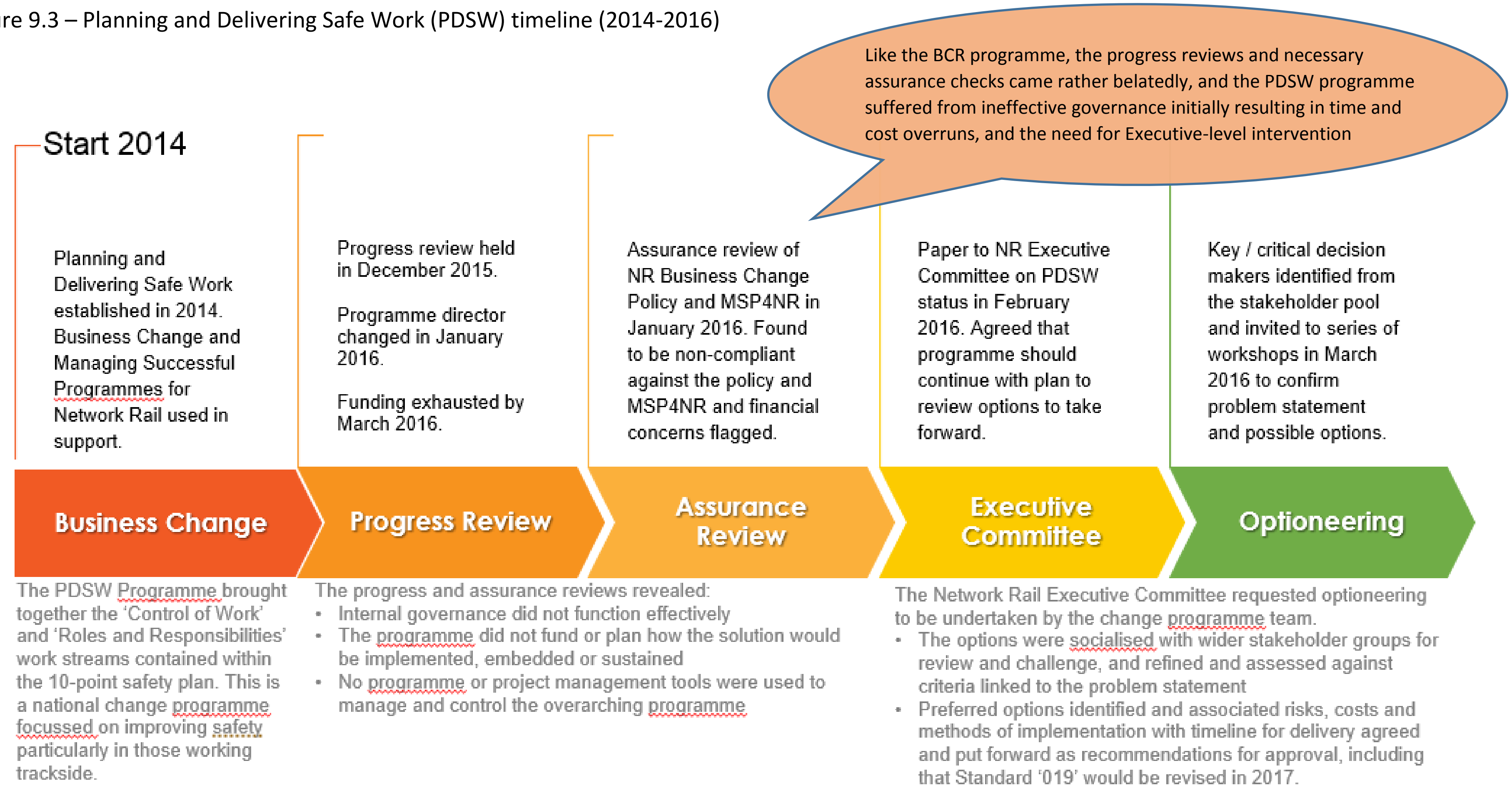


Figure 9.3 (continued) – Planning and Delivering Safe Work (PDSW) timeline (2017-2020)

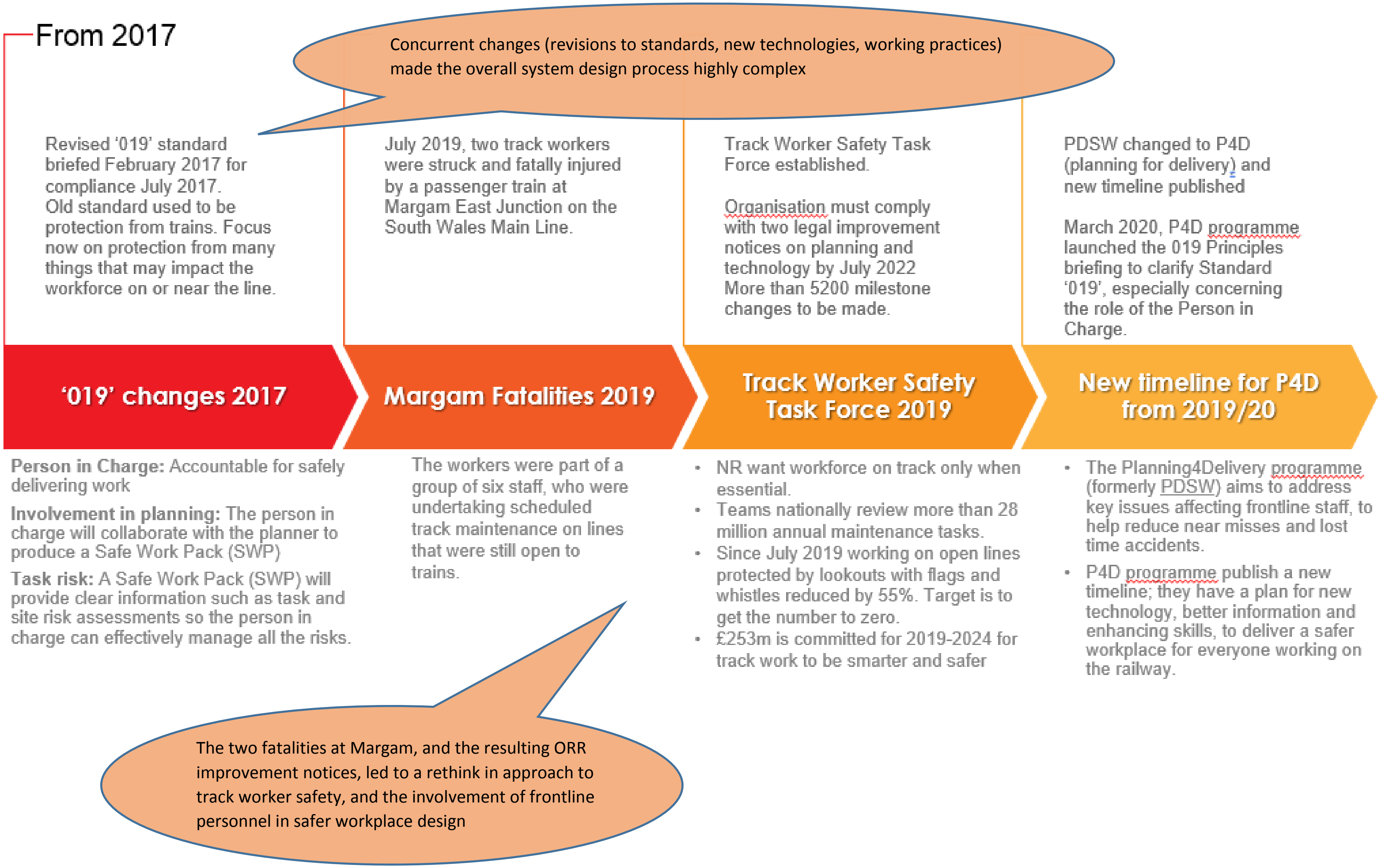


Table 9.1 – Principles of socio-technical design (Clegg, 2000) and the evidence of these in the two Network Rail national change programmes

Clegg Principle	BCR Findings	PDSW Findings	Main learning points
1. Design is systemic *Technical and social systems are interdependent (Klein, 1994).*	A handbook (NR-TRM-BCR-000002) (Network Rail, 2013(b)) guiding development of the framework, the products, bow ties etc., was produced in 2013 and made available to those involved in the programme, and was routinely updated as the design evolved. It sought to cover ALL asset groups but did not address ALL interdependencies (for example, compliance with existing arrangements was actually very poor, but not anticipated).	Whilst in theory the business wide framework mandated for all national change programmes was to be used for PDSW, known as MSP4NR[50], it was still relatively new to Network Rail in 2014 and the business did not have a broad or deep experience in using this framework, and no programme had yet gone through the entire MSP lifecycle to allow maturity to develop.	**There were unintended consequences of the various change initiatives, and they only became obvious when the planning system and tools were put into operation.** For example, it was found that there were poor levels of non-compliance with existing arrangements, and these needed addressing before the new technology could be introduced, else the old planning problems of the past were being perpetuated in the new tools.
2. Values and mindsets are central to design *(challenging the misconception that humans are error-prone and need to be controlled if they cannot be designed out of systems)*	The objectives of the BCR programme were made clear from the outset in 2012, i.e. to put in place a new control framework, with the necessary tools, to enable Network Rail to better manage the risks and the controls required to enable its employees and contractors to consistently achieve the published corporate safety vision. Getting the balance of existing operators with new processes (e.g. bow ties and means of control) was considered, but time dictated that many end users were not involved in the bow tie workshops started in 2014 and the opportunity to capture 'work as done' was missed.	The PDSW programme that started in 2014, and its various iterations since, was borne of an intent to improve the safety of all Network Rail and supplier staff working trackside. However, what was noticeable from observing the various programme boards was a desire to realise the safety benefits as quickly as possible. This time pressure appears to have led the programme to take a 'big bang' approach using consultants which not only made the initial scope of the programme vast, requiring changes to the underlying processes, organisation, and technologies, but it was also incredibly complex.	**A human-centred approach was lacking to support change programme designs.** Operators were, unfortunately, not seen as the experts in the system-side of the process and the view was taken that others should design the tools to support them in their work.

[50] Managing Successful Programmes for Network Rail (MSP4NR) (Network Rail, 2013(a))

Clegg Principle	BCR Findings	PDSW Findings	Main learning points
3. Design involves making choices *(for example, agreeing how the system will operate, how work will be managed and organised, what technology is needed in support)*	To deliver the planned roll out of BCR products, the initial phasing was based on asset groups, followed by system interfaces and non-asset specific areas. Agreement as to what would be in each phase included input from the engineering asset heads of department. The approach was then validated with identified 'champions' and the BCR programme team and endorsed via the relevant programme board. Resource (and time) constraints meant that there was little flexibility once the roll out plan was agreed.	Network Rail Regions and the supply chain affected confirmed to the programme team that they were struggling to achieve compliance with the standard '019' which governs the planning and delivery of safe work. Options for the programme and how to improve compliance with safe working principles were therefore socialised in 2016, and the solution agreed upon. The revisions were introduced across Network Rail in 2017, with the programme design team developing a suite of business change activities to embed the amended standard.	**Design choices were not seen as interdependent, and so systems were designed without thinking through what other systems or processes were required.** For example, once the revisions to the Standards was introduced and agreement reached to launch them nationwide it became apparent that there was insufficient briefings and training available, which became an immediate constraint to roll-out.
4. Design should reflect the needs of the business, its users, and their managers *(fit with business strategy? Does system contribute to core goals of the business?)*	Akin to standards development under the BCR framework, a top-down approach to bow tie development was also established. Although Network Rail has operations across multiple sites with a high level of similarity / standardised tasks, it is also the case that there is local knowledge which determines what should be done on these sites. Standards were to be created that every site should adhere to but allow for local changes via a document referred to as the Means of Control (MOC). The advantages presented to the early programme boards were that the knowledge on how to manage risk are present on a corporate level, but allow for site specific risks to be assessed and controlled locally. The reality was however quite different and very few end-users were involved in the bow-tie workshops observed, or the development of the MOCs which were made available in 2014.	The researcher's observations of PDSW showed that the programme team designed a single solution for the whole business with a standard approach to measuring compliance that assumed that first, all business areas were already compliant with the existing standard and secondly, that all parts of the business (and the supply chain) would be equally capable of implementing and sustaining change. The reality was system change meant that end users had to change too and their needs evolved over several years as they better understood that the technology-led solution had the potential to improve their work / workload.	**The needs of the business changed over time, but the systems developed were not easily adaptable. Also, users and their managers were not asked what they wanted, and their own needs changed over time too.** For example, when training was belatedly delivered, and some refreshers were given, there was a growing confidence in the tools available, but these took 3+ years from initial roll-out. By then the business was changing focus to a more decentralised structure and expecting greater levels of autonomy than actually existed.

Clegg Principle	BCR Findings	PDSW Findings	Main learning points
5. Design is an extended social process *(design is not a one-off and evolves beyond implementation and throughout use)*	The BCR programme started in 2012 and formally closed in July 2018. A review of Network Rail's 2017/18 'Home Safe Plan'[51] did not contain close out detail referring to any handover arrangements between the programme and when it became Business As Usual (BAU) within the Regions. Various stakeholders, therefore, had the potential to shape and moderate their respective standards without cognisance of other changes elsewhere.	As the PDSW programme team attempted to implement the technology changes in the East Midlands via a 'trial' it became apparent that Network Rail was not compliant with the existing planning standards there, and that there were varying degrees of planning capability across the wider business. Observation of the programme boards identified that these differences were magnified in the binary compliant / non-compliant approach to measuring standards compliance, which the BCR programme didn't address either, and it meant that it was extremely difficult for the PDSW programme board to target efforts.	**Whilst consultants were used to develop the design of the systems (processes, tools, and new technologies) there were users and managers later involved in implementation, use, management, evaluation, and upgrades.** Systems were tailored locally to suit them, and it follows that there were many interpretations of the design without a structure or mechanism through which non-compliance or changes were then controlled.
6. Design is socially shaped *(potentially mixing supply-push and demand-pull)*	Observation of the programme boards revealed a disconnect between the programme team and other change teams. As new technology was emerging in other parts of the business the BCR programme did not pay attention to this and its implications for end users, e.g. the roll out of Apps on phones to access Standards without teaching users to use them!	The longitudinal (observational) study identified that the PDSW programme's primary focus was on developing a system for planning and delivering safe work, through a series of technology solutions: 1. New electronic permitting (ePermit) technology, to replace voluminous (and generic) safe system of work packs, with the new system able to produce paperwork that fully describes the plan, alongside track schematics to visualise all activity on the particular infrastructure.	**The various systems were shaped by Network Rail in conjunction with consultants, and not end users.** The change teams with the consultants had an interest in promoting particular tools, and so their attention and efforts were seen by some with negative connotations, i.e. this was supply-push, not demand-pull, and system adoption as a result at a local level was slow and ineffective.

[51] Network Rail's 'Home Safe Plan' consisted of 21 national projects which were identified to provide the biggest risk reduction to its work force, public and passengers. It was first produced in 2016 and then reviewed annually, and in 2017/18 a number of original projects were closed successfully; the BCR programme among them.

Clegg Principle	BCR Findings	PDSW Findings	Main learning points
		2. A single national control of work process (a system called Proscient), to plan, risk assess, deliver and hand back all work carried out on the given piece of infrastructure. The programme boards showed that Network Rail was actively seeking to adopt systems already proven in other industries who have better workforce safety performance than the UK rail sector. As a result, the programme team designed a national training package that directly involved over 22,000 delegates. Unfortunately, the programme ran into financial and commercial difficulties with the chosen technology systems and PDSW was paused in September 2018 to allow for a revised concept to be presented to the Network Rail Executive ready for another 'launch' in the summer of 2019.	
7. Design is contingent *(design choices do not necessarily have universal applicability)*	Over 100 risk bow ties were delivered by 2018, but the bow tie workshops demonstrated that there was no 'one best way' for their development. What this led to was a host of bow-ties limited to what the workshop attendees knew about particular hazards and controls, rather than a comprehensive picture of risks and how these might be managed proactively.	Because of the nature of the design, i.e. a single solution for the industry, the PDSW programme team found itself having to develop a 'generally applicable' planning process, but without an understanding of current compliance, and so what would represent an optimal design choice proved extremely difficult to answer.	**Context was important but not considered here, i.e. the organisational culture of non-compliance, the skills and capabilities of staff to undertake risk assessments, national variations in expectations (central teams versus local teams) etc.**

Clegg Principle	BCR Findings	PDSW Findings	Main learning points
8. Core processes should be integrated *(design integrated processes to avoid splitting a core process across artificial organisational boundaries)*	The BCR programme sought to simplify what was already established, but this was taking a long time, and so the approach taken in 2016 – and observed during programme board reviews – was to finally agree the 100 critical rules which would cover technical regulations and core requirements for managing the business (such as expectations of leadership).	The PDSW programme attempted to create a single person who would be responsible for delivering work safely – from planning to completion – but the understanding of what such a 'person in charge' does varies widely across Network Rail and the industry, which became apparent from the various lessons learnt reviews held. In recognition of the absence of a clear assessment of competence for a 'person in charge' (PIC) role it has more recently been agreed that three separate competences (controller of site safety, safe work leader, and individual working alone) would be realigned to create a single safety competence for the PIC role, and additionally include safety leadership, safety communications and behaviour modules in the related training.	**Network Rail took some time to identify its core processes and, in the interim, there was fragmentation that led to problems with responsibility, accountability and understanding with the revisions to the track safety standard '019'.**
9. Design entails multiple task allocations between and amongst humans and machines *(factoring in job design, hardware and software, humans, technology)*	The primary focus of the BCR framework was to put in place a simpler, risk-based, rules framework which is underpinned by the bow-tie methodology of risk management. This was only partially achieved under the auspices of the programme team, due to resource constraints, and hence the decision to move to BAU in July 2018 so that local ownership could be established. The programme boards regularly discussed the issue of understanding task allocations per discipline in a systemic way, but it later proved too complex for some asset groups.	Network Rail will introduce a RailHub safe work planning system from April 2021, after testing, to replace archaic safe system of work packs. Following programme board discussions, and learning from the ineffective introduction of the EPermit technology and planning (Proscient) tool, the RailHub has involved end users in trials, and has business support change as part of the technology launch to help users with the new planning system.	**Early system design focused more heavily on technical issues, rather than task allocation choices between whether a human or a machine should be used to undertake particular activities.**

Clegg Principle	BCR Findings	PDSW Findings	Main learning points
10. System components should be congruent *(old systems fitting with new systems)*	The new simplified BCR framework was intended to replace the former complex system, but instead – through the observational study – it became apparent that it ended up being an overlay to the old system, because the programme boards acknowledged that starting from scratch was not feasible, especially where rules and procedures were not easily tailorable.	The new RailHub system will have to become assimilated into the existing system until such times as the current safety competencies are realigned to create the safety competence for the PIC role (see 8 above). The work to simplify Standard '019' even further will take at least 12 months, commencing October 2020.	**The inter-related systems needed to be consistent with one another, but instead the new systems being designed were seen as replacements for the old systems without thought given to related information and control systems that were not changing,** i.e. non-compliance database, competence management system etc.
11. Systems should be simple in design and make problems visible *(ease of use, ease of understanding, and learnability)*	Whilst the BCR framework was meant to simplify standards, the development of bow ties and Means of Control was complex and did not address ease of use or understanding. Programme boards sought solutions but visibility of problems with the design proved difficult when there was an inconsistency in the way the bow ties were developed, particularly during the early workshops in 2014.	The PDSW programme failed to recognise from the outset the business readiness and capacity for change, and the design didn't allow for implementation to be tailored to the specific part of the business into which it was being delivered. For example, multi-team worksites, whilst not new to rail, were not considered as part of the change impact assessment until frontline teams, in particular, let it be known how the new requirements were too complex to be understood / complied with.	**The systems designed were not simple which presented issues for their ease of use and learnability.**
12. Problems should be controlled at source (unprogrammed events)	The longitudinal (observational) study identified that a Plain Line Track trial was undertaken in 2014 which involved selected delivery units operating, as far as possible, within the plain line track component of the BCR framework. For the trial, the 'boundaries' were the plain line track rules and some other related rules involving maintenance, risk management and fair culture.	Letting elements of the programme fail or slowing progress through stages gates was not a real option for the programme board on a 'must-win' programme. Observing these programme boards revealed that solving problems as they occurred helped to move the change programme forward.	**The advantage of controlling problems at source meant that there was a degree of control over what was being faced and how this might be resolved, especially at a time when Network Rail was pushing for greater autonomy and localised decision-making.**

Clegg Principle	BCR Findings	PDSW Findings	Main learning points
	It also included using the new documents in the BCR framework that tell individuals how they meet the rules such as critical limits, bow-tie diagrams, the Means of Control documents, relevant reference material, and the mechanism to review and adapt to suit local conditions. The intention was to identify where problems might exist with aspects of the design and where work systems needed to be made more certain as a result, or more flexibility afforded, depending on the conditions.	However, this also meant a lot of extra work by the leadership, and it further highlighted areas of weakness in the change capability of Network Rail when raised during programme board meetings.	
13. The means of undertaking tasks should be flexibly specified *(the ends should be agreed, but the means should not)*	Per 12 above. The documentation provided was in the form of Role Manuals, issued in 2014, for particular roles within the plain line track community, including the Route Asset Manager (Track), Track Maintenance Engineer, Rail Management Engineer, and the Section Manager (Track). Nb: these were not issued as controlled documents whilst they were in a period of development / evolution. A key area for each delivery unit involved in the trial was to use the information in the role manuals to make changes to their Means of Control, thus undertaking tasks more flexibly to suit local conditions.	Supporting Network Rail's local teams to own the change and identify what they needed for their level of maturity when implementing change was a positive aspect of the PDSW programme, but there was still a degree of the change being seen as 'done to them' and there were, at times, conflicts between the agendas of the central teams and the decentralised businesses which led to a belief that the system was rather more 'fixed' than 'flexible'.	**Conflicts arose because of the belief that technological systems and the associated work processes were tailorable, but the change teams wanted to avoid system revisions, e.g. to the new planning tools, as much as possible, and also took the view that standardisation and common work practices were often still required.**
14. Design practice is itself a sociotechnical system *(design should involve an interdependent mix of social and technical sub-systems)*	It was clear that the BCR programme design was intended to cover the entire system and the socio-technical aspects associated with that, but the programme team themselves did not operate in such a way themselves.	Active leadership and engagement were considered critical to deliver the PDSW programme successfully. Previous lessons learnt during 2016 and again in 2017 noted an absence of visible leadership at each level of the organisation.	**Concurrent changes (revisions to standards, new technologies, working practices) made the overall system design process highly complex, without the dynamic, systems thinking approach and ideas-sharing required.**

Clegg Principle	BCR Findings	PDSW Findings	Main learning points
	Observation of the progress reviews shows that many key interdependencies were missed, not least of which was the ability of the business to implement the plain line track trial because they could not demonstrate they could comply with the new BCR material and/or put in action plans to achieve compliance or adapt the Means of Control locally to how the delivery unit works.	Since these reviews, a change in emphasis around programme leadership has reportedly improved the situation and the latest design has additional resources to support business change.	
15. Systems and their design should be owned by their managers and users *(compatibility between process and outcome)*	A review of the programme team structure and supporting guidance reveals those managers responsible for the development of the new BCR framework were not the same managers involved in management, use and support of the system, thus 'user participation' was expected rather than designers helping users to design how work is to be done.	The lessons learnt report from September 2016 of the PDSW programme found that the programme was solution and output driven and did not give sufficient attention to the people element of the change. Much is reported to have improved with the programme since its inception in 2014, and a more proactive approach to engagement with senior leaders, business change leads, trade unions has been noticeable since summer 2019 when the programme was 'relaunched' under the umbrella of the [track worker] safety taskforce. More communiques, briefings, and supporting videos are widely available on a safety-related central hub for affected parties to access.	**Ownership of the new systems, and of their designs, was not appropriated by the managers and users responsible for putting them into operation.** People responsible for design, implementation and use of the new systems were different individuals for each element. The longitudinal (observational) study of the programme boards discovered that fixed requirements written into contracts based on 'work as imagined', and technological change to be implemented at pace, meant that there was not much time to incorporate user feedback from early parts of the programmes, nor rescope work without incurring financial penalties, and so the problems continue to be perpetuated.

Clegg Principle	BCR Findings	PDSW Findings	Main learning points
16. Evaluation is an essential aspect of design *(undertaking a systematic evaluation of the investment against the original goals)*	There has to-date been no systematic evaluation of the multi-million-pound investment against the original vision of the BCR programme. Some attempt to assess achievement of certain programme elements has been carried out, e.g. 100 bow ties completed, but the overall intended benefits were never quantified in terms of safety metrics or efficiency measures, so there is little to prove or disprove that the work to-date has delivered the real change envisaged, i.e. safety and performance improvement through implementing a systematic control framework to understand and manage risk across [the] business.	The PDSW programme has had two lessons learnt reviews undertaken (although these are not in the public domain), as well as various Network Rail internal audits and ORR reviews to better understand if track working improvements have been made. These have all made recommendations, but before the agreed actions could be implemented there were two track worker fatalities at Margam in July 2019. The subsequent RAIB investigation and report (RAIB, 2020) show that the introduction of Standard '019' and the way it was rolled out originally has meant that aspects of the planning and delivery of safe work are misunderstood and there is limited compliance, hence proposals to now make the standard clearer, realign current safety competencies, and address non-technical skills to provide for behavioural change among frontline staff.	**Evaluation is a requirement for learning; Network Rail has undertaken this to an extent but not across both programmes collectively, or with the explicit inclusion of social, technical, operational, and financial criteria.**
17. Design involves multidisciplinary education *(bringing people together from different roles and disciplinary backgrounds)*	The BCR programme sought to involve subject matter experts, change practitioners, and engineering heads of department to design and develop the BCR framework and associated bow ties etc. What the programme board recognised belatedly was that the programme team didn't manage to bring these people together from different roles, and disciplinary backgrounds with different skills and experiences to contribute to the entire process.	The PDSW programme has sought to engage with different stakeholders at different stages of the programme's evolution. What was evident from the early programme board reviews and progress reporting by the change team is that very few meetings and workshops had a multi-disciplinary aspect to them, i.e. they tended to focus on the expertise thought to be needed for the meeting or workshop at that time, rather than a blend of participants.	**Network Rail sought to undertake a multidisciplinary approach to the design of the new systems to encourage creativity and innovation, and support the identification and mitigation of risk, but became constrained by tight schedules and resource availability.** Both the BCR programme and PDSW suffered for this.

Clegg Principle	BCR Findings	PDSW Findings	Main learning points
	Instead, the approach was piecemeal, and who attended the various workshops depended on availability rather than need.	Issues around interfaces and interdependencies were often overlooked until later flagged (if raised at all). During the process of the longitudinal (observational) study it became apparent that the PDSW programme was symptomatic of a wider lack of clarity on the governance structure of change programmes and how they interface within the business, in particular on the escalation of risks and issues and spans of control.	
18. Resources and support are required for design *(money, time and effort)*	The BCR programme was heavily invested in from a financial perspective, but time and effort were also required and usually from the same people called upon to do other things too. The observational study shows that little attention was paid to the resource requirements after the move to Business As Usual (BAU) in 2018. The system has not yet become operational regarding role based capability and related requirements for training across all asset disciplines. That said, a number of programme successes were captured and reported in Network Rail's update to its 'Home Safe Plan' for 2018/19. Unfortunately, the move to BAU coincided with a number of structural changes within the Network Rail business and put a temporary 'pause' on the roll out of related training.	There were numerous internal (and independent) reviews, and at one point in 2016 optioneering, to try and move the stuttering PDSW programme forward. Lessons learnt reviews report high levels of executive support, built through strong senior engagement (Executive Programme and Senior Business Sponsors), which provided much needed ongoing advice and input to resolve issues. Programme Boards sought to elicit where problems might lie so that support could be provided, but it was usually funding that got discussed most as the programme haemorrhaged money on training on a tool that was not implemented, revisions to standard '019' that proved too complex, and technology that was eventually de-commissioned after 5 years of ineffective use.	**The technological issues commanded the vast majority of resources, and at the expense of social concerns.** System development continues, but still with a focus on technology to support the socio aspects of the change.

Clegg Principle	BCR Findings	PDSW Findings	Main learning points
	The BCR framework no longer operates under the guise of a 'programme' but does have a supporting standard for the development of bow ties, and a process to allow for challenges to Standards in line with the Hansford review recommendations (around contestability) – for which over 130 standards have been challenged upto end December 2020 for which 65% of these have been accepted for change following detailed evaluation.	Akin to the BCR programme, PDSW has attracted significant investment but the restatements of the programme and the numerous stops / starts with the technology has resulted in a re-think of the approach(es) going forward, and how best to re-launch what is seen as a not particularly credible change initiative. The question is whether a re-badged programme, coming under the umbrella of the safety taskforce, will help resolve some of the problems PDSW has become synonymous with.	
19. System design involves political processes *(senior management commitment, cannot abrogate responsibilities etc.)*	Whilst there was the 'political will' to implement the BCR programme from within the senior ranks of Network Rail this did not necessarily extend to the delivery units and end users. The debates and discussions with those affected by the design were held belatedly which means many of the benefits are proving a 'hard sell' to the various stakeholders concerned, and especially since several organisation changes have occurred since the programme was launched in 2012 removing some of the much-needed resource for future roll out around standards 'challenges' and bow-tie upkeep / development.	The over-arching imperative for the PDSW programme (which is now relaunched as planning for work), and the umbrella safety taskforce, is for track workers to work smarter and safer. The ORR issued two Improvement Notices on Network Rail in July 2019 which are designed to eliminate planned work taking place on railway lines that are open to traffic where the only protection is a lookout – hence the [track worker] safety task force being established to attend to these matters.	**'Political' processes – debates and discussions – will continue as the systems evolve and the programmes morph into their new / revised initiatives. Different perspectives need to be respected and addressed; especially for those most affected by the changes.**

The longitudinal (observational) study has established that both Network Rail national change programmes have a very definite focus on workforce safety, especially planning of work and removing error, but their approach to change implementation has been quite different in parts, and the way the designs evolved was handled separately, not jointly. Despite having a common purpose around delivering technological solutions, reducing risks and/or harm to people, the two change programme teams did not use their collective power or collaborate in support of the changes, particularly around technology introduction, and early supplier engagement associated with this.

It became apparent from the observational work that the BCR and PDSW programmes depended on tools being effectively introduced to frontline staff, but there was also a reliance on third parties to develop these new technologies and deliver the training required to end-users. There were unintended consequences of the various change initiatives as a result, which only became obvious when the planning system and tools were put into operation.

For example, the longitudinal study uncovered that there were limited plans in place to deal with any delays in release of the electronic tools and systems, nor contingencies to address the subsequent problems with either the BCR and PDSW software. This oversight resulted in 'knowledge fade' across the workforce – impacting on both change programmes – after initial training and documentation was rolled out in anticipation of system(s) delivery to more than 20,000 personnel.

A systems approach is in evidence in elements of the two national programmes. For example, the objectives of the BCR programme were to put in place a new control framework, with the necessary tools, to enable Network Rail to better manage the risks and the controls required to enable its employees and contractors to consistently achieve the published corporate safety vision. Similarly, the PDSW initiative required a systems-thinking approach as new tools were developed alongside existing processes, and with it the introduction of new technologies. These programmes required multiple interfaces and hierarchical levels to be understood and documented, and communication flows to be effective. However, early assumptions in the two programme's system designs, around levels of existing compliance and 'work as imagined' versus 'work as done', proved wrong and difficult for some to admit to and then unpick, especially as the new risk management and planning tools were already in development and training was being rolled out.

9.4.2 Incident report recommendations

As the researcher had been the former Head of Corporate Assurance & Accident Investigation, and more recently a Director in Network Rail, access to and review of incident data and report recommendations were 'part and parcel' of the respective roles.

A selection of incident-related reports and digests, and a class investigation, from the last 5 years, and all published by the RAIB[52] that have relevance to the research aim, have now been revisited and analysed as part of this study, including the Margam report referred to in section 9.3.1.3 above.

[52] All RAIB reports are available, in the public domain, via their website:
[Rail Accident Investigation Branch reports - GOV.UK (www.gov.uk)]

The 20 reports are considered representative of the many others that are issued and available in the public domain, although these particular ones are more recent and have an emphasis on workforce safety, akin to the two national change programmes that have been the focus of this study.

Analyses of the selected 20 reports published by RAIB since 2017 (see Table 9.2) shows:

- 1 class investigation[53] into accidents and near misses involving track workers, which identifies issues around understanding and/or compliance with standards and procedures, competences of those planning and delivering safe work, the issue of effective communications, and incident analyses.
- 10 safety digests regarding collisions or near collisions between trains, equipment and/or track workers, where a lot of the emphasis is on the need for better planning and communication of the working arrangements, but also for organisations to focus more on developing the safety behaviours of all frontline staff, supervisors, and managers.
- 7 investigation reports relate to near misses between trains (or in one case, a track trolley) and track workers. These all in some way refer to workforce safety, compliance to rules and procedures, and issues of communication (verbal or written) – whether this is communication with the workforce, among the workforce, across teams or with individuals.
- 2 fatal accidents, at Stoats Nest in 2018 and Margam in 2019, which identify quite different underlying factors, but with both reports pointing to ineffective assurance systems, where management processes had neither identified or prevented issues of procedural non-compliance and unsafe working practices.

The table also includes details of the main findings from each of the RAIB reports, and the text in bold reflects the common, underlying factors, identified across the RAIB reports (and related recommendations).

[53] A class investigation is not unique to a particular incident or location but instead the RAIB look at a series of events, or underlying factors emerging from such events, and groups them into a ‘class’ report that gathers together various different features of previous incidents and seeks to identify common areas of concern and systemic issues.

Table 9.2 – List of selected RAIB investigation reports and study analyses of their main findings

No.	Report No.	Location	Date	Type	Main Findings
1	07/2017	Class investigation into accidents and near misses involving track workers	02/02/16	Class Investigation	• **procedures** and/or training for those in leadership roles to be able to adapt to changes in circumstances • **training** of track workers in non-technical skills • changes in the **competence requirements** for people who lead track work in higher-risk situations • making location-specific photographic and video information more easily available to staff involved in **planning and leading work** on the track • improvements in the collection, analysis, and **reporting of information on incidents involving track workers**
2	05/2017	Near miss between a train and a track worker at Shawford	24/06/16	Investigation	• **safe system of work** • management of fatigue for staff • **breakdown in vigilance** and safety discipline • being able to accommodate a short-term loss of resource and peaks in workload • not following rules and **procedures**
3	D06/2017	Near miss at Surbiton, south-west London	02/11/16	Investigation	• ensuring **safe system of work** for the workgroup, including the positions of safety, are clearly understood before going on or near the line • making sure that staff with safety critical roles on site, including lookouts, are familiar with the location • always remembering that the space between two lines (the 'six foot') is a dangerous place to stand or walk
4	16/2017	Track worker near miss incidents at Camden South Junction	28/02/17	Investigation	• **procedures** and methods for managing and communicating information regarding engineering work in modern, multi-panel signalling centres • processes for setting up a **safe system of work** still require people to be present on track, exposing them to risk in the transition period before protection is fully implemented.
5	D09/2017	Near miss at Ascot, Berkshire	06/04/17	Safety Digest	• highlights the **importance of good quality safety critical communications**, and of both parties confirming a common understanding of the message being conveyed. • preferable for controllers of site safety to receive a **face-to-face briefing** from the protection controller before signing the RT3181 line blockage form and authorising the team to start work.

No.	Report No.	Location	Date	Type	Main Findings
6	D12/2017	Near miss between Audley End and Great Chesterford	21/04/17	Safety Digest	• ensuring **planning documentation** is appropriate to the task that is to be performed, taking account of the nature of the work activity and the characteristics of the site of work • correctly positioning appropriate lookouts as part of **safe system of work**, after properly considering how they can both obtain adequate sighting of approaching trains, and reliably communicate with the group that they are protecting • regular reassessment of sighting, and a review of the lookout arrangements, by the person in charge of safety as mobile work activities proceed along the line
7	D19/2017	Track worker struck by a train near Wimbledon, south-west London	22/08/17	Safety Digest	• ensuring the precise boundaries of maintenance responsibility, such as those between neighbouring infrastructure owners, are correctly documented and understood by staff and managers • providing **clear signage** to mark maintenance boundaries so that inspection and maintenance staff are sure they are working to the same boundary
8	D16/2017	Collision between passenger train and trolley near Clapham, North Yorkshire	25/08/17	Safety Digest	• importance of a COSS re-briefing the workgroup whenever there is a change to their **safe system of work**.
9	D18/2017	Near miss between train and workers on Dutton Viaduct, Cheshire	18/09/17	Safety Digest	• never entering the railway in a red zone prohibited area while lines are open to traffic • **challenging unsafe behaviours** within a work group, even if the person in charge of safety has instigated or agreed to an unsafe act • promptly and accurately **reporting near miss incidents** • **safe system of work**, including safe access and egress using authorised routes • ensuring **deviations from the planned safe system of work are properly considered and authorised** by a responsible manager • responsible managers testing the effectiveness of their processes to assure themselves there is **compliance with procedures**
10	11/2018	Near miss with a group of track workers at Egmanton level crossing	05/10/17	Investigation	• working under an unsafe and unofficial **safe system of work** • safety **leadership behaviour** on site • **rule breaking** by those responsible for setting up and maintaining safe systems of work • adverse effects that client-contractor relationships can have on the **integrity of the ‘worksafe’ procedure** • clarifying to staff how the Train Operated Warning System (TOWS) should be used

No.	Report No.	Location	Date	Type	Main Findings
11	D02/2018	Near miss with staff at Clapham Junction, London	17/01/18	Safety Digest	• adopting **safe systems of work** which are suitable for the task being carried out, and modifying if the area of work changes • maintaining awareness of the risks involved when working on a live railway, and the limits of protection under the safe system of work
12	20/2018	Near miss with track workers and trolleys at South Hampstead, London	11/03/18	Investigation	• Track workers placed trolleys on a line which was still open to train movements, instead of on the intended adjacent line that was blocked • No-one designated as the 'Person in Charge' (PIC) • **Unofficial working practices** being used by the workgroup • **Introduction of PIC role in '019' Standard (issue 9) did not make responsibilities of the role sufficiently clear**
13	D11/2018	Near miss with track workers at Dundee	10/07/18	Safety Digest	• **safe system of work** planning can be vulnerable to misunderstanding, particularly where duplicate mileages on adjacent or nearby routes causes confusion • the need for the person in charge of the work to be actively involved in the planning process to minimise the chance of such misunderstandings occurring
14	04/2019	Near miss between a train and a track worker at Peterborough	20/07/18	Investigation	• The way in which work was planned defaulted to using the least preferred **safe system of work** in the hierarchy (i.e. the use of lookouts) • Current rules for **communication** when lookouts are used are impractical, leading to a disregard for the rules and the use of unofficial and uncontrolled practices.
15	07/2019	Fatal accident at Stoats Nest Junction, Purley	06/11/18	Investigation	• The track worker was **exposed to risk while putting out protection** for the possession • The labour supplier's management processes had not sufficiently identified and addressed the **risk of fatigue** among zero hours contracted staff • The labour supplier's management processes had neither identified nor prevented staff absenting themselves from work without being detected.
16	D05/2019	Near miss with track workers at Sundon, Bedfordshire	02/12/18	Safety Digest	• providing **signage** so that staff can reliably identify access points, and the track layout relative to them. • people responsible for the safety of others to have appropriate local knowledge of the area they work • staff to have **mapping that helps them reach the correct access points** from areas outside the railway boundary • reaching a clear understanding during **face to face safety critical communication**

No.	Report No.	Location	Date	Type	Main Findings
17	12/2019	Near miss with a track worker near Gatwick Airport station	12/12/18	Investigation	• **safe system of work** provided no protection from train movements at the actual location of the task • COSS recognised planned system of work lacked adequate protection from train movements but undertook the task without implementing an alternative safe system of work. • A second track **worker did not challenge the COSS about the unsafe method of working**. • Network Rail isolation processes did not provide planners outside Network Rail with sufficient information to always be able to plan safe systems of work.
18	D06/2019	Narrowly avoided collision between a train and a track worker at Ynys Hir, Ceredigion	02/04/19	Safety Digest	• A Controller of Site Safety and their **work group need to keep together**, so that they can remain in contact with each other and the COSS can give them clear instructions • Lookouts to remain alert and carefully watch for approaching trains once work is complete • Train drivers giving a series of short warnings on the train horn to alert anyone that has not acknowledged an initial warning or moved clear of their train
19	11/2020	Track workers struck (and killed) by a train at Margam, Neath, Port Talbot	03/07/19	Investigation	• The **safe system of work** that the controller of site safety had proposed to implement before the work began was not adopted, and the alternative arrangements became progressively less safe as the work proceeded Other factors included: • The way the safe system of work was planned and authorised • The way in which the plan was implemented on site • The **lack of effective challenge by colleagues on site** when the safety of the system of work deteriorated.
20	D03/2020	Near miss with track workers near Kirtlebridge, Dumfries and Galloway	14/11/19	Safety Digest	• staff **failed to reach a clear understanding when communicating messages** affecting the safety of people on the track • safety critical **communication protocols** need to be concise and easy to apply by those working on site • LOWS lookouts to treat the system as live following a successful test, and to always start giving warnings of trains unless the LOWS controller has specifically instructed them not to

The accidents at Margam (July 2019) and Stoats Nest (November 2018) sadly created the industry focus that was needed on track worker safety[54]. Before Stoats Nest it was almost 5 years since the previous fatal staff accident involving a moving train. That said, the warning signs were there, and an analysis of the 20 reports shows how those in the industry (but mainly Network Rail) had not created the conditions that were needed to achieve a significant and sustained improvement in track worker safety. Indeed, the RAIB reports highlight recurrent issues around:

- The lack of clarity around roles and responsibilities, and developing and maintaining competence among frontline workers;
- The inconsistency around planning and delivering safe work (and protection system design) to give high levels of protection on the railway;
- The need to greatly improve monitoring, supervision and assurance (including better track worker safety metrics, understanding issues of non-compliance with standards and procedures, and the introduction of leading indicators to track and influence a sustained approach to improving safety and performance).

Also, an underlying factor in a number of the RAIB report recommendations is the call for making greater use of technology to reduce risk to those working on or about the track; this is a frequent theme when talking about planning and delivering safe work, and safe work systems.

Finally, of note, is that the ORR issued two Improvement Notices on Network Rail in July 2019 which are designed to eliminate planned work taking place on railway lines that are open to traffic where the only protection is a lookout positioned on the track to alert colleagues to approaching trains – hence the [track worker] safety task force being established to attend to these matters. Network Rail has confirmed to the ORR that consideration is to be given by the task force to all related RAIB report recommendations to avoid future accident occurrence.

9.4.3 Unplanned events influencing change implementation

9.4.3.1 Findings from Margam

Two track workers were struck and fatally injured by a passenger train at Margam East Junction, near Port Talbot, on the main line railway, on 3rd July 2019. A third track worker also came awfully close to being struck. The three workers, working as part of a group of six, were carrying out track maintenance.

The accident occurred because the three Network Rail employees were working on a line that was open to traffic, without the presence of an appointed ‘lookout’ to warn them of approaching trains.

All three track workers are thought likely to have been wearing ear defenders, because one was using a noisy power tool, and it is suggested they had become focused on the task being undertaken, with none of them aware that the train was approaching until it was too late for them to move clear of the line.

[54] There was also a workforce fatality at Roade, near Northampton, in April 2020, when a trackworker was struck by a train. This was investigated by RAIB, and the findings were published in June 2021 (Report 03/2021).

The RAIB investigation found that the system of work that the controller of site safety had proposed to implement before the work began was not adopted, and the alternative arrangements became progressively less safe as the work proceeded. RAIB found several factors which led to this situation, relating to the work itself, the way the safe system of work was planned and authorised, the way in which the plan was implemented on site, and the lack of effective challenge by colleagues on site when the safety of the system of work deteriorated.

The RAIB report for Margam (RAIB, 2020) directly criticises Network Rail for being *"….too focused on technological solutions and new planning processes"*, primarily around the introduction of safe work planning tools and new duties introduced by a revised Standard. RAIB's concern was centred around the fact that Network Rail had not adequately taken account of the variety of human and organisational factors that can affect working practices on site, by this they specifically mean to address the promulgation of process requirements, task briefing and training. They mention in relation to this also that Network Rail's safety management assurance system was found to be ineffective in identifying procedural non-compliance and unsafe working practices and did not trigger the management actions needed to address them.

RAIB suggest in their Margam report, when reflecting on previous incidents too, that the protection of track workers from moving trains had not been adequately addressed over many years, despite good intent to do so, and the change programmes in place that should have led to improvements.

The ORR's annual safety report for 2018/2019 (ORR, 2019) goes further, and suggests the 'imperfect realisation' by Network Rail of its ambitions to improve track worker safety enshrined in the PDSW programme had *"resulted in timidity about future change".* This seems to strike at the heart of the concerns also later identified by RAIB, i.e. that the major changes required to fully implement the standard governing track worker safety were not effectively implemented across Network Rail. RAIB reported there was no evidence that substantive change had occurred, despite the recognition that action was required.

In July 2019, after these two fatalities at Margam and the ORR's strong criticism of Network Rail to address track workers being involved in too many near-collisions with trains, Network Rail launched a task force, backed by tens of millions of pounds, to target track worker safety. Each Network Rail Route is reported to have fully funded project teams for this work, and the Safety Taskforce will ultimately subsume other related initiatives to improve safety – the newly re-badged 'Planning For Safe Work' programme being one of them.

Twelve specific compliance criteria have been developed by the Safety Taskforce to allow Network Rail to comply with the ORR improvement notices, previously referred to above, by July 2022.

These include:

- The eradication of working under unassisted lookout protection – with the objective of making working with unassisted lookout warning[55] the exception, not the norm.
- The optimisation of line blockages and safe access – the ambition is to address many of the long-standing barriers to track worker safety including work bank reviews and safe access[56], signaller capacity, line blockage data, safe planning and working, and track safety equipment.

There are thirteen separate teams across Network Rail's business focused on developing detailed programmes and their focus is on some 'big wins' around having no more 'lookouts', no more 'open line' working, and 100% compliance with the '019' standard and its associated safe working practices.

Network Rail report progress periodically to the ORR. Good progress has been made on several fronts, including a thorough review by Network Rail Routes on the annual work bank which shows 4.3 million work orders, but with over 0.6 million of these being no longer required (Network Rail, 2020). This creates greater visibility of work, allowing teams to negotiate improved safe access to track, but also plan maintenance standard tasks into possessions, and take line blockages.

Earlier in this study there is commentary on the pressures on Network Rail and the rail industry to improve safety and performance. In the wake of the prospective changes required by 'The Williams-Shapps Plan for Rail' (DfT, 2021), and the advances in technology, track working, and the use of safe working systems, it is only ever likely that these pressures will increase for some time to come – and Network Rail and its Safety Taskforce team acknowledge this fact in the way they plan to address the ORR improvement notices by specifically targeting three key areas: people, information and technology (Network Rail, 2020).

People

- Empower the Person In Charge, improving safety behaviours
- Upskilling planners to improve Safe Work Pack quality

Information

- Digital platform with safety information for frontline colleagues
- Interactive management information tool with graphical insights/data on safety and planning of work

Technology

- New software to integrate with current systems to produce electronic Safe Work Packs
- New line block system - an industry wide solution
- National schematic solution - graphic image of the network using core asset data sets

[55] Network Rail intends replacing human lookouts with protection and warning technology to alert groups of workers to approaching vehicles on the track.
[56] This involves looking at the current workload and (re-)prioritising tasks. The intention is to reduce unnecessary site visits, and ensure where these do take place this is safe access for staff and protection from moving trains.

9.4.3.2 Observations regarding the GB Rail response to the Covid pandemic

To support the GB rail industry's response to the covid pandemic, Network Rail established a Strategic Crisis Management Team (SCMT) in February 2020, and the researcher was a member of this group from March 2020 (until September 2020) representing the Wales & Western Region as the Strategic Commander.

The SCMT was part of a wider industry structure involving government, regulators, train and freight operators, Trade Unions, the British Transport Police, contractors, and suppliers, that held a series of meetings daily for a period just a little over 6-months. These daily meetings / calls formed the basis of a coordinated response to the emerging crisis, although they were not without difficulty as the pandemic was unfolding during a period of decentralisation of power by Network Rail to its Regions, and the two national change programmes were also continuing in the background, seeking to address matters pertaining to workforce safety.

Meeting minutes were made available soon after each daily call, and actions were tracked through a log maintained by the meeting secretariat. The researcher had direct access to these meeting minutes, having participated in the calls, but their circulation was limited to attendees and senior rail executives only and not available for wider reference.

A number of observations were made by the researcher as an active participant during the Covid related calls, and are captured below under three key headings:

- Crisis planning;
- Crisis response;
- Good practice and sharing lessons learned

Crisis planning (and particularly civil emergency risks): whilst business continuity plans exist, they were not tailored to the unique characteristics of each type of crisis deemed material in respective company crisis management plans, nor aligned to the Cabinet Office's National Risk Register (2020)[57] (which was used to guide organisations through the key phases of the pandemic).

The researcher, in her capacity as Strategic Commander, found it difficult to formulate a crisis management plan for the Wales and Western Region without an overall – system-wide – plan being in place for the industry. Whilst operational performance was not directly affected, the pressure to respond to daily requests and government policy changes often led to a reactive rather that proactive approach. Horizon scanning of the types of civil emergencies to prepare for, akin to those that the oil and gas sector must plan for in response to a major fuel supply disruption in Great Britain, might have enabled greater resilience to have been built earlier at a regional and national level across the GB rail industry, particularly regarding for things like major / larger station operations (e.g. putting in place social-distancing measures and one-way systems, erecting covid signage, providing hand sanitiser at entry and exit points, limiting platform usage to avoid over-crowding etc.).

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[57] The National Risk Register 2020 outlines the key malicious and non-malicious risks that could affect the UK in the next two years and provides resilience guidance for the public.
https://www.gov.uk/government/publications/national-risk-register-2020

Crisis response – How the industry and Network Rail was prepared to respond to the pandemic, or indeed any other crisis, was perhaps rather telling in the way it had to come together very quickly to deal with the difficult circumstances encountered (e.g. having to rapidly reduce passenger numbers on trains and the impact this had on services, as well as significantly increasing freight train paths). They also had to manage the fallout out of a reduced workforce (due to Covid restrictions and illness) and the resulting cancellation (and replanning) of major engineering work. The implications of all this on critical functions such as maintenance, and the two national change programmes built in support of this (and worker safety), cannot be overstated.

Both the BCR and PDSW (re-titled to P4W) programmes were affected during 2020 by the pandemic; the industry response to the crisis meant attention being diverted elsewhere and away from some key elements of these organisational initiatives, e.g. the planned training of maintenance engineers and section (depot) managers was deferred for over 6 months.

Consequently, various 'taskforces' were set up to help better manage the crisis response, and the broader lessons from this, and how organisations deal with change more generally, are helpful for future reference. For example, the industry was quick to recognise that in a complex system it can suffer from a lack of clarity as to where decisions lay and can get approval – the issue of roles and responsibilities was certainly a common theme to emerge during the daily meetings / calls, and directly observed by the researcher. Decision-making authority versus being responsible for coordinating information flow was a regular topic of concern (e.g. to be able to make a decision directly about allowing additional freight traffic, over someone having to ask various others for a decision).

What was very noticeable with the Covid response as these complex interactions were understood was the ability to get agreement quickly when the right people were involved and sufficiently informed to make decisions (with Rasmussen and Svedung (2000) being proponents of such an approach). Some of these issues were able to be addressed with clear protocols developed for public communications, employee briefings, and Trade Unions liaison.

The risk was with the speed of some of the changes and so, to mitigate against something being missed, collaboration, and keeping track of critical network changes, non-compliances to Standards, and revised work schedules were all key to the response. A systems approach was developed by the SCMT, using a simple framework (in this case, the INCOSE[58] (2009) V-Model – see Figure 9.4 below) to guide their approach in seeing / understanding the inter-relationships between different activities, in a dynamic, complex, sector where change is constant, and people come and go but the accountabilities remain.

[58] INCOSE – The International Council on Systems Engineering is a not-for-profit membership organization and professional society in the field of Systems engineering.

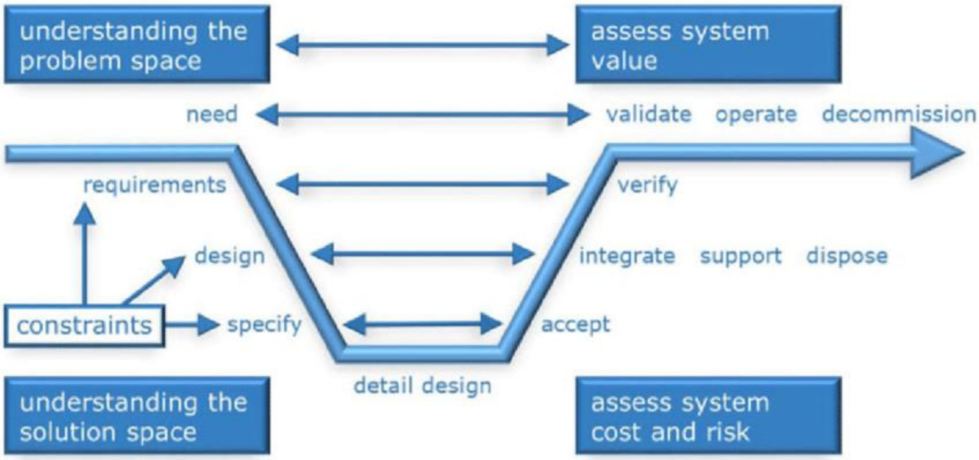

Figure 9.4 – The INCOSE (2009) V-model

Finally, due to the prolonged nature of the pandemic, over time things were able to settle, and risks were formally captured (individually and as an aggregate) and their impact assessed to support further downstream decision-making both in Network Rail, but also industry wide. The risk-based approach seemed to allay concerns of Trade Unions when maintenance tasks and major engineering works were reprogrammed, and demonstrated an ability to make changes at pace, in a controlled way, and perhaps not always previously thought possible. This positive approach to Union engagement also meant that the two change programmes, and things like missed training, could be quantified and re-baselined.

Good practice and sharing lessons learned was observed by the researcher throughout the March to September 2020 national Covid calls. Collaboration and ingenuity across the GB rail industry resulted in quick solutions being developed during the crisis, and information sharing was freely undertaken.

Applying a systems approach (see Figure 9.4 above), based on socio-technical systems theory, seemed to be beneficial, and the steps to expedite processes, considering emerging risks and issues, had to be found quickly whilst understanding both the operational and people impacts. The focus of the systems approach was centred around four elements: people, systems, design, and risk.

The approach allowed for the network to be considered as a 'whole', and for clear hierarchical control structures to be implemented to manage timetable change and manage and mitigate a range of operational and engineering risks through a process of rapid learning and sharing.

As an example, as the two national change programmes were paused, and restarted during 2020 it became evident that a strict adherence to rules and procedures was not going to be possible during the crisis.

The researcher in her capacity as the Wales & Western Region Strategic Commander was able to offer advice locally, and nationally, that saw Network Rail take a lead role in workforce safety matters (and related communications across the industry). This enabled changes to maintenance work practices being rapidly re-designed and introduced (e.g. changes to inspection frequencies, the wearing of face coverings, segregation in vehicles), and with the full cooperation of frontline staff, supervisors, and Trade Union officials alike. This involved decision-making suitably informed as much about how 'work is done' and stated in corporate standards and work instructions, as opposed to 'work as imagined' and undertaken in practice. This has had implications for bow-tie risk assessments, and the planning and delivery of safe work, but also how industry standards might be challenged in future, and the (re-)shaping of control documents.

9.5 Discussion

Exploring each of the two Network Rail national change programmes in detail, as well as incident report recommendations and recent events influencing change, has really exposed some of the challenges required to bring about a sustainable transformation (of systems, work processes and organisation structures) across GB Rail.

Earlier research reported in Chapters 5 to 8 helped to inform this fifth study around socio-technical systems, although applying a longitudinal (observational) method over 6 years, during which various situations arose and changes were made, has allowed for a much deeper understanding of the systems-related issues that can arise in real-work contexts. Matters concerning organisational learning in a complex GB Rail sector have been brought to the fore, revealing the difficulties that can be experienced when trying to implement change, and at pace.

What also emerged from the research and observational work is that no change programme is the same (Jimmieson *et al*; 2004); comparing the two major change programmes has highlighted similarities but also some differences in the systems approach to change. Many of these differences are because of the various interactions involved in the two separate, but complementary programmes. The BCR programme particularly struggled with integrating human components with the technical aspects of Standards change, bow-tie development and analyses, whereas the PDSW programme was more aware of the people aspects, but it still tended to worry about technical solutions and the production of information from the new systems than it did around the wider socio, political or economic issues likely to impact on the effective implementation of change.

The study has shown how Network Rail has sought to undertake a multidisciplinary approach to the design of its systems (procedures, technologies, and work processes) to encourage creativity and innovation, through the use of asset and subject matter expertise to support the identification and mitigation of risk, but the organisation's programmes soon became constrained by tight schedules and resource availability.

Even with a ready-made method available to manage change initiatives, i.e. Managing Successful Programmes for Network Rail (MSP4NR) (Network Rail, 2013(a)), the experience of programme directors, and their team's capability in programme management was very limited, and meant they did not use MSP4NR to best effect.

What happened, as a result, was that Network Rail failed to learn and respond quickly enough to the perturbations that occurred with new technology introduction and changes to working practices, and the situational and contextual factors associated with this.

Clegg (2000) suggests STS theory has the idea that design and performance of new systems can be improved, and in fact only work satisfactorily if the 'socio' and the 'technical' aspects are brought together and are interdependent parts of the overall work system.

Clegg does, however, also say that many organisations lack such an integrated approach, and invariably users have little influence on the system developed (Clegg *et al*, 1997), whereby the technology is seen as a 'given' and so the task becomes one of developing a social system around this. His solution was to advocate the use of his nineteen principles (Clegg, 2000) to help illustrate the context in which changes / revisions might be needed. He seeks to balance the socio and technical aspects, having the view that Cherns' principles (Cherns, 1976 and 1987) were too focused on social attributes (at the expense of more integrated concerns and technical matters).

This study has shown that, applying Clegg's principles to the Network Rail national change programmes, can help identify inter-relationships and interconnections between the two programmes and, as such, afford the researcher to take a 'net-like' view – considering a range of questions across the entire change effort (who will use the system(s)? who are the stakeholders? how well are needs being met?) rather than a linear (step-by-step) view for each individual programme's system designs and subsequent implementation plans.

The principles also help with taking a wider systems-thinking approach, and the question of how organisations can implement 'technology' and 'people' change when they are dealing with an array of other pressures – whether in response to previous incidents or accidents, or unforeseen events like the covid pandemic. The research suggests that the joint design and optimisation of social and technical systems has been and remains rare (Mumford, 1987). How this can be overcome, without still having too much of a technical emphasis, is worthy of discussion here.

Certainly, for the two national change programmes, the technological issues commanded most resources, and at the expense of social concerns. Even now, as the two national initiatives continue, the systems development (particularly new technologies and changes to work processes) tend to focus on technology rather than the human / people aspects of the change.

Network Rail has clearly wanted to design its systems and processes to be proportionate to the risk being managed. The training it has provided in relation to the two change programmes, and more broadly safe working, has sought to blend technical, leadership, and behavioural needs. It is an approach intended to take a 'whole system' view based on an awareness of the impact on the wider infrastructure and environment from a safety, sustainability, and performance perspective. However, from observations of the programme boards, and a review of the 20 selected incident-related reports and their recommendations, it is clear that organisational learning opportunities are often missed and result in recurring issues and events – both in Network Rail and also its contractor base.

During the crises of the covid pandemic – where the researcher played an active part in her Strategic Commander capacity – a more systems-thinking approach was deployed, considering the network as a 'whole' system requiring clear hierarchical control structures to manage things like timetable change, and control operational and engineering risks; learning fast and sharing experiences.

There is a substantial amount of literature regarding organisational learning approaches including a White Paper from the Chartered Institute of Ergonomics and Human Factors (CIEHF, 2020). It's clear that organisational learning is not a new phenomenon for Network Rail and GB Rail colleagues to address, but viewing this from a risk management, and safety-driven design perspective, and understanding how resilience engineering is a way to best use employees to help find solutions, rather than them being a problem to control, should be a feature of the framework that is developed (Dekker, 2015).

Clegg's principles have demonstrated that they are an effective means of providing such a framework to evaluate the design of programmes (such as BCR and PDSW), however, they are over twenty years old now and, having reviewed them as part of this study, the researcher believes they need a little updating to make them more relevant to today's increasingly interdependent complex systems, reflecting things like trade-offs, the need for local contextualisation, and learning lessons early (and fast).

Waterson and Eason (2019) revisited Clegg's principles and suggested a 're-crafting' of some of them to make them relevant for the next decade. This research supports their view – to a large extent – that all of Clegg's principles remain relevant, but perhaps some could be combined or revised to encourage greater take up and use in other studies or work domains – see Chapter 10, where this is discussed further.

9.6 Study limitations

Without doubt there have been sustained improvements in rail safety over the past two decades, but this has not been the same for workforce safety. With ever greater funding and performance pressures, and the likely further upheaval to come from 'The Williams-Shapps Plan for Rail' (DfT, 2021), this longitudinal (observational) study has necessarily focused only on how GB Rail, and Network Rail and its contactors particularly, have learnt lessons from the past five years or so related to workforce safety – and then how such organisational learning might be applied and adapted to new and evolving challenges and change management. Although familiar to the researcher through her previous roles in Network Rail, no attempt has been made to reflect on past approaches to industry-wide systems for recommendations management, or why lessons learned from decades ago have since been lost or have faded in the corporate memory.

9.7 Conclusions

Much of the literature on using socio-technical principles for system design (Cherns, 1976 and 1987; Clegg, 2000) has involved illustrating change within individual companies, rather than across companies or supply chains, or other types of networked ways of working.

This study broke that mould and has purposefully set out to explore change across Network Rail and its contractors, using a longitudinal study to observe changes within the ‘system’ – whereby the ‘unit of analysis’ has been across organisations within GB Rail.

The process of analysis, using Clegg’s socio-technical principles for system design, was useful in identifying how the principles can be used to guide organisations, and how they might form part of a framework to be adopted by Network Rail with the potential to support workshops that proactively discuss the socio-technical issues, and where multiple-layers of the organisation can be invited to work through the implications of system(s) designs at each stage of development.

The longitudinal study and approach to the research was helpful in being able to demonstrate very clearly how things have changed over time since the two national change programmes were first introduced by Network Rail and deployed across its business and contractors. The work has also aided the identification of the technological, social, operational, and financial factors that have significantly influenced this.

The review of incident reports and their recommendations, and other influencing factors such as Margam and Covid-19, has put into sharp focus how learning from adverse events can be a positive force for good if addressed in the right way. The availability of track worker protection technologies and better planning offer the industry the real opportunity to make incidents and accidents, and their impact on the railway and passengers, a thing of the past. A framework is likely to be needed to help with the design and implementation of these change initiatives such that joint design and optimisation of the socio (human / people) and technical aspects is achieved. Adopting systems thinking and a ‘systems approach’ needs to be all encompassing not a passing attempt at it – analogous to the work of Clegg (2000) – and it is suggested that key elements address people, systems (technology, process etc.), design, and risk – see Figure 9.5. A framework such as this can be used to support workshops with engineers and other key stakeholders to explore the relevance of each element on track worker safety improvement and some key questions can be asked and answered linked to the Clegg principles, e.g. who will use the system(s)? how well are needs met? what could go wrong? is the system performing as intended?

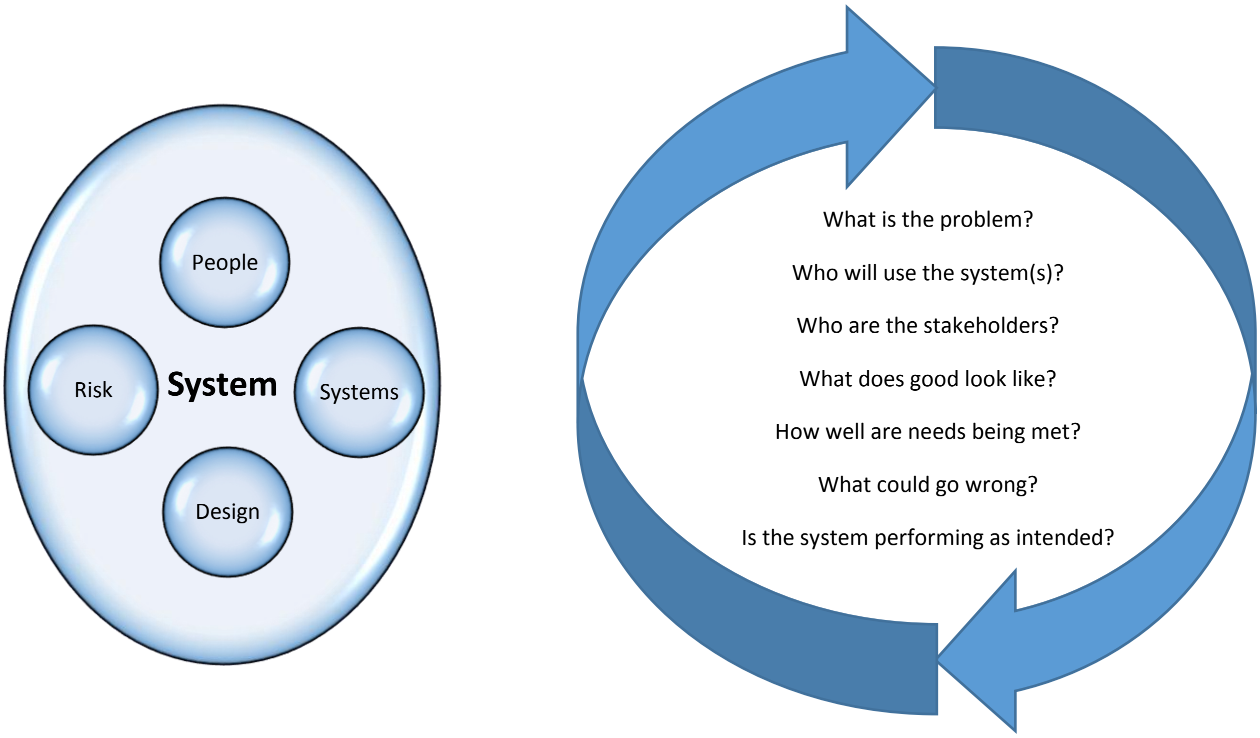

Figure 9.5 – The elements of a systems approach, and key questions

If adopted, this simple framework, affording a continuous cycle of review, could give programme teams the chance to consider the inclusion of end-users in the design process, how technology and human systems are best integrated, and help identify what makes for well-designed jobs, and function allocations, as well as where potential risks might lie. Guidelines in support of such an approach are provided, and discussed, in Chapter 10.

10. Discussion

10.1 Chapter overview

This chapter starts with a summary of the research findings from the five studies undertaken, and that are presented in detail earlier in this thesis. The overarching topic of how a complex socio-technical system and, in particular those within GB rail, can design new technological systems and processes during periods of significant change is explored, and how they can continue to support human performance, whilst being resilient to unanticipated events, is discussed.

The outputs are recommendations that help guide the implementation of continuous improvement in safety and performance in GB rail and culminate in a series of steps guiding managers and programme teams on how they might design, implement, and embed change.

The strengths and weakness of the overall research are discussed in a review of the methodological considerations, and finally conclusions are drawn, reflecting on the contribution this work makes to the bodies of knowledge in socio-technical system theory, resilience engineering, and human factors, whilst future work is also suggested.

10.2 Introduction

The aim of this research was to evaluate the GB rail socio technical system and to develop guidance that supports implementation of sustained improvements in safety and performance.

This thesis presents the findings from five studies which have variously examined socio-technical systems and systems theory in a complex rail sector. The part rules, procedures, standardisation, and compliance play in organisations is also addressed. Literature has also been introduced throughout that has contributed to the investigation of organisational learning and a systems approach to safety-driven design, and related systems analysis methods, and perforce resilience engineering. A summary of the findings from each study is presented in section 10.3.

Based on these findings, what can be said about systems approaches to change and organisational learning? Firstly, the GB rail socio-technical system (in which structural, equipment and human reliability depend on the management processes, organisation, and the safety culture in which the organisation operates) is indeed very complex. Therefore, it is difficult for individuals to know the system intimately as a whole, and the part they play in that. If this gap is to be bridged then future resilience engineering must first and foremost address the apparent contradictions in Network Rail between safety and autonomy, centralisation versus decentralisation, and stability versus flexibility, without which the human dimension can become disenfranchised, and sustainable performance is difficult to achieve.

Avoiding the potential for a drift into failure (Rasmussen, 1997), and having an organisation adapt effectively to cope with the complexity of its own structure and that of the industry, means that human factors (and safety) can play a critical role in looking at ways to better ‘engineer’ resilience, and equip people with the capability to recognise, adapt to, or recover from a loss of control should it occur. Space needs to be created where learning is possible, and where people can speak truthfully about what it means to get ‘work done’ under pressure from multiple goal conflicts and resource constraints (Dekker, 2015).

10.3 Summary of research findings

10.3.1 Study 1: To identify important components of the GB rail socio-technical system, and how STS theory can be applied in support of sustained safety and performance improvements

This study sought to identify important components of the GB rail socio-technical system, and how STS theory can be applied in support of sustained safety and performance improvements. The research included an investigation of how senior business leaders talk about the management of change in a complex rail socio-technical system, where the industry has faced unprecedented demand for its services in the past decade, whilst addressing technological transformation, and with multiple objectives in relation to safety and performance.

Twenty-five interviews were carried out with senior executives and managers in the railway industry. These interviews were designed to explore the perceptions of people in policy setting and senior management roles, and what they see as barriers to change within a dynamic, fast moving, industry. This included exploring both the 'work as imagined' in the corporate strategy and company procedures, as well as their understanding of 'work as done'. Two national change programmes that affect the frontline rail engineering workforce were used as contexts to frame consultations within the study.

Relevant socio-technical systems theory and reference to real-world application were found in the literature, and this helped with the identification of important points to consider for the design of change in a complex industry, and how a socio-technical system framework or model might be adopted and applied in practice.

The study very clearly outlines the perceptions of and barriers to organisational change in a complex rail industry, from the perspectives of the Executives and Senior Managers that operate within the system. The research has reflected on the applicability of aspects of Rasmussen's and Svedung's (2000) proposed dynamic approach to risk management in the context of complexity, and gathered insights into decision-making, and the decision-makers subsequent capability of control.

The research also revealed that whilst there is good intent to apply systems-thinking to organisational design – such as the move to a matrix structure by Network Rail that better reflects social and organisational levels, using a clear hierarchical control structure (Rasmussen, 1997; Rasmussen and Svedung 2000) – the study also uncovered how difficult it is in practice (due to a multitude of issues, including time pressures, and the dynamic nature of the sector) to identify organisational contexts or conditions to assess and understand how the socio-technical system really functions, and the gaps between 'work-as-imagined' and 'work-as-done'.

Guidelines were, therefore, developed to support managers, setting out how they ought to consider using a socio-technical approach as they design, implement, and embed change. The intention being to assist them in delivering their multiple objectives in relation to safety and performance, whilst making the process as simple as possible for already busy people.

10.3.2 Study 2: To investigate the inter-connectedness of human actions, decisions, and technological factors as part of an overall 'systems approach' to change

This study investigated the inter-connectedness of human actions, decisions, and technological factors as part of an overall 'systems approach' to change, and whether this was evident in examples of two Network Rail national change programmes; also taking into account the views of management on these programmes.

Thirteen interviews of Executive, senior and middle managers across Network Rail and its supply chain focused on how these programmes were designed and implemented to transform worker safety across Great Britain's railways.

The interviews uncovered numerous examples of the change programmes being launched, paused, restarted, reprogrammed, and yet the impact on these changing demands on human actions (teams and individuals) was addressed belatedly rather than proactively, and without appropriate coordination mechanisms across the two national change programmes.

Review of the literature suggests that, had a more systemic approach been used by Network Rail (for example, Clegg's nineteen principles related to the socio-technical system approach (Clegg, 2000), then the inter-connectedness (i.e. interactions, dependencies and potential conflicts) of the change programmes might have been better understood, and mitigated, before each phase of 'go live'.

The study results go on to show that Network Rail had to factor in how people and the things they do affect others, the tools and equipment needed to undertake work, job design, and decision-making authorities, but they did not necessarily do this in a systemic way. Instead, they focused on 'big ticket' items and missed the opportunity to provide conditions where there are no surprises and no time pressures to deliver sustainable performance.

The findings of this study also exposed the challenge of whether there can ever really be a clear understanding of how human actions, decisions and technological factors are connected in a dynamic, complex hierarchical structure, whilst change continues at pace. Whilst it is acknowledged that just one factor may be sufficient to prevent change programme success, it was more the multitude of factors (notably new technologies for e-permitting and planning work, and revised standards for safe working, job design, and decision-making authorities) that, when combined, suggested a need for a more systemic approach to change implementation.

The question of how best to approach socio-technical system design and system change, seen and developed through the lens of the workforce, considering information flow(s), system demands, pressures and constraints, is reviewed as part of the literature described in Chapter 3, but also answered in section 10.4 below.

10.3.3 Study 3: To investigate the perceptions of frontline staff on policy and processes intended to improve workforce safety

The focus of this third study was to investigate the perceptions of frontline staff on policy and processes intended to improve workforce safety.

The study involved a survey of more than 1000 frontline (mostly maintenance) staff, consulting them on how two national change programmes have aided the transformation of workforce safety, at a local level within Network Rail and its supply chain. The study explains the methods used to gather the views of frontline personnel, and to integrate these with best practice ideas identified in the array of literature available. For example, the views of four distinct groups of frontline staff were captured through a questionnaire designed specifically for the survey work, which helped with understanding the workflows, interactions, and interdependencies of the two change programmes.

Survey participants were asked for their perceptions on the practical application of technologies introduced by the two change programmes; these were employees who were identified as being best placed to have an appreciation for the demands of implementing change within a complex work system on the frontline.

Given what the literature says, particularly the work of Hollnagel *et al* (2006; 2013), about 'work as imagined' as described in formal rules and procedures, as well as 'work as done' in the way tasks are carried out in practice, one of the objectives of this study was to consider what this might mean for the two national initiatives, including during technology introduction, and maintenance regime change.

The questionnaire was, therefore, designed in such a way as to investigate how things have changed (e.g. technology, processes, work practices, safety and performance) for frontline staff over time since the two change programmes were first introduced, and how working practice compares with prescribed standards and procedures.

After detailed analyses of the 1000+ survey responses, the study discusses the implications of the pace of change and the challenges of user-influenced design in the context of a railway system where there are rapidly evolving technologies, and a need to consider the skills workers will need to engage with them.

Introducing new technology and partially automating planning processes did not come down to the manipulation of a single variable, and where multiple factors were instead at play. Unfortunately, some important features were missed, like systems integration, effective technology introduction and process change, without securing acceptance of the changes, and issues of compliance arose (and continue) since revisions to Standards were introduced.

The findings also show that as individuals have evolved their experiences in using technology, their confidence in and adoption of new systems is growing, and so issues of usability, accessibility and system responsiveness have become bigger concerns as capability and expectations have developed.

The study concludes by acknowledging the difficulties Network Rail has had in bringing about the intended organisational, process, and safety-related changes envisaged, and highlights how such research can bring awareness of real-world situations, that businesses face, to the practitioner community, and importantly where the human factors/ergonomics field can help by involving workers and teams in decisions regarding the future design and implementation of systems, tools, and technologies.

10.3.4 Study 4: Evaluation of systems analysis tools (i.e. STPA with bow ties) and their suitability as prospective analysis tools for industry to use

An evaluation of systems analysis tools was undertaken, reviewing the bow-tie analysis technique used by Network Rail along with the STPA method, as part of STAMP. Consideration was given to these two different techniques / analysis methods, and whether they are suitable as prospective analysis tools for industry to use to support future interventions in change programmes.

Several observations regarding the researcher's experience of these systems analysis tools were made. For example, whilst the technique of Bow Tie Analysis has seen steady take up within or across sectors, often in safety-critical domains, there appears to be little in the way of standardisation or recognised best practice about how to conduct and implement this barrier-type method in organisations (CIEHF, 2020). Network Rail took its lead from others when it decided to adopt the Bow Tie approach back in 2013, e.g. Royal Dutch Shell. However, even when it came to practical implementation, Network Rail did not adopt a particularly structured approach – primarily because of the sheer volume of workshops and 'hazards' it decided to address – and this resulted in an inconsistent picture of plausible accident scenarios that could exist around a certain hazard. The research reaffirms the need for clear guidance on bow tie analysis to give confidence to those constructing a bow tie that they are following a recognised method, and that there is a clear linking of barriers to threats and degradation factors to controls.

Similarly, although the STPA method captured the complex system of controls and feedback inherent in Network Rail's change processes, and demonstrates the potential to help redesign them, the researcher found the methodology to be time consuming due to the large amount of information generated, even for just a small sample, and the obvious shift from linear causality thinking. This analyses of the STPA method went on to identify that a simplified process for hazard analysis of organisation design to manage system safety risk is required which could use STPA as a framework, but also guide preparations before application.

Finally, the study shows that both the bow tie analysis technique and STPA can be used either as stand-alone or complementary tools for prospective risk assessment and analyses. If applied exclusively or mutually, they could help industry to undertake prospective analysis, using the tools in a range of settings / contexts.

The approach to bow tie analysis, i.e. understanding barriers, failure mechanisms, controls and additional safeguards it can generate, is unbiased in terms of any underlying model of accident causation. As a result, the bow tie model could be used in support of or on the back of the STPA method to serve as a prospective analysis tool, seeking to evaluate the quality of controls proposed to ensure they will have the capability of providing the intended protection(s), besides affording the opportunity to explore where the controls might fail.

That said, an important first step would be to improve the usability of the techniques, and supporting graphical representation tools, to increase the take up of these analysis methods both by researchers and practitioners. Comment is made further on, in section 10.4, about the wider fit and application of socio-technical system approaches.

10.3.5 Study 5: To undertake a longitudinal (observational) study to understand the extent to which a 'systems approach' has been applied to two Network Rail national change

Implementation of Network Rail's two national change programmes, to improve workforce safety, previously described in earlier chapters, and as part of studies 1 to 3, was tracked over a period of 6 years as the researcher undertook this part-time PhD.

Undertaking the longitudinal (observational) study allowed for the various stages of the two programme's implementation, pauses and changes to be monitored over an extended period, revealing the differences in how end-users and subject matter experts have been involved, and how the changes have been managed and evaluated. Unplanned events, such as two track worker fatalities, and the Covid-19 pandemic, also impacted on the change programmes and were added to the original scope of the study. The research identified how lessons were learned and addressed as the programmes were rolled out, and the impact of the pandemic on these was also noted; there were various reviews and opportunities taken to signify delivery of the changes that the researcher was able to observe and report upon.

Human performance has been considered in the context of the Business-Critical Rules programme and its associated elements of Bow Ties and Means of Control, the PDSW programme, and the rail industry's Covid-19 response.

Learnings from incidents and accidents, and the coronavirus pandemic recovery by the rail sector, present an opportunity to shine a light on the many positive responses, but there has also been the potential to highlight where there are gaps in things like systems thinking, or human and organisational factors (HOF) and the application of HFE theory in real-world problems.

Whilst the literature suggests there are researchers who continue to explore and consider the behaviour of increasingly complex and larger 'systems of systems' (Dekker *et al*, 2011; Stanton *et al*, 2012) as part of accident analysis, it became evident from this longitudinal study that looking 'up and out' (Dekker, 2011), to get a holistic view, even just across two national change programmes and the various factors that influenced their success (and organisational learning), is difficult to achieve because of the sheer volume of stakeholders and levels involved.

Having a clearly defined, bounded, approach to organisational learning and a systems approach to safety-driven design requires new thinking – that equally address the technological, sociological, and political conditions of the day – such that implementation of change across Network Rail's business and the wider rail sector is achieved and sustained.

This study proposes to build on the guidelines developed as part of Study 1; a proposed framework is presented below in table 10.1, seeking to align where conceivable, the earlier guidelines from Chapter 5 with a slightly re-worked set of Clegg principles discussed in Chapter 9, simplifying some of the 19 principles wherever possible[59].

The framework has been derived as a result of the learning from the other studies, and rather than simply produce a refined set of guidelines, instead the proposed framework is also sympathetic with Clegg's principles.

Commentary is also provided where a suggested change between Clegg's principles and those by the researcher are made.

The intention is that Network Rail could use the guidelines and revised principles as a blueprint to support their ongoing change programmes, to make a significant contribution to the overall systems that are being developed, (re-)designed, and delivered operationally. The key elements of a systems approach and questions that might be asked are referred to in Figure 9.5 in Study 5 (Chapter 9) and could act as an enabler to this proposed framework.

[59] Note that Study 5 (Chapter 9) identified that Clegg's principles are more than 20 years old and need some 'freshening up' to reflect the more dynamic world in which we now live and operate, particularly with technology introduction and resulting changes in human-machine interfaces.

Table 10.1 – Proposed framework that supports organisational learning and a systems approach to safety-driven design

Line Manager Guidelines (from Study 1)	**Clegg's Principles (used here in Study 5)**	***Commentary***
1. There is a need for transparency about the roles people play, preparing people for change through clearly defined and shared objectives, supported by strong messaging using media to suit the different audiences	1. Design is systemic 2. Values and mindsets are central to design 4. Design should reflect the needs of the business, its users, and their managers 5. Design is an extended social process 6. Design is socially shaped **and contingent** 15. Systems and their design should be owned by their managers and end users	*Design is contingent (no. 7) is combined with the social shaping of the design, to allow for multi-level input, but also local contextualisation and implementation (per Network Rail's decentralisation plans and ambitions for greater autonomy at the frontline)*
2. There is a need to understand goals, plans, and expectations in the overall context, i.e. the flow of work and the system as a whole		*There is no direct correlation to Clegg's principle here, but the importance point is that 'context' is key, e.g. what affects the system? What does good look like? Etc.*
3. Being clear on processes and the limits of control, safe performance, and operational constraints will help with achieving agreed targets, and enable informed, decision-making	8. Core processes should be integrated, and **components congruent**	*Principle No.10 is combined with principle no. 8.* *As Network Rail found, the interrelated systems should be consistent with one another, not new systems introduced without thought given to related information and control systems that were not changing*
4. There is a need to align the organisational structure, accountabilities of staff and skills of people to achieve agreed targets, and conduct continual, systematic, evaluation of its effectiveness	16. Evaluation is an important aspect of design	*Change the word 'machines' for 'technologies' to allow for those new systems, tools and technologies being designed and introduced.*
5. It is important to have the people with the right knowledge to make informed, co-ordinated, competent decisions	9. Design entails multiple task allocations between and amongst humans and **technologies** 17. Design involves multidisciplinary education	*The two change programmes sought to bring people together from different roles and disciplinary backgrounds to support change, but clarity of accountabilities and responsibilities was sadly lacking in parts, and training focused on tasks not roles, and with it the interfaces and competences required*
6. Blurred lines of responsibility need to be better managed to build resilience, and effective coordination of decision making is required at all levels		
7. It is important to agree the resources required to achieve sustainable performance and understand the trade-offs to deal with unforeseen disturbances	3. Design involves making choices **and trade-offs**	*Trade-offs added to principle no. 3 as the two national change programmes proved that difficult decisions had to be made, and system design needs to be more flexible*

Line Manager Guidelines (from Study 1)	Clegg's Principles (used here in Study 5)	*Commentary*
8. Implications of decision-making need to be understood and managed across all levels	12. Problems should be controlled at source 13. The means of undertaking tasks should be flexibly specified	*As the two national change programmes found, there are advantages of controlling problems at source, and therefore a degree of control over what is being faced and how this might be resolved. Greater autonomy, bounded by business critical rules and means of control, lend themselves to revised procedures where the ends should be agreed, but the means should not*
9. Risk assessment and risk perception need to be managed within the flow of work; analysis of the interactions between tasks, technology, information, and organisational elements may identify conflicts that introduce new risks, priorities and a change in workflow	11. Systems should be simple and make problems visible 14. Design practice is itself a **dynamic**, socio-technical system	*Agree with Waterson and Elson (2019) to make principle no. 11 wording clearer, and to include the word 'dynamic' in principle no. 14* *In Network Rail the concurrent changes (revisions to standards, new technologies, working practices) made the overall system design process highly complex, without the dynamic, systems thinking approach and ideas-sharing required*
10. Learning processes are needed to model past, present, and future system interactions, to give the organisation the foresight to manage operations intelligently	18. Resources and support are required for design, **and implementation**	*Amended wording to reflect the concern that there were inadequate resources in place for local implementation and changes to work practices for the two national change programmes, nor processes for routinely evaluating lessons learned at an early enough stage of system design / development to influence how these might impact on implementation*
11. Regulatory efforts need to be balanced; there may need to be socio-, technical- and economic trade-offs.	19. System design involves political processes	*It became apparent from the two change programmes that the various / different perspectives on system design and implementation need to be respected and addressed; especially for those most affected by the changes. Organisational contexts or conditions that influence the system and its functioning need to be understood and made resilient.*

10.4 The GB Rail socio-technical system is complex

10.4.1 Adopting a socio-technical / systems thinking approach to change

In principle, socio-technical systems theory is quite simple, in that work or technical systems, such as work processes, task definitions, equipment and information flow are usually defined or evolve in an organisation - and there are social systems such as the 'people' aspects (e.g. job design, compliance, autonomy, motivations etc.) or culture that are integral to the working environment. The technical and social systems are inter-dependent - each impacting on the other. It should then seem obvious that each should be designed along with the other (Walker, 2015). From the Executive and Management level interviews undertaken as part of the overall research (Study 1, Chapter 5), good examples of such a joined-up approach were not readily identifiable, instead these two systems appear to have been designed independently. This, in part, is because human actions, decisions and technological factors are not well understood in the wider – whole system – context, nor the interconnections made within the rail industry, sometimes because of the way organisational sensitivities or work silos govern what is shared, but also because of different political drivers and funding pressures (Study 2, Chapter 6). To work well in practice a multi-factorial, holistic, systems approach is required with the opportunity to design systems that reflect the needs of the business(es), end-users and managers, and the means of undertaking tasks flexibly specified wherever possible.

However, there appear to be gaps in what the theorists such as Clegg (2000) and Walker (2015) suggest as an approach, and the practical execution of this. For example, the GB rail industry leaders in Study 2 (Chapter 6) found it difficult to imagine developing change from the outset, without being encumbered by existing processes or working practices. These same interviewees also identified that having the resources and support required across multiple layers and disciplines to deliver change at scale was essential, but rarely achieved due to affordability and an issue of competence – and as such they were seeking to improve matters but establishing dedicated change teams.

Given these research findings, and the perceptions and concerns raised regarding the many barriers to effective change, a systems-thinking approach offers the opportunity to focus on the system taken as a whole, considering all facets relating to the socio- and technical- aspects including design choices, simplicity over complexity, and core processes being integrated.

The proposed framework (Table 10.1) deliberately uses simplified wording and is designed to act as a checklist / blueprint for future system design. The intention is that organisations, like Network Rail, would be encouraged to consider social and technical aspects concurrently, as change programmes are designed, developed, and implemented (among other workstreams and competing priorities).

10.4.2 Using systems analysis tools for prospective safety (and performance) management

As has already been identified earlier in the chapter, the rail socio-technical system is complex, and is likely to remain in a dynamic state of change as the GB rail sector continues to recover from the Covid pandemic and resulting significant passenger shortfalls, which remain well below pre-pandemic levels.

There is also political will to implement changes set out in 'The Williams-Shapps Plan for Rail' (DfT, 2021) where organisations face further disturbances and a call to end the fragmentation of the past 25 years, bringing the rail network under single national leadership and requiring wide-ranging structural changes across GB Rail.

Safety leadership will be required during what is likely to be a lengthy period of change, and transformational leadership according to Zohar and Luria (2010) will be important for promoting safe behaviour when the priority of safety may not be sufficiently embedded in company values. That said, attempts to improve safety and performance abound in GB rail, and there are tools and models that can clearly help.

For example, reflecting the findings of Study 4 (Chapter 8), there is clearly the potential to consider the use of prospective analysis (the investigation of an event that has not yet occurred), and a model of causality such as STAMP (System-Theoretic accident model and processes). This could assist with informing future 'safe by design' decisions and prevent accidents; whether organisational, technological, process, economic, or politically driven.

Along with established processes for hazard identification and barrier management, techniques like bow tie analysis (already familiar to those in Network Rail) and STPA could be combined to give a deeper understanding of controls expected to protect loss, but also expose how they might fail. The findings from Study 4 show the value of both tools, and how they can be applied in industry both retrospectively and prospectively. The analyses undertaken demonstrated what can be accomplished in a complex socio-technical system, and the benefits that can be realised from such an approach before a complex change is designed and implemented, albeit the tools are labour intensive, and should be used where the value of the technique can be justified (e.g. time, cost, resource) and can be offset against the occurrence of top events with the potential to cause loss of life, damage to property, environmental harm, or reputational damage.

Study 4 helpfully offers a simplified process for hazard analysis and, if used, it is suggested that risk identification is done using STPA to extract a set of risk scenarios related to different asset types and organisation structures in Network Rail. Following on from this would be an evaluation of these risk scenarios performed by using the bow tie technique. A key feature of both methods is really having a thorough working knowledge / understanding of the organisation, or design, or changes that are to be analysed – this requires actual workforce involvement so that 'work as done' is put into context and workarounds and trade-offs are factored in. Training should, therefore, be a pre-requisite before undertaking the analyses – both for participants and practitioners – to ensure high quality, reliable, outcomes.

10.5 Resilience Engineering, Trade Offs, Decision-Making, and Organisational Learning

Within a socio-technical system, and thereby the system of systems within that, there are many challenges including sub-systems, each with their own purpose to fulfil (Maier, 1998). Some interviewees, during the research, questioned whether there can be such a thing as a legitimate 'trade-off' in a safety critical industry when different pressures come to bear on parts of the sector, i.e. the sub-systems.

Analysis of the interview responses, where Executive and Senior Manager interviewees in Study 1 (Chapter 5) offered their perspectives on management information and reporting would suggest that different sources of risk in rail need to be more visible, considering trade-offs between socio-, technical and economic performance when making decisions, and the effects on reputation and service. The later analyses in Study 4 (Chapter 8) shows how bow ties and the STPA method might bring greater visibility to these different types of risk and in different work settings; applying the tools can provide a greater understanding of the organisation, or design, or changes that are to be analysed so that 'work as done' is put into context and workarounds and trade-offs are factored in.

As others have also previously found, it is difficult for individuals to make decisions when they do not necessarily understand the wider context or how a decision might translate across boundaries (Leveson, 2012) and/or the impact on the overall system (Salmon *et al*, 2012). Rasmussen (1997) said that safety management of organisations with "dynamic" operations should be based on *"an identification of the boundary of safe performance by analysis of the work system, and the criteria that drive the continuous adaptive modification of behaviour"*, but in the case of the rail 'system' these boundaries are constantly under pressure to deliver a safe performing railway – often arising from operational perturbations. That said, there was good practice identified from the interviews of resilience engineering and reliable performance – *despite* constraints imposed by divergent goals or perceived mixed messages with respect to safety, profitability and/or performance. As an example, the industry has made great efforts around capacity planning and scheduling to forecast timetable risks before conflicts occur, and it's been important for different functions to know each other's ways of working but also capabilities and limitations, including where there might be issues around train driver training roll out, signaller workload considerations, and back-up power supplies (for new services).

The research in Study 2 (Chapter 6) identified that system-level approaches to managing safety are complex and the apparent contradictions in Network Rail between safety and autonomy, centralisation versus decentralisation, and stability over flexibility, must at least be better understood by those within the system, even if they cannot be readily overcome. The move to a more devolved business in Network Rail is being pursued but, as Perrow (1984) has previously explored, the supposed safety and autonomy conflict means that organisations face irreconcilable demands for centralised and decentralised decision-making. This dilemma for the rail industry remains where there is a concurrent need for stability and flexibility, i.e. centralisation brings management control and stability, whereas decentralisation affords flexibility by encouraging proactive and adaptive (but traceable) decision-making.

The need for individual and team adaptability became apparent after the survey responses in Study 3 (Chapter 7) were analysed, particularly feedback proffered in support of the replies given. Having rules and standards such as those for safe work planning were clearly intended to provide stability for team functioning, but team members didn't then feel they could question these or speak up to promote better, perhaps safer, more flexible working. As Weiss, Grote *et al* (2017) have previously written, rules without flexibility can stifle people's perceived freedom to challenge and adapt existing procedures.

Senge (1990) advocates team learning as a way for teams to learn together and work within a complex system. He suggests dialogue helps teams to share their respective 'intelligence', and Senge argues that when dialogue is joined with systems thinking there is a common language that is more suited for dealing with complex change; getting away from the distractions of personality and leadership styles, which can sour relationships and trust, and effect decision-making. In practice, Senge suggests a series of steps that include team members understanding the 'what' and 'why' of change, and what these same people 'know' and 'need to know' to help drive the change, having a shared vision and bringing 'realism' through their 'experience'. This was in evidence in the rail sector during the covid pandemic when teams worked collaboratively to remove bureaucracy to be able to respond, at pace, to the emerging crisis – learning as they went – but also taking time to reflect as changes were made to core processes including station operations, timetable revisions, and maintenance and renewal activities.

Finally, to embrace the broader topic of organisational learning, such that organisations and/or systems and their people can recover after disturbances, it is important that practitioners are guided to design resilient organisations that can operate in response to changing demands, with the necessary capabilities to build adaptive capacity across all levels of the socio-technical system (Woods, 2019). This involves improved top-down communication of objectives and goals, and improved bottom-up information on the actual situation 'on the ground' in terms of reporting, resources, and different classes of risks. The literature shows that strategic safety leadership plays a crucial role here, but requires significant investment in training for leaders, and an appreciation of different 'worldviews' when trade-offs may be necessary due to tensions and conflicts from dynamic requirements (Grote, 2019). For example, Study 1 (Chapter 5) highlighted where individuals are required to prioritise train paths, such as a faster running passenger train ahead of a slower running freight operator, and yet – during the covid crisis – these freight trains were perhaps given priority as they moved around essential goods for health care.

Through this research, and the literature review, it is clear that organisational learning is not a new phenomenon for Network Rail and GB Rail colleagues to address, but viewing this from a risk management, and safety-driven design perspective, and understanding how resilience is a way to best use employees to help find solutions, rather than them being a problem to control, is an issue that isn't going to go away without intervention and foresight (Hollnagel, 2012; Hollnagel and Woods, 2005).

The rail industry came together during 2020 in a way it hadn't for many years to respond to the coronavirus pandemic, and the systems approach it implemented (for example five national timetable changes in a matter of weeks rather than months (Network Rail, 2021)) must be nurtured and developed for the future. The proposed framework (Table 10.1), if adopted by the rail sector, could support the necessary perspective-taking required, and cross-learning still needed, such that resilience engineering is built and sustained through strong change leadership (Mumford, 1987; Kotter, 1996; Clegg (2000)).

10.6 Human Factors / Ergonomics in support of 'engineering' resilience

The research – particularly Studies 1, 2 and 3 – has highlighted how reliable performance occurs (e.g. safe operations, on-time train running, asset performance) in complex organisations like Network Rail *despite* often conflicting constraints imposed by divergent goals or perceived mixed messages. As Rasmussen (2000) noted, the importance given to activity in situations and to user intelligence has constantly grown. Within imperfect systems, humans often are the ones to mitigate risk. The Executive and Management interviews in Studies 1 and 2, and the survey of frontline personnel undertaken in Study 3, investigating matters related to the people affected by change and their personal connections to the national programmes, show that there was insufficient attention to the human factors and what people do / need to do in their roles which, in part, explains the difficulties in delivering successful change across the two programmes.

The rail industry is likely to remain in a state of dynamic change following the Williams-Shapps review (DfT, 2021) and, as Network Rail seeks to transform its business, safety and performance can be viewed as emergent products of the complex rail socio-technical system. The Executive and Senior Managers who were interviewed as part of Study 1 (Chapter 5) acknowledged that things are going to happen on occasion in unexpected ways, that work arounds will be found, and/or new and better ways to do things will be identified, because – in their experience – the railways have always had to adapt (e.g. the commercialisation of British Rail in the 1990s, and how Railtrack and rail franchising have come and gone in the past two decades).

Study 3 (Chapter 7) highlighted that learning lessons even as change programmes are implemented will be critical to success, but so too will be the need to have an 'honest' position on 'work as done' and what appetite there is for change, and where resistance will most likely come from (e.g. Trade Unions). As Wilson *et al* (2009) have previously described, with emergent properties there are also human components that are affected, often requiring people's jobs to change. Practically, for Network Rail, with increasing technological demands and for the national change programmes to become embedded, comes an emergence of new roles, communication channels, relationships, power structures, sources of decision making, competence and capacity of managers, and collaborations to consider.

The attribute view of complexity (Walker *et al*, 2010) – where complexity has several distinct features – defines the ergonomics problem space as containing, among other things, multiplicity (multiple interacting factors), dynamism (system state changes over time) and uncertainty (difficulty and vagueness in determining the final system state). Therefore, to meet the demands of an increasingly complex industry, Network Rail knows it must change and at pace.

The two major change programmes were intended to deliver safety benefits quickly, but criticism of their early phases around “being too ambitious, too quickly” has resulted in a review of their scopes and ultimately led to redesign and re-baselining of key deliverables – but without necessary consideration of the ‘human factors’ required to affect change, for example: job (re)design, employee engagement, and end-user input to describe ‘work as done’.

Human and organisational factors can certainly play a part in future change implementation; the extent to which this can be achieved where there is a disconnect between those supporting greater decentralisation with those preferring centralised standardisation would undoubtedly warrant further examination. Getting human factors expertise involved in the discussion around where tasks should be flexibly specified might be a good first step; understanding how safety and autonomy might then be reconciled through appropriate safety management would be an important part in future design considerations.

10.7 Reflection on the aim and objectives of the thesis

The overall aim of this Doctoral Thesis was to evaluate the GB rail socio technical system and to develop guidance that supports implementation of sustained improvements in safety and performance. This has been achieved through four specific research objectives which were:

1. To develop a description of the GB rail socio-technical system, including consideration of the multiple objectives in relation to safety and performance.
2. To investigate the extent to which a systems approach is applied within rail industry processes and practices.
3. To investigate the perceptions of senior business leaders, managers and frontline staff on policy and processes intended to improve workforce safety and performance.
4. To apply systems analysis tools (e.g. STPA, bow ties) and determine their suitability as prospective tools for industry to use to support future interventions in change programmes

Five studies were conducted over a six-year period and their findings demonstrate the complexity of the GB rail socio technical system; one that continues to evolve and adapt to deliver sustained improvements in safety and performance. Recommendations are made below that follow on from extensive data analysis, research outcomes and study conclusions, and are presented in section 10.8.

10.8 Recommendations

The rail industry will have an important role to play in Britain’s recovery post the coronavirus pandemic, but in a period when public funding will be in short-supply, and ‘efficiency’ and ‘value for money’ will be the new watchwords (Network Rail, 2021). It is hoped that simplification and integration of the railway, through better alignment and shared goals can create a system that works for all. Recommendations are, therefore, made here that help guide the implementation of continuous improvement in safety and performance in GB rail, culminating in a series of steps that guide managers and programme teams on how they might design, implement, and embed effective and sustainable change.

An approach is suggested below (Figure 10.1) on how the recommendations might be pulled together as a framework, reflecting a series of stages akin to the work of John Kotter (1996) on how to lead change. Accompanying notes are provided in Table 10.2 setting out the steps for implementing change, and how to use the tools and best practice identified from the research, to promote structured continuous improvement in safety and performance in GB rail.

Importantly, there is a learning loop to address the dynamic nature of business, technology, better data, and predictive tools. By understanding the various stages of change, and the possible pitfalls, it should help with successful transformation (Kotter, 1996).

A key consideration for Network Rail, and indeed GB Rail organisations, is that the Common Safety Method for Risk Assessment remains a requirement (even post-Brexit) for assessing significant change in the rail sector (ORR, 2018)[60]. Railway undertakings and infrastructure managers continue to be required to develop safety management systems (SMS) to manage the risks associated with their activities and to meet specific criteria on the mainline railway system; the proposed 6-step framework for implementing change, set out below, has been developed to support such an approach.

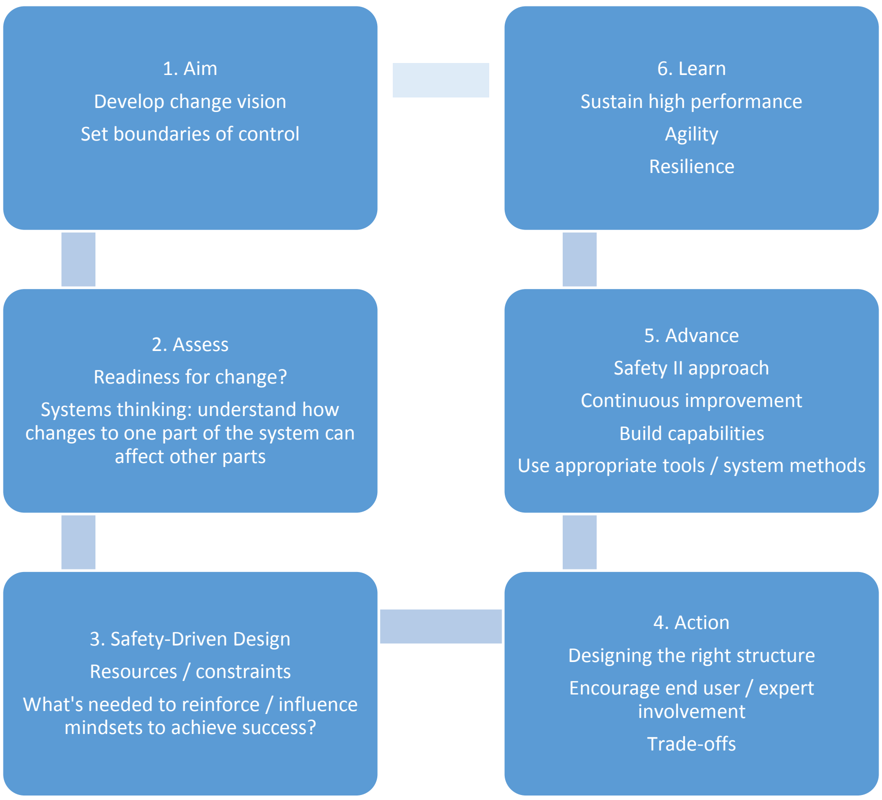

Figure 10.1 – Proposed framework for implementing change, to promote structured continuous improvement in safety and performance in GB rail

[60] ORR Guidance on the Common Safety Method for Risk Evaluation and Assessment https://www.orr.gov.uk/sites/default/files/om/common-safety-method-guidance.pdf

Table 10.2 – Notes / recommendations to accompany the proposed framework for implementing change, to promote structured continuous improvement in safety and performance in GB rail

Step		Notes / recommendations
1	**Aim** Develop change vision Set boundaries of control	Requires a clear vision for change to be developed and effectively communicated, and for the boundaries of acceptable performance to be visible to staff, management, and regulators (Rasmussen and Svedung, 2000). Understanding the scale of change is important here, e.g. are the steps to be applied to small projects or large programmes? It is suggested, given the experience of investigating changes of different scales for the thesis, that the focus – at least initially – should be on complex change that would fit within the criteria of the Common Safety Method for Risk Assessment. Examples might include: (a) the large-scale removal of posts from Network Rail under the voluntary severance scheme, (b) the track worker safety programme affecting frontline roles, (c) rail modernisation aligned to the Williams-Shapps review (DfT, 2021). Guidelines proposed as part of Study 1 and forming part of a framework proposed in Table 10.1, are also relevant here, particularly around Line Manager guidance no. 2 *"There is a need to understand goals, plans, and expectations in the overall context, i.e. the flow of work and the system as a whole"* and Clegg's principle no. 4 "Design should reflect the needs of the business, its users, and their managers" (Clegg, 2000). It is further recommended that Network Rail uses the proposed framework in Table 10.1 in conjunction with programme management tools (e.g. MSP4NR) and appropriate system analysis methods that can support prospective analysis. In this way, and with the right training provided, the organisation stands a better chance of identifying and implementing change in a way that is sustainable; one that has an adaptive capacity, that enhances resilience in a complex socio-technical system, and which pays greater attention to human factors such that individuals have clear goals and understand the expectations of them.
2	**Assess** Readiness for change? Systems-thinking: understand how changes to one part of the system can affect other parts	Requires the assessment of the organisation and its readiness for change, and where a systems-thinking approach is required to understand how one part of the system can affect other parts. This is where the work of Clegg (2000) and his principles of socio-technical design are particularly useful, especially those referred to in the framework in Table 10.1 around *"design is systemic"*, *"systems should be simple and make problems visible"*, and *"design practice is itself a dynamic, socio-technical system"*. To achieve this in practice will require systems and interfaces to be kept simple wherever possible, for people affected to be convinced about the change and bought into it, and for there to be a sense of urgency to deliver change and not for it to be drawn out and protracted by resistance to change (either from individuals or Trades Unions).

Step		Notes / recommendations
3	**Safety-Driven Design** Resources / constraints What's needed to reinforce / influence mindsets to achieve success?	Should focus on safety-driven design and the resources required, and constraints to be considered, that will reinforce / influence mindsets to achieve success. Rasmussen and Svedung (2000) talk about the development of a proactive risk management strategy that supports dynamic, learning organisations, to deal with rapid change, the introduction of new technologies, and design of effective decision support systems. They recognised, as did Clegg (2000), that organisations need to understand the mechanisms that generate the behaviours seen in decision-makers, and the information needs of these individuals at all levels. The guidelines developed in Study 1, and again included in Table 10.1, help bring this to life in a real-world context, particularly around the resources required to achieve delivery, understanding the implications of decision-making (and trade-offs) required across all levels, and learning from experience to give foresight to manage operations intelligently. Change leadership and commitment to change are the watchwords here. The research undertaken as part of Study 4 is also relevant, given that the proposition is that both bow tie analyses and an STPA approach, when combined, could afford prospective analysis, albeit only when justified, i.e. for major change, given the labour intensive nature of the tools and analyses. Such an approach could assist with informing future ‘safe by design’ decisions and prevent accidents; whether organisational, technological, process, economic, or politically driven.
4	**Action** Designing the right structure Encourage end user / expert involvement Trade-offs	This requires action to be taken, getting the design of the structure right, with appropriate end user input / involvement, and a recognition that there may need to be trade-offs. The use of a combined bow tie / STPA suggested in Study 4 can help here as it can evaluate design factors and any potential shortcomings in an organisation’s design, management system or decision-making process. Safety and risk considerations can be analysed and provide critical insights that prevent or mitigate a potential drift into less safe conditions (Leveson *et al*, 2006). However, the challenge remains of how best to approach socio-technical system design and system change, seen and developed through the lens of the workforce, considering information flow(s), system demands, pressures and constraints. Rasmussen *et al* (1994) and Leveson (2012) discuss the importance of ‘context’ and local work systems within larger social contexts. Clegg (2000) similarly touches on this, and so the proposed framework offered in Table 10.1 can play a significant part in supporting line managers to develop change proposals that are socially shaped and contingent – empowering people to act, recognising success and identifying some short-term wins.

<table>
<tr><td colspan="2">Step</td><td>Notes / recommendations</td></tr>
<tr><td>5</td><td>Advance

Safety II approach

Continuous improvement

Build capabilities

Use appropriate tools / system methods</td><td>This is about thinking about safety and performance, and change management, differently from what is done today. The research has shown that the GB rail industry is complex, and whilst a lot of work is done to identify and control risks in the sector, the bow ties and risk assessment methods used do not necessarily do justice to that complexity because of the tendency to focus on linear progression of failures, and the assumption that risk is in components of the system rather than the system in and of itself.

Dekker (2015) offers some useful ideas for transitioning from current safety thinking to a new era, e.g.

<table>
<tr><td>Current safety approach (Safety I)</td><td>Future safety approach (Safety II)</td></tr>
<tr><td>Safety is about measuring where things go wrong</td><td>Safety is the presence of capabilities and capacities, and competencies to make things go right</td></tr>
<tr><td>Safety is bureaucratically directed upward in the organisation</td><td>Safety is an ethical responsibility directed downward in the organisation</td></tr>
<tr><td>Cause-effect relationships are linear and unproblematic</td><td>Cause-effect relationships are complex and non-linear</td></tr>
<tr><td>Control and constraint</td><td>Empowerment, diversity, and opportunity</td></tr>
</table>

Modelling live socio-technical systems and using appropriate tools and system methods to do so (e.g. STAMP) can help to build a picture of the current control structure, but the research has also shown that internal models of the controllers can – over time – become inconsistent with, and no longer match, the system to be controlled (Leveson, 2012). Given that this real-world research has shown that complex change is rarely definite, repeatable, or stable, then the approach to using such methods should be similarly flexible and adaptive. Study 5 (Chapter 9) shows how STPA can be used variously to suit the organisational context, but a key feature of future design should not be in trying to look at every single change, but instead focusing on those that are significant, whilst anticipating the effects on operational and human performance (e.g. the removal of frontline roles in maintenance and what this means for the workload of others (who remain), and policies and processes impacted by this change).

Resources are often scarce and so the method selection and approach should allow for the primary focus to be on evolution and potential for improvement, the emergence of new capabilities, and complexities (Dekker, 2015). This might mean developing proposals in stages rather than an entire ‘system’. For example, changes at a local delivery unit level in Network Rail rather than an entire maintenance organisation made up of multiple delivery units). In this way, it affords the opportunity to develop people as the changes evolve, build confidence in the change (rather than a ‘big bang’ approach), and allows for some innovation / reinvigoration as change is rolled out and lessons are learnt.</td></tr>
</table>

Step		Notes / recommendations
6	**Learn** Sustain high performance Agility Resilience	The focus here is on learning, and being able to sustain high performance, and develop agility and resilience to deal with perturbations and disturbances. It was evident from the research in Study 1 (Chapter 5) that balancing competing demands for high levels of safety and performance with pressures for efficiency and production is very difficult. Executives and Senior Managers were able to cite examples of resilience in people and processes, *despite* these tensions. Those in GB Rail, and indeed Network Rail, need to be able to develop proposals for change suitably informed by the lessons from previous events, and assessment of the risks it is faced with as new learning emerges. Later, as the process of change management matures, it might be appropriate to develop a resilience strategy to help prevent future failures; this can only be developed if risks are continuously monitored, and safety and performance are dynamically balanced. The work of Ryan *et al* (2021) might be able to help here as part of future plans for change implementation, using their proposed framework to express the role of people in establishing and maintaining system safety for railway socio-technical systems. It is acknowledged that the model is complex, and there may be some merit in testing their framework against a relatively self-contained rail system, such as a metro or urban rail system before potentially widening its use, or perhaps (for Network Rail) a local delivery unit. Using this human-centred approach could help to identify and define concepts that influence what people do to deliver safety as part of a resilient organisation; something that was not in evidence when reviewing the two national change programmes as part of Study 2 (Chapter6).

10.9 Methodological considerations

The limitations of the individual studies have been discussed within each study chapter (see Chapters 5 to 9). The remainder of this section describes the strengths and weaknesses of the research as a whole.

10.9.1 Strengths

A mixed methods approach was utilised for this research; this afforded the researcher the opportunity to examine different aspects of the GB rail socio-technical system and associated national change programmes, which provided a number of benefits. For example, interviews used in Study 1 and Study 2 helped to inform the types of questions developed for the survey in Study 3. The use of multiple methods in Study 4 (workshop observations, a small number of interviews, and the use of STPA in practice) also enabled the researcher to experience first-hand some of the available systems analysis tools being used by industry, including the use of bow ties.

Study 5, using the longitudinal (observational) method, also gave a valuable insight into the complexities of change management in a dynamic setting. The researcher was able to monitor and track changes over a lengthy period of time, exposing how business and process changes can impact on the implementation and success of programmes. This method also afforded the researcher an opportunity to observe reactions to disturbances and unforeseen circumstances in real time, including individual's responses to pressure and their leadership in a crisis when they were really tested, usually seen in the 'work as done' and not 'as prescribed' processes (i.e. the covid pandemic, and worker fatalities).

The overall research approach provided a strong foundation for the study of the GB rail socio-technical system and the two Network Rail national change programmes, and it is considered that this would not have been as enriched without the unique, unfettered, access to people, systems, and processes, that was afforded to the researcher in her real-world practitioner capacity, and having subject matter expertise and insider insight.

10.9.2 Weaknesses

Inevitably, as the research, data collection and analyses, was performed primarily by the researcher (the exception was the support of a colleague for the STPA evaluation in Study 4) it might be argued that there might be researcher bias. That said, the researcher is a skilled interviewer and used her experience to develop a pre-defined set of questions to guide interviews conducted as part of Studies 1 and 2 to avoid any accusations of influence. Interviewees were also invited to review and/or redact their interview transcripts to support the research and improve the quality and reliability of the studies (Robson, 2015).

One other observation is that it was necessary to learn or improve existing knowledge in a number of methods used during the course of the studies, e.g. the use of STPA as an analysis method. However, these were overcome, and the benefits of the mixed methods approach were realised.

Finally, it is considered that involving managers and researchers directly in research (and practice) might help the case for greater understanding of human and organisational factors (HOF) and the part they can play in supporting the delivery of HOF alongside other business objectives (Ryan, 2019). This research certainly benefited from the researcher herself also being a senior manager / executive in an industry setting that she was familiar with, although this 'insider-researcher' role is probably a fairly rare occurrence, and the researcher was mindful that she would have to 'reframe' some of her beliefs and understanding of her organisation given the potential for problems in fulfilling a dual role (Coghlan, 2001) but also ethical issues such as ownership of the data, the nature of working relationships between the researcher and the researched, and the level of anonymity and confidentiality for individuals and the organisations involved in the studies (Galea, 2009).

11. Conclusions and future work

11.1 Conclusions

The overall aim of this thesis has been to evaluate the GB rail socio technical system to help guide the implementation of continuous improvement in safety and performance. In summary, bringing all the various elements together to paint a picture of how change is made at scale in GB Rail – and specifically in Network Rail and its supply chain – has been the challenge.

The previous chapters have explored the key fields of knowledge including socio-technical system theory, resilience engineering and human factors / ergonomics that support the research carried out. They reflect the situation and developments relevant to the investigations, put forward in the introduction, related to the socio-technical systems of GB Rail viewed through the lens of two Network Rail national change programmes, and the perceptions of railway workers across all levels. The early work supported the study of the extent to which the systems approach is evident in examples of current national change programmes; understanding if managers have applied systems thinking and how this can affect work they prescribe and oversee. The impact of these change initiatives on frontline staff has also been considered, and the way in which track work and track worker safety is achieved. The part policies, rules, procedures, standardisation, and compliance play as part of this has also been addressed.

Key questions have been raised around whether using a socio-technical systems approach can lead to a more mature learning organisation, and safety and performance that is sustainable. Other related questions have sought to establish what it means in practice to use a systemic approach to change, and what resilience means in the rail sector. Studies 1, 2 and 3 have answered these questions, and Chapters 5, 6 and 7 describe in detail how the rail system often has to adjust its functioning during perturbations, and sustains required operations under both expected and unexpected conditions, e.g. the GB rail response to covid-19.

Examining the assumptions and paradigms that underpin organisational learning from a risk management and safety-driven design perspective as part of Study 5 (Chapter 9) has also helped to identify the problem as to why organisational learning is so difficult in a real-world context, particularly cross-industry such as rail. Alternatives based on systems thinking have been explored as part of Study 4 (Chapter 8) to see if Bow-Ties and the STAMP model can help with prospective analysis, and guidance has been developed in Chapter 10 offering a stepped approach to change implementation, such that it can be effective and sustainable.

The Williams-Shapps 'Plan for Rail' (DfT, 2021), as a reform package and White Paper, seeks to create a new structure for rail that would facilitate the opportunities for efficiencies identified by previous reviews conducted by Sir Roy McNulty (2011) and Richard Brown (2013). Socio-technical system and resilience engineering theories seem to offer solutions to the challenges, and the research identifies ways in which joint optimisation of the social and technical aspects might be achieved through recommendations and guidelines that deliver sustainable change in Network Rail, but also the wider sector.

11.2 Knowledge contribution

When this research was started in 2014/15 the rail industry in Great Britain was facing unprecedented demand for its services, whilst addressing technological transformation, and with multiple objectives in relation to safety and performance. At the time there had been little research on how rail organisations can establish processes and build resilience during periods of significant change that are complementary with the theoretical approaches that are described herein.

The literature and methods explained in this thesis have been examined before, but not to the extent to how they might be applied to evaluate the GB rail socio-technical system in a real-world setting, or the perceptions of complex change on large numbers of frontline staff. Also, no research had been undertaken of this nature (as far as the researcher can tell) regarding 'live' complex GB rail national change programmes before, and the implications of these on managers, operators, systems, and processes as part of a dynamic eco-system that is still evolving, and even as the covid crisis continues and rail modernisation is being politically driven to make the railways more affordable.

The longitudinal (observational) study also proved to be invaluable in not only being able to track change and the effects of this on people, processes, and technology introduction over a considerable period, but also the benefits of using such a methodology which had to be adaptive to emerging findings, unforeseen events, and organisational variables.

It is, therefore, considered the work presented here provides an original and important contribution to the bodies of knowledge around implementing socio-technical systems theory, resilience engineering, and human factors / ergonomics, and the wider, associated, literature, but also offers a detailed insight in terms of data and descriptive details on manager and worker perceptions of change. This is evidenced by the five studies and their reported findings, and the recommendations that culminate from the research outputs, including suggested revisions to Clegg's 19 principles to bring them more up-to-date, and the proposed framework detailed in Figure 10.1 setting out 6-steps for implementing change to promote structured continuous improvement in safety and performance in GB rail.

11.3 Future work

Several possibilities exist for further research that are contained within this thesis. This is illustrated in Figure 11.1, and suggestions of how this might progress are detailed below.

For example, having observed the bow-tie approach used by Network Rail, and having applied STPA to a specific organisation re-design to achieve a new future state for Network Rail, it was suggested that the approaches be combined to enable the analysis to focus on system design errors through prospective analysis. A natural step would, therefore, be to examine whether such an approach would indeed be able to account for the complex roles that technologies and humans are playing in newly developed systems. However, before anything is done at scale, it is proposed that some further work is undertaken to combine the methods to make them more useable and less labour intensive.

Similarly, the framework with supporting notes / recommendations, for implementing change, to promote structured continuous improvement in safety and performance in GB rail, could be used in a real-world context by Network Rail as part of its response to the Williams-Shapps plan for rail reform (DfT, 2021). An opportunity exists whereby the organisation (and perhaps others in the sector), could work alongside a researcher and/or HFE practitioners, and apply the proposed approach in support of the Common Safety Method for Risk Assessment (that must be completed as part of the requirements for assessing significant change in the rail sector). Such collaborative participatory-based research could help both organisations and practitioners understand how the various methods described in the framework can support their needs, e.g. the Human Functions in Safety (Framework) (Ryan *et al*, 2021) in support of a resilience strategy, line manager guidelines etc. An element of this might be to better understand how and why the Covid response – where bureaucracy was removed and change was made at pace – proved to be so effective, e.g. was this because of a more flexible rather than stable / standardised approach in the application of core processes?

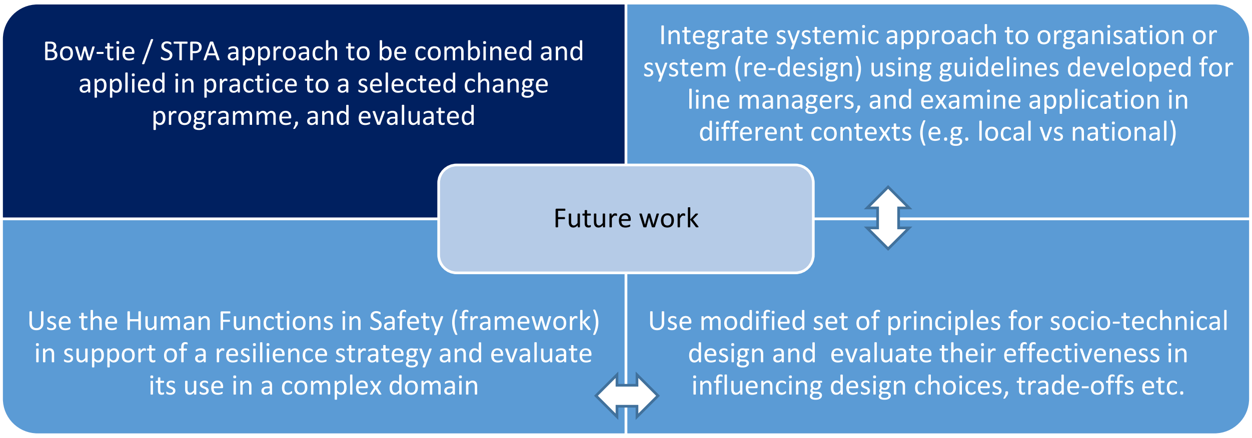

Figure 11.1 – Possible future work

The findings from this research and proposed future work can certainly be used by Network Rail, and the newly formed GB Railways, to develop a coherent structure (and put new leadership in place) that will allow for integrating activities across track and train, and facilitate wholesale reform of the complex rail system, firmly focused on implementing sustained improvements in safety and performance.

The researcher, for her part, has already been invited to offer her insights to help inform the future industry design, drawing on lessons learned but also possible future improvement opportunities over a 30-year horizon.

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