Integrating Stability and Flexibility in Complex Socio-Technical Systems: The Case of the GB Rail System

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Abstract

Conventional approaches to operational safety management rely on centralised hierarchical control structures, emphasising strict adherence to standards to minimise risks and uncertainty. This method aims to maintain stability and reduce variability in processes and behaviours, creating a predictable operational environment. This centralised control approach is dominant in modern complex sociotechnical systems in which safety is critical. Researchers have challenged this approach, arguing that the complexity and uncertainty in modern systems render preestablished, standardised control measures insufficient. They advocate for developing adaptive systems capable of navigating complexity and uncertainty, arguing that flexibility to handle contingencies in context by local actors is crucial.

These two approaches represent contrasting paradigms in operational safety management: one emphasising stability and central control, and the other prioritising flexibility and decentralised, local control. The challenge is to reconcile these contrasting approaches and find effective ways to integrate them.

The Great British (GB) railway system offers a unique opportunity to explore this contradiction and a clear example of the importance of such integration. Rail is a complex sociotechnical system where operational safety is managed through a centralised control approach. With recent and upcoming sector reforms, budget cuts, and post-pandemic changes in service demands, the GB rail industry is facing unprecedented uncertainty and pressures, necessitating increased efficiency and flexibility. Thus, it is essential to explore ways to integrate the existing safety management approach with alternative methods directed to increase flexibility and adaptation.

Overall, this doctoral research investigates that integration. The aim is to explore ways to increase flexibility in work processes and behaviours without compromising the system's stability and safety. To do so, stability and flexibility are used as key concepts. The research adopts a dualist stance, investigating these concepts as separate yet not necessarily antithetical.

A variety of qualitative methods were employed in this research, resulting in four studies. Study 1 (Chapter 5) uses document analysis and interview data to explore how standards provide users with the flexibility needed to adapt to

specific contextual circumstances. Study 2 (Chapter 6) uses interview data and document analysis to describe the railway standards development process, demonstrating how central control and operational realities are bridged through collaborative rulemaking.

Study 3 (Chapter 7) explores issues around stability and flexibility in railway operations management by interviewing individuals involved in rulemaking. The study draws conclusions regarding the risks, barriers, and preconditions of flexibility, highlighting important functions of centralisation. It also describes how the system faced and dealt with demands for high stability and high flexibility during the COVID-19 pandemic. Chapter 8 (Study 4) presents a case study conducted in a Rail Operating Centre. Using observations, interviews, and documents as data sources, the study examines the activities of rail infrastructure incident controllers, describing sources of stability and flexibility in real-life practice.

Overall, the main findings relate to:

- The system is performance-focused; safety is a quality and a precondition for performance.
- The risks associated with flexibility and the importance of maintaining a holistic view of the system, the risks and the operation. Mechanisms to bridge centralisation and decentralisation are described.
- The greatest barriers to increasing flexibility – and thus integrating both approaches – are social. The findings highlight the importance of interprofessional understanding and managing social processes to increase flexibility safely and efficiently.
- While the research describes stability and flexibility-enhancing mechanisms, understanding the degree of stability and flexibility needed is crucial. A framework to consider the mechanisms available in relation to differing operational needs is proposed (Chapter 9)

These findings have implications for both theory and practice, and the thesis concludes by reflecting on its contributions. The research provides insights useful for those involved in the safe and efficient management of rail operations. It also highlights issues that seem obvious to industry professionals but are often overlooked by researchers, provides empirical evidence to support safety research and theory, and offers a foundation for future investigations.

Acknowledgments

This research has been possible because of the generosity and support of many people, and I would like to thank them.

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Table of Contents

Tables

Figures

1 Introduction

Managing safety in complex systems has long been a deeply challenging endeavour due to the unpredictability and interdependence of system components, which can lead to unforeseen failures (Perrow, 1999; Rasmussen, 1997; Weick & Sutcliffe, 2015). As a solution to these challenges, much of the focus in safety research on complex systems has been on resilience and adaptability. However, a foundational issue underpins these efforts: the tension between negotiating stability and flexibility.

Stability characterises an approach to safety management that, through hierarchical control structures and adherence to standards, aims to increase safety by controlling hazards and minimising uncertainties. This centralised control approach is dominant in safety-critical systems. Flexibility characterises an approach based on the decentralisation of decision-making that enables local adaptations and improvisation in unprecedented situations (Grote, 2020).

The emphasis on resolving tensions, contradictions and paradoxes is pervasive in safety and organisation research (Reiman et al., 2015; Schad et al., 2016; Reason, 2000). Decades of studies on high reliability organisation (HRO) demonstrate the criticality of balancing centralisation and decentralisation for consistent high levels of safety outcomes in safety-critical organisations.

This thesis engages with the tensions and contradictions between stability and flexibility in the context of the railway system in Great Britain (GB). As detailed in the next section, the British railway system provides an ideal case to explore the contradiction for various reasons. First, its complexity (Nolan-McSweeney, 2022); second, despite safety being managed under a centralised control approach, the system has proven adaptive capacity and flexibility; and third, the increasing requirements for flexibility.

1.1 Background

The rail industry in Great Britain faces significant pressure and uncertainty due to economic challenges, skills shortages, industrial relations, extreme weather, and sector reform. These factors increase the need to maintain safety while reducing costs. The COVID-19 pandemic exacerbated these challenges; passenger numbers fell drastically, reaching just 4% of previous demand in April 2020. By 2021, keeping services going had cost the taxpayer around £12 billion (DfT, 2021).

Despite the challenges posed by the COVID-19 pandemic, the system adapted and continued running while maintaining safety performance. After the pandemic, and despite unprecedented demands and pressures, GB Railways continued as one of the safest railways in Europe, with 0.5 fatalities per 10 million passenger journeys in 2022-23[1]. These safety figures make GB Railways an ultrasafe transportation system (Amalberti, 2001).

As with other ultrasafe systems, such as aviation or oil and gas, railway safety is governed under a paradigm based on hazard control. Under this paradigm, accidents are prevented by controlling or containing the possible causes of failure (the hazards). After identifying and assessing hazards, controls are implemented to mitigate them and reduce risk to an acceptable level. Examples of these controls, named by Reason (2000) 'defences-in-depth', encompass 'hard' barriers such as automated safety features, physical containment, alarms, and non-physical measures such as standards and protocols documented in Safety Management Systems. These 'soft' defences (Reason, 2000) are centrally prescribed and enforced across the organisation. Hard and soft defences are directed to maintain processes and behaviour stable ensuring, in turn, a stable outcome: high levels of safety.

Theories and models focused on resilience propose a shift from the predominant approach in safety-critical industries, which relies on central control, to one that emphasises building adaptive systems (Hollnagel, 2014; Dekker, 2014; Hollnagel et al., 2006). Resilience has been described as the system's ability to adjust to sustain operations under expected and unexpected conditions (Hollnagel, 2014). In turn, adaptation or adjustability depends on the system's capacity to be flexible. Flexibility is critical to resilience at (at least) two levels: at the system level, it represents its capacity to restructure itself to respond to changes and unexpected circumstances (Woods, 2006); at the individual level, flexibility embodies the capacity to deviate from standard behaviour to respond to changing demands and to correct minor failures (Hollnagel, 2014; Perrow, 1999; Peries et al., 2010).

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[1] ORR (2023). Statistics: Rail safety https://dataportal.orr.gov.uk/statistics/health-and-safety/rail-safety/

However, some argue that ultra-safe industries are not ready for such a shift in safety management approach. Furthermore, the impressive safety records of these industries raise questions about the necessity of such a change. Instead, a proposed better solution is to integrate the two approaches (Kirwan, 2015; Amalberti, 2001; Remain et al., 2015; Grote, 2020). One challenge lies in resolving contradictions between the needs for stability and flexibility when integrating these approaches. How to achieve this integration remains an ongoing issue in the safety management debate (McDonald, 2006; Grote, 2019a, 2020; Kirwan, 2015).

Individually or in collaboration with other authors, Gudela Grote has published research addressing the challenge of balancing stability and flexibility at the individual, team, and organisational levels over the last two decades. Grote (2015) proposes a framework to manage uncertainty in safety-critical systems, asserting that good risk management is established when uncertainties are well managed. 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"* (Grote, 2015, p. 78).

From her investigation of the GB railway system, Nolan-McSweeney (2022) highlighted the difficulties individuals face in knowing the system as a whole and their role in it. She concluded that to bridge the gap between central and local action, efforts must first and foremost address apparent contradictions between '*safety and autonomy, centralisation versus decentralisation and stability versus flexibility*' (McSweeney, 2022, p. 229). She argues that failure to reconcile these contradictions can lead to disconnection from the human dimension and hinder sustainable performance.

1.2 Aims and objectives

In recent years, the GB railway system has shown resilience by handling unprecedented demands and surprises while maintaining safety performance. However, rising demands for efficiency and innovation, along with budget cuts and sector reforms, require greater flexibility. This flexibility must be achieved within the current safety framework, making it essential to explore ways to integrate the existing safety management approach with alternative methods.

The overall aim of this thesis is to explore ways to increase flexibility in work processes and behaviours without compromising the system's safety. To achieve this, stability and flexibility were used as key concepts. The research takes a dualist approach, using these concepts as two separate dimensions, not mutually exclusive. With a view of informing theory and practice, the objectives of this research were:

1. To describe sources, preconditions and barriers for stability and flexibility.
2. To provide a nuanced understanding of stability- and flexibility-enhancing tools and mechanisms in relation to operational needs for stability and flexibility.
3. To investigate whether stability and flexibility integrate, and if so, describe how they do.

1.3 Structure of the thesis

The rest of this thesis is structured as follows:

- **Chapter 2** provides an overview of the context in which the research was conducted: the railway in Great Britain. It includes an overview of the industry's main organisations, regulatory bodies, recent changes and the coming reforms.
- **Chapter 3** reviews literature relevant to this research.
- **Chapter 4** elaborates on the methodology, presenting the research paradigm, context, methods and the reasons for selecting those methods.
- **Chapter 5 (Study 1)** explores the detail in the railway regulatory framework and delves into different ways in which flexibility appears to be embedded at different levels (i.e., system, organisational and standard levels).
- **Chapter 6 (Study 2)** draws on interview data collected for Study 3 to describe how stability and flexibility are integrated through the development of rail standards.
- **Chapter 7 (Study 3)** reports on interviews with people involved in the development of rail standards to explore issues surrounding stability and flexibility in railway operations management from their perspective.

- **Chapter 8 (Study 4)** presents a case study looking at everyday frontline operations in a rail control centre.
- **Chapter 9** discusses the main findings across the individual studies and their relevance to the field of safety management. It draws final conclusions and reflects on methodological challenges encountered during the research.
- **Chapter 10** presents the concluding remarks, discusses the overall contribution of this project, and offers suggestions for future research.

2 Research context

This research was conducted under a grant from the Engineering and Physical Sciences Research Council (EPSRC). The research focused on the rail industry in Great Britain [2] (GB), a complex sociotechnical system (CSS). Although this research revolves around safety management in rail operations, providing a basic understanding of the rail industry is necessary to support and interpret the research results. This chapter provides an overview of the railway industry in Great Britain with a broad description of the components of the industry most relevant to this investigation.

2.1 The rail system

The British railway system is the oldest in the world. The first railroad built in Great Britain to use steam locomotives was opened on September 27, 1825, which used a steam locomotive built by George Stephenson. It ran from Darlington to Stockton, carrying 450 persons at 15 miles (24 km) per hour; railroad transportation was born[3]. By 1870, Britain had about 13,500 miles (21,700 km) of railroad[4].

As of March 2023, the railway system in GB is a vast and complex network encompassing 9,846 miles (15,846 km) of route, about 20,000 miles (32,200 km) of railroad and 2,578 stations in which the latest engineering solutions cohabit with infrastructure and elements from the Victorian's times. This network is used by 15,220 passenger railway vehicles[5], running at a maximum speed of 186 mph (296 kph)[6] alongside freight vehicles. There were 1.4 billion

[2] While the UK Parliament devolved some competencies to the Scottish and Welsh Governments, railways in England, Wales and Scotland operate and are regulated as a single network. However, Railways in Northern Ireland are fully devolved, independently managed and governed by a different legislation, hence the focus on railways in GB.

[3] Encyclopaedia Britannica (2024). George Stephenson. https://www.britannica.com/biography/George-Stephenson

[4] Encyclopaedia Britannica (2024). British Railways. https://www.britannica.com/topic/British-Railways

[5] DfT (2024). Official Statistics: Rail factsheet: 2023. Rail factsheet: 2023 - GOV.UK (www.gov.uk)

[6] This speed is achieved by Eurostar trains between London and the Channel Tunnel. In the rest of GB, the maximum operational speed is of 125mph (200kph). Trainline (2024). High speed trains in the UK. High-Speed Trains in the UK | Trainline (thetrainline.com)

passenger journeys[7], and the total freight lifted was 72.2 million tonnes[8] in 2022-23, all powered by around 240,000 people employed by the many organisations that form the rail industry.

The railway system comprises seven subsystems, categorised into two main areas: structural and operational[9]. The structural areas are:

- **Infrastructure** – the tracks, station infrastructure (platforms, zones of access, etc.), structures (bridges, tunnels, etc.), safety and protective equipment.
- **Energy** – the electrification system, overhead lines, and current collectors.
- **Control-and-command and signalling –** equipment to ensure safety, command-and-control movements of trains, etc.
- **Traffic operation and management** – the procedures and related equipment enabling a coherent operation of the different structural subsystems, including train driving, traffic planning and management.
- **Rolling stock** – all train structure and equipment (e.g., traction, energy conversion units, man/machine interfaces, and so on), safety devices and provisions for the health of on-board staff and passengers.

The operational areas include:

- **Maintenance** – procedures, equipment, and logistics centres for maintenance work.
- **Telematics** – this subsystem comprises two elements:
    - Applications for passenger services, including systems providing information about the journey, reservation, payments, luggage management and connections.
    - Applications for freight services, including information systems, marshalling and allocation systems, payment, reservation and connections management.

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[7] Office of Rail and Road (2023). Passenger rail usage. Passenger rail usage January to March 2023.docx (orr.gov.uk)
[8] Office of Rail and Road (2023). Freight rail usage and performance. Freight rail usage and performance January to March 2023 (orr.gov.uk)
[9] European Commission (2001). DIRECTIVE 2001/16/EC. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX%3A32001L0016%3AEN%3AHTML

Although this classification 'tidies up' the system into distinct subsystems, it represents a complex compound of elements. These include a wide diversity of old and modern infrastructure, different types of rolling stock, procedures, all sorts of equipment, and great technological diversity, all interfacing and interacting with each other and largely depending on each other. Furthermore, the structural and technological elements interact with a changing environment and the people who work the system, use it, and cross it, which makes it even more complex.

2.2 Rail organisations

Infrastructure managers (IM) are those responsible for maintaining, repairing, and developing the railway infrastructure. Network Rail is the main infrastructure manager in GB. It provides the tracks, signalling, electrification tracks, and so on to train operating companies (TOCs) and freight operating companies (FOCs) to run passengers and goods. There are 29 TOCs and seven FOCs in GB, known as rail undertakings (RUs). They buy or lease the trains from manufacturers and rolling stock owners. They are all supported by a vast supply chain of plant and component manufacturers and suppliers, maintainers, consultants, assessment bodies, and specialists. Each of these organisations has its own specific safety responsibilities[10].

Companies with defined safety duties are referred to as 'duty holders'. Infrastructure managers (IM) and railway undertakings (RU) are the main railway duty holders. Each entity is accountable for its respective part of the railway network and must have and implement a safety management system to ensure the safe operation of its infrastructure and vehicles[11].

Supporting rail organisations is a range of other industry and safety bodies and organisations, including the Rail Delivery Group (RDG), the Rail Safety Standards Board (RSSB), the Office of Rail and Road (ORR), and the Rail Accident Investigation Branch (RAIB). These organisations, together with the duty holders, form the so-called Rail Safety Leadership, depicted in Figure 2-1.

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[10] RSSB (2020). Cooperation for railway safety. https://www.rssb.co.uk/about-rssb/what-we-do/cooperation-for-railway-safety

[11] RDG (2020). Safety on the railway. Safety on the railway (raildeliverygroup.com); Gov.uk (2018). Roles of organisations in the UK's railways. Roles of organisations in the UK's railways - GOV.UK (www.gov.uk)

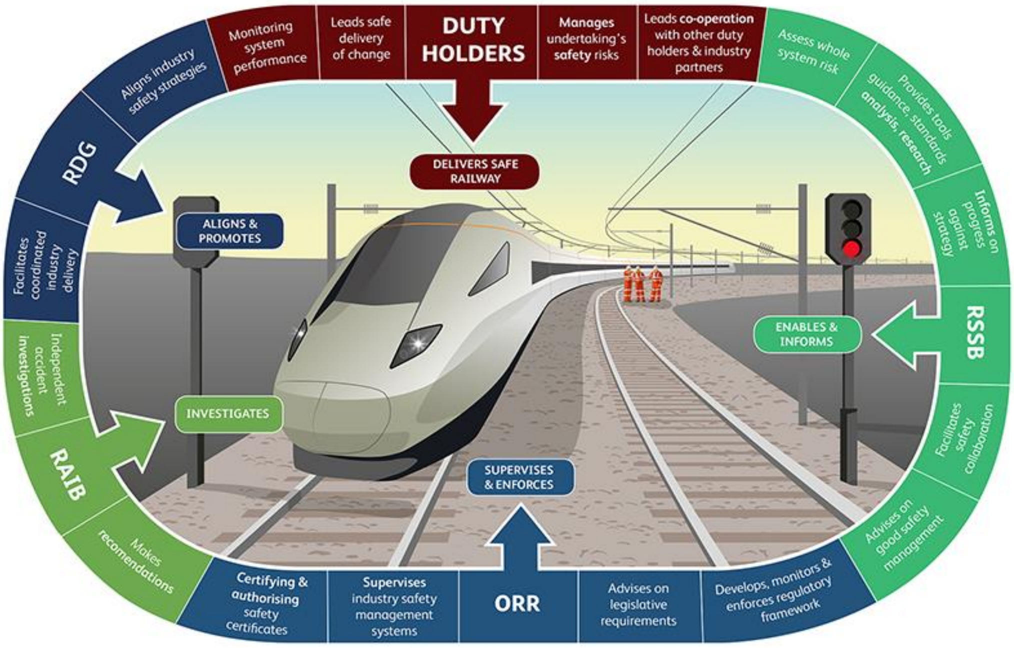

Figure 2-1Rail Safety Leadership (ORR, 2024), available at https://www.orr.gov.uk/about/who-we-work-with/safety-bodies

2.2.1 Rail Delivery Group (RDG)

RDG is an industry leadership body that works with all major TOCs, FOCs, and Network Rail. It was established in 2011 to coordinate and lead cross-railway industry initiatives. RDG engages with operators, suppliers, Network Rail, and other partners on various aspects of rail operations, such as rail strategy, policy, engineering, security, personnel, stations, crisis management and network performance. Liaising with transport authorities, suppliers, and other stakeholders, RDG also supports their members in areas such as retail, customer service, technology and data[12].

RDG's future is currently on hold. In 2021, the Government announced a new strategic direction for the industry: the Plan for Rail. The Government created the Great British Railways Transition Team (GBRTT), a new organisation responsible for integrating track and train operations decisions, providing accountable leadership and leading the railway to this new stage. Some of the RDG staff will be drawn into Great British Railways, while others have, or will, join Rail Partners, a group formed to continue the sponsorship and policy activities undertaken by RDG [13]. The Plan for Rail is presented in Section 2.6.

[12] RDG (2020). About us. About Us (raildeliverygroup.com); RDG (2020). Safety on the railway. Safety on the railway (raildeliverygroup.com)
[13] RSSB (2022). Cooperation for railway safety. https://www.rssb.co.uk/about-rssb/what-we-do/cooperation-for-railway-safety

2.3 Safety bodies

Safety bodies serve as cornerstones for regulating and assisting duty holders in operational safety, making them highly pertinent to this research context. However, it's important to note that they are not the sole safety bodies supporting the industry. Other organisations, including the Health and Safety Executive (HSE), the Railway Industry Health and Safety Advisory Committee (RIHSAC), and the British Transport Police, also play significant roles.

2.3.1 Office of Rail and Road (ORR)

The ORR is the health and safety regulator and enforcement authority for the railway, as well as the economic regulator. The ORR works with infrastructure managers, rail undertakings, freight customers, and rolling stock leasing companies (ROSCOs). Its contribution to safety leadership is to:

- Certify and authorise the safety certificates required to operate on the mainline railway.
- Supervise duty holders' safety management systems, ensuring all risks are identified, assessed, and controlled.
- Advise on legislative requirements.
- Develop, monitor, and reinforce the rail regulatory framework.

The ORR also liaises with other safety bodies, the RDG, and three government bodies essential to transportation in the mainland: the Department for Transport (which in England and Wales provides funding, strategic direction and buys rail franchises), Transport Scotland (which has responsibility for most rail powers in Scotland except safety regulation that remains with the ORR) and the Welsh Government (which specifies and monitors the train passenger franchise in Wales).

2.3.2 Rail Safety Standards Board (RSSB)

After the Ladbroke Grove Rail enquiry[14], The Cullen Report (HSE, 2000) recommended an independent body to steer collaboration and support the industry in managing risk. RSSB was established in 2003 to provide a system-

[14] The Ladbroke Grove Rail enquiry took place after the 1999 Ladbroke Grove rail accident at Ladbroke Grove in London. In the accident, 31 people were killed and 417 injured when two passenger trains collided after one of them had passed a signal at danger. Lord Cullen held the public inquiry into the crash in 2000 (HSE, 2000).

wide perspective on standards, research, and a range of cross-industry functions.

The standards agreed by the industry are developed, maintained, and published by RSSB. They provide tools and guidance to help companies to create and apply their safety management system. RSSB helps rail organisations manage safety efficiently by supporting them in many functions such as safety incident reporting, risk assessment, safety culture or human factors issues, to mention some. RSSB's research contributes to finding solutions to railway problems with safety implications[15].

2.3.3 Rail Accident Investigation Branch (RAIB)

The Cullen Report after the Ladbroke Grove rail accident also recommended the creation of an independent organisation to investigate railway accidents and incidents to improve safety. RAIB[16] started operating in 2005 as a totally independent body. RAIB inspectors investigate rail accidents on mainline railways, metros, tramways, and heritage railways throughout the UK. Their expertise is in both railway operations and railway engineering.

RAIB investigations are focused solely on improving safety. It is not a prosecuting body and does not assign blame or liability; other organisations, such as the police and safety authorities, deal with breaches of legislation. The investigations are set to enhance safety by bringing safety learning and awareness to the industry. The inspectors identify causes and potential factors that could result in similar incidents, locate safety gaps, and make recommendations to prevent recurrences. The results of their investigations are published as an investigation report and safety digests, which are publicly available on the UK Government website.

2.4 Network Rail

Network Rail owns and manages most of the railway mainline[17] infrastructure in GB. It operates 20,000 miles of track, 30,000 bridges, tunnels and viaducts, thousands of signals, and level crossings. While it owns most train stations in

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[15] RSSB (2024). About RSSB. https://www.rssb.co.uk/about-rssb

[16] Gov.uk (Undated). About us. https://www.gov.uk/government/organisations/rail-accident-investigation-branch/about#who-we-are

[17] Mainline refers to the rail network in GB that excludes underground, light rail, tramways, and minor and heritage railways.

mainland GB, many are managed by TOCs. However, Network Rail still directly operates 20 of the country's largest and busiest stations[18].

As a publicly owned (not for dividend) company, Network Rail is constituted by members such as the industry, public representatives, the Treasury, and the Department for Transport, which has special membership rights. Other stakeholders cooperate with Network Rail in the operation and development of the network, including representatives of passengers, TOCs and FOCs, contractors, Unions, lineside neighbours, local communities, and employees (Ferreira, 2011; Nolan-McSweeney, 2022).

Network Rail receives five-year funding settlements, known as control periods (CP), to fund some of its operational activities. Currently, it is in Control Period 6 (CP6), which runs from 2019 to 2024. Network Rail was allocated £48 billion for the current control period[19].

2.4.1 Devolution

Network Rail initiated a transformation towards becoming a more customer and passenger focused business. The change programme, 'Putting Passengers First,'[20] involved decentralising many business functions. This decentralisation process, devolution, was set to transfer decision-making and responsibility from a centralised organisation to smaller, customer-focused regions. Functions previously managed centrally, such as the Infrastructure Projects division and strategic planning, were decentralised.

They established 14 routes supported by five Network Rail regions, each overseen by a managing director accountable for their region. Each region is accountable for delivering all projects within its borders, including track and signalling. The routes are responsible for operations, maintenance, minor renewals, and the day-to-day management of train performance and relationships with local train operating companies.

Network Rail has not decentralised all the functions; it maintains a central team, the Technical Authority[21], to support the regions within nine areas.

[18] Network Rail (2024). Who we are. Who we are - Network Rail

[19] UK Parliament (2022). Rail FAQs. CBP-8731.pdf (parliament.uk)

[20] Network Rail (2024). Our routes. https://www.networkrail.co.uk/running-the-railway/our-routes/

[21] Network Rail (2019). Safety, Technical and Engineering Strategic Plan. Strategic-Plan-Safety-Technical-and-Engineering.pdf (networkrail.co.uk)

These areas are engineering and asset management, maintenance, operations principles, health and safety, security, sustainable development, quality, information management and technology, and innovation. Within this scope, the Technical Authority owns, develops, and maintains standards, policies, and processes and is responsible for industry coordination.

2.5 Who is responsible for what in the railway?

Changes in the governance of the railway system in GB are ongoing. Some changes, as highlighted in this and the next section, imply a complete restructuring with significant implications for how the system is operated.

A publicly owned company, British Rail was responsible for running the railway before privatisation. The UK Government restructured British Rail in 1993. Passenger and freight traffic was separated into 25 train operating companies and six freight operating companies franchised to private-sector operators. Railtrack was created in 1994 as a state-owned company to own and manage the system's track, signals, land, and stations. In 1996, Railtrack was privatised. Privatisation resulted in British Rail being divided into over 100 separate companies[22,23].

After the Ladbroke Grove in 1999, Railtrack announced losses of 534 million pounds in 2001. Railtrack was replaced by Network Rail in 2002. Currently, the responsibility for operating the railway is divided among several different organisations:

- Network Rail leases the stations to TOCs, which, along with FOCs, paid to Network rail for using the track.
- Privately-owned TOCs run most passenger services under multi-year franchises let by the UK, Scottish and Welsh governments.
- Private-owned ROSCOs lease the rolling stock to TOCs.

Figure 2-2 summarises the different stakeholders' main responsibilities. The black arrows represent the directions of payments. As the economic

[22] Encyclopaedia Britannica (2024). British Railways. British Railways | History & Facts | Britannica

[23] UK Parliament (2022). The future of rail. The future of rail - House of Commons Library (parliament.uk)

regulator, the ORR is also included, although its role does not involve financial transactions.

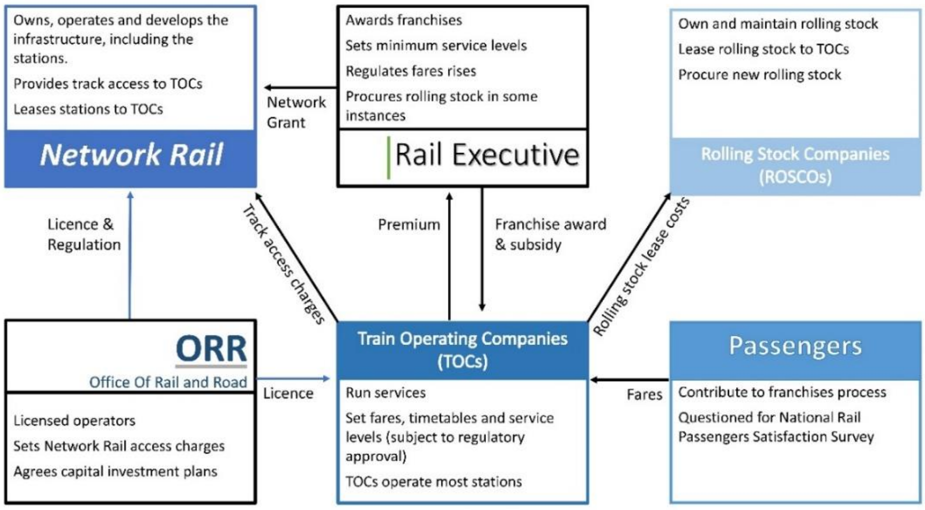

Figure 2-2 Who is responsible for what on the railway? Adapted from Rail Executive (2015). Available at https://bettertransport.org.uk/wp-content/uploads/legacy-files/research-files/franchising-guide.pdf

Successive governments have sought to address the fragmentation within the rail sector by bringing infrastructure management and service operations closer together. Yet, the current system, particularly the so-called *delay attribution*, hinders collaboration and efficacy. Coordination operates within a costly, rigid system of adversarial relationships, penalties, and misaligned incentives. Network Rail and rail undertaking companies employ nearly 400 full-time 'train delay attributors' to dispute whose fault a delay is. One example of disputes is whether a pheasant is a small bird (the train operator is to blame for a delay after hitting one) or a large bird (Network Rail's problem) [24]. About 40% of delays are disputed, and only about 25% result in a change to the original attribution. Yet, as a Delay Attribution Review conducted for the ORR noted, *"this is time consuming for all parties and it would be much better if resources were focused on solutions to reduce delays"* (RDG, 2020, p. 8) [25].

2.6 Great British Railways (GBR) – the future of railways in GB

In the first 20 years after privatisation, passenger numbers in GB railways grew by 92%, the fastest growth rate among major European railways (Brown,

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

[25] RDG (2020). Delay Attribution Review. Rail Delivery Group Delay Attribution Review for the Office of Rail and Road (orr.gov.uk)

2013). Nonetheless, since privatisation – the railway cost has escalated, and gold-plating and over-specification reduced the capacity to respond to opportunities and innovate. Two reviews commissioned by the DfT highlighted major problems regarding efficiency and costs (McNulty, 2011) and the problems caused by an over-complicated franchising system (Brown, 2013).

In May 2018, a new timetable was introduced, causing weeks of major disruptions to passengers' services, particularly in the North of England and in the South East[26]. The government originally appointed Keith Williams to conduct a system-round railways review. The Williams Rail Review was mostly completed by early 2020. Still, it was extended to ensure its conclusions remain relevant amid the ongoing pandemic. The Williams-Shapps' Plan for Rail (DfT, 2021) was presented a year later as a reform package and White Paper.

The Plan for Rail states that "*the current sums being paid to operate and maintain the railways are not sustainable*" and urges a radical change (DfT, 2021, p. 7). It exposes a railway that lacks coherent leadership, strategic direction, and customer focus. The review points out that the system is too fragmented, complicated, and expensive to operate, running with outdated working practices and lacking innovation. It stresses the overly-complicated "contractual spider's web", giving examples of franchise agreements typically covering around 1000 pages or the Ticketing and Settlement Agreement that comes in at 922 pages. The needs for simplifying the system's unnecessary complexities are emphasised. The reviewers argue that a simpler and more integrated structure will facilitate economies of scale, reducing costs. They advocate for a change towards a more customer-focused approach that attracts passengers, increases punctuality, and delivers value for money. They claim that this requires increasing operational flexibilities and agility to react to opportunities and respond quickly to changing demands. All of this while ensuring safety.

Summarising, The Plan proposes the following measures to make the change possible[27]:

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[26] ORR (2024). Inquiry into May 2018 network disruption. *Inquiry into May 2018 network disruption | Office of Rail and Road (orr.gov.uk)*

[27] UK Parliament (2022). The future of rail. https://commonslibrary.parliament.uk/research-briefings/cbp-8961/

- The establishment of Great British Railways (GBR) as a single entity to oversee infrastructure ownership, fare revenue, network operation, planning, and fare/timetable setting.
- A new 30-year railway strategy coupled with five-year business plans to establish long-term objectives that promote collaboration, unlock efficiencies, and encourage innovation.
- Creating a national brand and identity to present the railways as a unified network, featuring both national and regional sub-identities.
- A reform of the fares system to increase interoperability, simplicity, and flexibility.
- The replacement of franchising with Passenger Service Contracts where fare revenue is directed to the public sector, and private operators receive a fee for running the services.

In May 2022, the Government announced its intention to introduce a Transport Bill, encompassing the legislative changes required to implement the Williams-Shapps Plan for Rail. The consultation on the proposed legislative changes began in June of that year and is currently analysing the feedback. Meanwhile, the Great British Railways Transition Team (GBRTT), created to support the change, is developing guidance on simplifying and reforming industry processes to inform legislation, rules, and contract changes[28].

2.7 Chapter conclusions

This chapter has offered a brief overview of the rail industry in GB. While the chapter has provided only a simplified overview of the industry with surface-level descriptions, the industry's complexity is evident. In the chapter, not only the complexity of the industry is made apparent, but also the intricate moments the industry is navigating through. Network Rail's decentralisation process, devolution, is being completed while the industry is preparing for the biggest change in three decades – the transition to bring the railway under a single national leadership. Furthermore, all taking place amidst the ongoing aftermath of the pandemic.

[28] GBRTT (2023). GBRTT commission on simpler, better industry processes. Great British Railways Transition Team (gbrtt.co.uk)

3 Literature Review

Operational safety management in safety-critical systems is inherently challenging due to the system's complex nature and contextual demands and changes. The traditional safety management approach was developed when systems were less complex. It is directed to maintain the system and its operators under stable conditions and performance to avoid error. However, approaches and theories have emerged to tackle the challenges brought by increased complexity and uncertainty. These approaches focus on flexible performance to create resilient, adaptive systems. Key frameworks include Resilience Engineering (RE) and High-Reliability Organization (HRO). Central to these approaches is the ongoing negotiation between stability and flexibility to manage risks and uncertainty.

This literature review explores the diverse practices and theoretical underpinnings of different approaches to operational safety management. It highlights their evolution, contributions and the fundamental challenges they address. The railway system is introduced as a complex sociotechnical system, and this thesis' key concepts, stability and flexibility, are discussed.

3.1 Safety Management

3.1.1 Introduction

Safety management refers to the practices within the system operations aimed to generate or maintain safety (Provan et al., 2020). Safety, however, is somehow an abstract concept to define as it is more often described and measured by its absence than by its presence - this is in relation to accidents or the risk of accidents (Reason, 2000). Leveson (2004), for instance, defines safety as the absence of accidents, where accidents are unexpected or unintended events involving negative outcomes and losses. Weick (2011), on the other hand, has described it as the continuous 'production of dynamic non-events', which conveys the idea of safety being a succession of positive actions directed to control the possible causes of accidents. Safety is also defined as the opposite of risk, where something is considered safe if it involves an acceptable risk (Aven, 2009, 2014). Safety management, therefore, strongly focuses on maintaining the risk as low as possible by identifying what causes accidents and taking the necessary measures to prevent them from happening.

3.1.2 Personal safety versus operational safety

When talking about safety management, some authors have stressed the importance of distinguishing between personal safety and process or operational safety (Grote, 2012; Hopkin, 2009; Reason, 1997). Operational safety is related to the primary task of the industry. For instance, in the railway industry, the primary task is transporting goods and passengers; therefore, dangers and risks come from wrong signalling or faulty infrastructure, for example. Personal safety – or occupational safety – refers to that of the workers and the risk related to the task they do as an operator. For example, a railway electrical engineer has the potential risk of being electrocuted. Personal safety may not be directly related to the primary task, in this example, transporting passengers or goods. Yet, sometimes operational and personal safety are closely related, as in the case of train drivers, in which their (personal) safety is bound to the safety of the operation.

Grote (2020) argues that while the distinction between personal and operational safety has not been systematically addressed in safety research, it is significant. Attention is sometimes given to promoting one aspect at the expense of the other, and personal safety records and statistics are often used as indicators for process safety. This is, however, not surprising, as personal safety is more visible and relatively easier to report, record, and quantify. In contrast, operational safety is more akin to the 'dynamic non-event' mentioned above. Operations-related accidents are uncommon, so operational safety is typically assessed by the number and severity of incidents over a given period. However, this metric is flawed because even the most resilient organizations can experience a significant accident, while the most vulnerable ones may avoid disaster, at least temporarily (Reason, 2000; Leveson, 2012)

3.1.3 Evolution

Traditional approaches to safety management viewed accidents as caused by uncontrolled or badly managed hazards - being hazards objects, situations, or actions with the potential to cause harm or damage (Hollnagel, 2014; Leveson, 2004). Safety management, therefore, has been directed at hazard identification and control. At first, as machinery was evolving and mechanical failure was the main source of accidents, mechanical components were considered the main hazard (technical period). In the '60s, as engineering progressed and machinery became more reliable, the focus shifted to the individual. Hence, people's performance and cognitions became the main hazard (human error period). Systemic theories and models emerging in the '90s (Rasmussen, 1997; Reason, 1990) spotlighted the systems and the interaction of the system components, with the human factor also included in the analysis (Leveson, 2017). This has been called the socio-technical period (Neveu et al., 2020). The ideas about the main hazards have changed over the 20th Century; however, the safety management philosophies have not changed significantly. The approach to safety management has remained underpinned by the traditional or classical approach: hazard identification and control.

3.1.4 Foundations

One of the most influential philosophies underlying the classic approach to safety management is *causal determinism* (Leveson, 2017; Hollnagel, 2014). Causal determinism assumes that every state is completely determined by a previous state. In other words, every state or event (a cause) produces a particular state or event (an effect). From this follows that events happen in a cause-and-effect fashion and that if an event A (cause) precedes an event B (effect), we can predict B from knowing A.

A second underlying principle is the principle of *bimodality* (Hollnagel et al., 2013). Classical approaches promote bimodal thinking of work and safety in which things either function or malfunction. Function means success: there are no adverse events (i.e., accidents, incidents), therefore, the outcome is acceptable. Contrarily, malfunction leads to failure and negative events, resulting in unacceptable outcomes.

Another principle on which early classical approaches rest is the principle of *analytical reduction*, which assumptions are that a) the system can be divided into distinct parts, b) these parts work in the same way independently as they do as a part of a whole and c) interactions are *linear* and without feedback loops (Leveson, 2017). This implies that systems are *decomposable* into their parts (Hollnagel, 2014) and that problems are *traceable* to their root causes.

3.1.5 Centralised control approach

Assuming that accident causes can be traced back and found also means that once the system components with the potential to fail are known, accidents can be prevented by controlling or containing the possible causes (the hazards). Therefore, following hazard identification and assessment, controls are implemented to manage those hazards and lower the risk to an acceptable level. These include physical controls such as barriers and redundancy systems and non-physical controls such as standards, rules, regulations, and others formally documented in Safety Management Systems (Li & Guldenmund, 2018; Madsen et al., 2020). These ‘soft’ defences (Reason, 2000) are centrally prescribed and enforced across the organisation. Due to the emphasis on managing safety by first, a central determination of what is safe and then, by prescribing and enforcing rules, standards, procedures and the like, this approach is referred to as ‘centralised control’ (Provan et al., 2020). In this approach, safety is based on prescription, and accidents mostly result from something that (or someone who) did not work as prescribed.

Hollnagel et al., (2013) explain that the centralised control approach (which they refer to as Safety I) is based on a view of safety developed between the mid-60s and the mid-80s, which rest on the following assumptions:

- Systems and work are well designed and maintained.
- Procedures and rules are comprehensive, complete, and correct.
- Operators have the skills and training to behave as expected, and they do so.
- Designers have foreseen every contingency, and so, the system has been provided with the capabilities to deal with them.

Hollnagel et al. (2013) conclude that while these assumptions were reasonable in the 1970s when systems were simpler, they are not today. Safety-critical[29] systems are no longer *bimodal, lineal, decomposable,* and *tractable*. Not only are systems more than the sum of their parts (Rasmussen, 1997), complexity makes systems behave unpredictably. Additionally, standards, protocols, barriers, and other traditional methods of reducing uncertainty contribute to a system's complexity by increasing the number of its components (Dekker, 2011). Hence, surprises will always emerge, and the system's actors will act under uncertainty (Goldstein et al., 2010). Furthermore, safety cannot be approached in isolation but from an expanded strategic business context because safety is not the only priority affecting

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[29] Safety-critical systems are those where a failure or malfunction could lead to severe consequences, including loss of life, severe injury, significant damage to property or the environment, and considerable financial losses.

business decisions (Lofquist, 2017). Business strategy is highly influenced by a wider, global, socio-economic and political context, which is also complex and uncertain.

Over the past twenty years, scholars such as Hollnagel, Woods, Leveson, Dekker or Taleb (e.g., Hollnagel et al., 2006; Dekker, 2014; Taleb, 2007) have argued that safety-critical systems and the context in which they operate have become too complex and uncertain to rely on predictions; they advocate for another approach to understanding the system. Von Bertalanffy's General Systems Theory (Von Bertalanffy, 1968) established the scientific foundation for an alternative to the deterministic, reductionist approach to safety management in the early 1970s (Dekker et al., 2011). That alternative is known today as complexity and systems theory.

3.2 Complexity

3.2.1 Complex systems

Paul Cilliers argues that, when thinking about systems, it is important to look at the distinction between 'simple' and 'complex' and the distinction between 'complex' and 'complicated' (Cilliers, 1998). He explains that some systems appear complex but can be described simply, while other systems appear simple but reveal remarkably complex when examined closely. To illustrate the second distinction, Cilliers wrote: *'I have heard it said (by someone from France, of course) that a jumbo jet is complicated, but that a mayonnaise is complex.'* (Cilliers, 1998, p. 3). Complicated systems have numerous components and execute sophisticated tasks, yet they can be analysed comprehensively and accurately. However, complex systems cannot be analysed comprehensively; they contain intricate non-linear relationships and feedback loops, limiting the analysis to one specific aspect or element at a time. That said, Reiman et al. (2015) acknowledge a further distinction between ontological and epistemological views of complexity. In the epistemological view, a closer inspection of the phenomenon may reveal that complexity is a consequence of limited knowledge rather than a property of the system itself, the ontological view taken by complexity science.

A complex system comprises a large number of parts or components. Still, it functions as a whole and cannot be understood by only examining their parts (Von Bertalanffy, 1972). This is because it is formed by both the constituent parts and the intricate relationships between them (Rasmussen, 1997;

Cilliers, 1998). Complexity emerges as the outcome of the intricate, non-linear interactions among the individual components (Dekker et al., 2011; Mansfield, 2010) and anything that increases the quantity and diversity of components and relations increases complexity (Versterby, 2008).

In complex systems, failure emerges from the system's interactive complexity. This means that system failure and accidents do not result from the working or dysfunction of any of its parts; they are *'one emergent feature of constituent components doing their (normal) work'* (Dekker et al., 2011, p. 942). Therefore, system accidents cannot be predicted by looking at their constituent parts; models to investigate system accidents should take into account the system's interactive complexity and emergent properties (Dekker et al., 2011; Amalberti, 2013). In a similar vein, Reiman et al. (2015) argue that safety is an emergent property of the system that cannot be managed by looking at its parts in isolation.

3.2.2 Railways as complex adaptive (sociotechnical) systems

'Socio-technical' describes systems comprising people and technology, where individuals interact with one another and the technology (Mansfield, 2010). Saurin and Sosa (2013) note that while most socio-technical systems (STS) have some characteristics of complexity, some systems, such as aviation, healthcare, and petrochemical plants, among others, are often considered strongly complex. Railways is such a system.

The railway system's complexity comes from the vast and diverse number of interconnected technical, organisational, economic, and human components. The railway system works across regional, national, and cultural boundaries, and the systems' customers have an increasing role in product and service design, contributing to increased complexity (Wilson, 2014; Carayon, 2006). Furthermore, as part of an industry, the system is highly influenced by a complex socio-economic and political context (Lofquist, 2017).

While the term 'socio-technical' is ubiquitous in human factors research (Walker et al., 2008) the term 'complex adaptive system' (CAS) is also often used to refer to complex sociotechnical systems (Woods, 2015). Reiman et al. (2015) characterise safety-critical organizations as CAS, highlighting the inherent uncertainty, complexity, and contradictory requirements within these organisations. Consequently, they argue that safety management in such organisations should be adaptive to effectively address the dynamic and evolving nature of the environment and the system. From a review delving into safety, organisational, and complexity theories, Reiman et al. (2015) described seven characteristics of complex adaptive organisations, presented in Table 3.1.

Reiman et al. (2015) emphasise that several risk-inducing characteristics of safety-critical organisations identified in safety research are better understood from a CAS standpoint. For example, one phenomenon emerging from the system complexity is *organisational drift*, (Rasmussen, 1997; Snook, 2002; Dekker, 2011). The concept represents an emergent pattern in which the system adapts the centrally designed practices to the local practices. These local practices have emerged as deviance from the (central) norms to adapt to the environment (e.g., resources or pressures) and maintain efficiency. This mutual adaptation of central and local norms results in the gradual and often unnoticed deterioration of safety or drift into failure.

With a view on systems and complexity, theories and models such as High-Reliability Organisations (HROs) (Weick et al., 1999), Safety-II (Hollnagel, 2014), Safety Differently (Dekker, 2014) and Resilience Engineering (Hollnagel et al., 2006) have emerged. These theories and models emphasise adaptation and resilience as key processes to deal with the unpredictable and unexpected events caused by complexity (Pettersen & Schulman, 2019).

Table 3-1 Key Features of Complex Adaptive Organisations adapted from Reiman et al. (2015)

Feature	Description
Non-linearity	Asymmetries between inputs and outputs, and highly responsive feedback loops. Small local changes may have major effects at the system level. All effects have several parallel contributing factors and time delays between 'causes' and 'effects'.
Emergence	New patterns and properties emerge at the system level from the interactions among diverse agents. Emergent properties are not decomposable or tractable, and the properties of the whole differ from those of the parts.
Self-organisation	Self-organisation emerges from non-linear interactions between local agents. CAS can self-organise into higher complexity states; system order is generated without external control.
Far-from-equilibrium conditions	Sometimes called the edge of chaos or the edge of stability, systems far from equilibrium are naturally in continuous flux and change (change is inherent rather than initiated from the outside). This enables self-organisation and adaptation to environmental changes.
Coevolution	A CAS exists within and is part of its environment. Environmental changes trigger adaptations in the system, which then affect the environment, causing mutual change and evolution. The environment, including organisations, can also be seen as a complex adaptive system.
Nested systems	CAS are ‘systems within systems’. For example, organizations are composed of individuals who are complex adaptive systems. The nested systems increase the diversity and uncertainty in the ‘parent system’.
History-dependence	CAS cannot go back to its earlier form and state. The system agents learn from experience and adjust their actions accordingly; past events shape their actions. This means that solutions are seldom transferable to another system and that initial conditions are less important than historical trends.

3.2.3 Resilience

Resilience is a pervasive concept within system approaches. From their literature review in the safety domain, Bergstrom, Wisen, and Henriqson found resilience to be '*an increasingly adopted, for some scholars even necessary, concept to deal with the growing complexity of our socio-technical systems*' (Bergströmet al., 2015, p.4). The concept of resilience is used across domains, from engineering to biology or psychology. Within the context of complex systems, resilience has been defined as '*the ability of a system to adjust its functioning prior to, during, or following disturbances so that it can sustain required operations under both expected and unexpected conditions*' (Hollnagel,2014, p. 183). Although this is only one of the many ways the concept of resilience has been used in this context, overall, resilience seems to represent the ability of a system to adapt to changing, unexpected or adverse conditions while retaining its capacity to function as close as possible to its normal conditions.

Adaptability is an integral part of the concept of resilience, and the term 'guided adaptability' has also been used to refer to this paradigm (Provan et al., 2020). The term is a good reflection of the core idea of the approach, where 'adaptability' refers to the ability to change to suit different conditions, and 'guiding' involves showing, influencing, or directing. Rasmussen has argued that control should focus on establishing clear, stable boundaries and facilitating the development of coping skills at these boundaries (Rasmussen, 1997). Provan and Rasmussen's arguments coincide with those emphasising the importance of creating systems that are both stable and flexible (e.g., Weick & Sutcliffe, 2011; Orton & Weick, 1990; McDonald, 2006; Grote, 2011; Reiman et al., 2015).

A key premise of these approaches is to shift focus from solely examining failures to also analysing successes. The conventional emphasis on negative outcomes alone may contribute to significant, fatal accidents in certain industries. This is because in 'nearly error free' operations (La Porte, 1982), the negative outcome data used to measure safety performance has declined to an asymptotic value. Once the plateau has been reached, negative outcome data are a poor indication of how safety is managed. Moreover, it can create a sense of false confidence and invulnerability detrimental to safety maintenance, learning and improvement (Reason, 2000; Dekker & Pitzer, 2016).

Attending to success does not imply disregarding accidents and other adverse events. Rather, it is about recognising safety as an active process, not merely the absence of accidents. Since most operations go smoothly, examining why things go right can significantly enhance safety (Hollnagel, 2014). Yet, many existing methods and tools are primarily designed to investigate negative outcomes (Reason, 2000).

Two approaches focused on resilience that actively attend to what goes right are Resilience Engineering (RE) and High Reliability Organization (HRO). Furthermore, both emphasised that the adaptability and resourcefulness of individuals enable them to perform resiliently and effectively in situations where failure is expected. Decades of influential research at the theoretical and practical levels have made HRO and RE well-established research traditions in safety management (Le Coze, 2019). The rest of this section briefly overviews these two research traditions, highlighting some of the key features of each. They will be further discussed in relation to stability and flexibility in Section 3.4.

3.2.3.1 High Reliability Organisations (HROs)

The HRO research tradition developed in response to normal accident theory (Perrow, 1999), demonstrating the capacity of some organisations to avoid ‘inevitable’ accidents. Rooted in organisational theory and political science, it grew from a series of ethnographic studies carried out in the 80’s and 90’s by Rochlin, La Porte, Roberts, Weick, Sutcliff, Shulman and Bourrier, among others (Le Coze, 2019). Their studies examined how complex systems such as nuclear power plants operate successfully and learn in ‘unforgiving environments’ (Weick & Sutcliffe, 2011) where error is not permitted. A second wave of case studies conducted in the 2000s expanded the scope to include various organisational contexts such as healthcare or firefighting (e.g., Weick & Sutcliff, 2011).

HROs are characterised by their flexibility to improvise by recombining resources, skills, and experience to respond to the unexpected. Weick and Sutcliffe (2015) identified five characteristics shared by HROs:

- **Preoccupation with failure**. Any lapse may be a symptom of failure. HROs encourage error reporting because, no matter how small, failures can accumulate towards disastrous outcomes.
- **Reluctance to simplify:** While simplification helps maintain focus, HROs recognize that too much simplification limits understanding. To grasp the complexities they face, they deliberately seek nuanced

perspectives through scepticism of conventional wisdom, negotiation skills, and attending the diverse experiences.

- **Sensitivity to operations**. The 'big picture' is less strategic and more situational [30]. Therefore, HROs prioritise frontline awareness and situational understanding, enabling them to prevent errors from escalating by making continual adjustments and addressing anomalies. Frontline is encouraged to speak up as all symptoms are important to develop a comprehensive understanding of the operation.
- **Commitment to resilience** HROs acknowledge the inevitability of errors and prioritise resilience. Resilience is defined as the ability to maintain or regain stability despite major mishaps or continuous stress. HROs focus on containing errors and improvising solutions to ensure continued functioning.
- **Deference to expertise**. HROs push decision-making down and around. Decisions are made on the front line, and authority migrates to the people with the most expertise, regardless of their hierarchical position. Note that the person with more expertise is not the one with more experience but with more specific knowledge of the event.

These principles show HROs concern about the 'big picture' and a nuanced understanding of the situation and what can go wrong. Since a resilient response is situational, decision-making is decentralised to those where the situation develops, the frontline. Control is not a matter of hierarchy but of expert knowledge of the event; therefore, hierarchies are fluid.

3.2.3.2 Resilience Engineering (RE)

Resilience Engineering evolved from the foundational work of Rasmussen, Reason, Woods, and Hollnagel in the 1980s and 1990s, mostly focusing on engineering design, risk assessment, and human error (Le Coze, 2019). An important contribution of this research tradition was to provide a 'New Look' at human error (Woods & Cook, 2003) that contested the traditional view of humans as a source of error. They employed real case scenarios and novel methods to investigate system failures and the human contribution to both success and failure (Rasmussen, 1997; Reason, 1997; Woods et al., 1994; Hollnagel et al., 2006). According to Woods and Cook (2003), the main idea from the New Look findings is that people create safety through learning and

[30] Perrow (1999) asserts that the "big picture" can only be appreciated from the centre.

adaptation, and failure occurs when efforts to deal with complexity break down. Therefore, progress comes from helping people cope with complexity.

The concept of performance variability is central to RE and crucial to understanding the success and failure of frontline adaptations. Under a centralised control paradigm, what is safe is centrally determined based on ideas about a system that will work as designed and planned. RE researchers postulate that those who establish rules and protocols (the blunt end) often lack insight into frontline realities, resulting in a disconnection between prescribed and actual work (referred to by Hollnagel (2014) as work-as-imagined and work-as-done). The prescribed work, work-as-imagined, encounters real-world situational dynamics, such as unpredictable demands and fluctuating resources. To cope with these realities, frontline operators make continuous adjustments which deviate from the prescribed work. These variations (work-as-done) are essential for safety maintenance as frontline operators adjust to the dynamics of the situation (Hollnagel et al., 2006; Shorrock et al., 2014; Hollnagel, 2014). Therefore, resilience relies on frontline variability to adapt effectively to changing circumstances. Likewise, understanding resilience involves learning how performance variability contributes to success and failure.

3.3 Uncertainty management

Uncertainty is at the core of risk. In an organisational context, uncertainty represents the 'unknown' in terms of information – lack of information needed to perform a task – or in terms of future events – not knowing whether something will occur or not or what the consequences of an event will be (Grote, 2018a; Aven, 2011). Widalvsky (1988) holds that the future is less uncertain under stable conditions. The need to reduce uncertainty by providing conditions as stable as possible is one of the cornerstones of the traditional risk management approach to safety. Gudela Grote proposes considering safety management in safety-critical organisations from an uncertainty management perspective (Grote, 2015). She suggests that risk management does not need to be constrained to uncertainty reduction and put forward a framework with three broad approaches to managing uncertainty: *reducing, maintaining,* and *creating uncertainty*.

Reducing uncertainty is the main objective of the classic risk mitigation approach introduced in Section 1.2. Uncertainty is reduced by maintaining the system under stable conditions, achieved through central control, adherence to standardised processes and automation. *Maintaining uncertainty* aligns with safety management approaches in complex systems that aim for resilience. The goal is to create flexible systems that can adapt to cope with the (unavoidable) uncertainties. Flexibility is achieved by decentralising control, that is transferred to the local actors. *Increasing uncertainty* is the approach in systems that seek to adapt while innovating. Complexity theory is at the heart of the approach, which assumes systems are open and self-organised. Self-organisation implies the emergence of new arrangements and behaviour in the system due to interaction among local agents and the environment. Thus, control is limited to shaping the context in which local agents self-organise.

Grote (2015; 2016a) points out that these three approaches to uncertainty management correlate with three approaches to safety management posited by Amalberti (2013) for different industries: ultra-safe, HRO and resilient. Ultra-safe industries like aviation and nuclear power prioritise reducing uncertainty, relying heavily on automation and regulation to minimise potential risks. Maintaining uncertainty characterises HROs such as healthcare, where numerous demands and pressures require active adaptation to cope with uncertainties. Resilient industries like sea fishing embrace a model of increasing uncertainty; for example, fishing ships deliberately seek the riskiest conditions to capture the most profitable fish (Amalberti, 2013). Both Grote (2015) and Amalberti (2013) present these three models as responses to distinct contexts, each with its own advantages and limitations. However, Amalberti suggests that the three models cannot be mixed; combining their characteristics may fail to improve safety and could even be counterproductive. Although Grote (2015) acknowledges that different industry sectors accommodate to either one or another approach to uncertainty management, she emphasises that organisations require concurrent stability and flexibility because the levels of uncertainty and internal demands they confront vary. For example, organisations' different functions and work processes require handling uncertainty differently, as presented in Table 3-2. This way, some functions and work processes in, for instance, ultra-safe industries will require maintaining or increasing uncertainty.

Table 3-2 Three approaches to uncertainty management adapted from Grote (2015)

	Reducing uncertainty	**Maintaining uncertainty**	**Increasing uncertainty**
Objective	Classic risk mitigation	Resilience	Complexity theory
Conceptual approach	Stability	Flexibility (to adapt)	Flexibility (to innovate)
Control paradigm	Central control	Control by delegation to local actors	Shaping contexts for self-organizing agents
Examples of measures	Standardisation; automation	Empowerment	Controlled experimentation
Industry sector	Nuclear power	Health care	Oil exploration
Organizational function	Production planning	Operations	R&D
Work process	Routine task	Problem-solving	Inventing

In his discussion about managing uncertainties in ultra-safe, HROs and resilient industries, Amalberti (2013) argues that these models can be plotted along a curve illustrating the trade-off between flexibility and safety. Contrarily, Grote (2020) argues that the dichotomy between safety and flexibility stems from a) the traditional belief that safety hinges solely on enhancing stability to reduce uncertainty and b) perceiving flexibility and stability as inherently contradictory. Whether stability and flexibility are seen as mutually exclusive or able to coexist has important implications for safety management. Some of these implications have already been discussed in this review. For example, approaches to safety management that focus on maintaining safety solely by promoting stability neglect the critical role of individuals' adaptation (Reason, 2000; Hollnagel et al., 2006). Similarly, optimising safety in a priori safe systems by further reducing uncertainty can lead to a safety paradox, wherein efforts to enhance safety introduce increased risk due to increased complexity (Reason, 2000; Amalberti, 2001; Dekker, 2011).

Grote (2015) highlights another safety paradox: increasing uncertainty may result in enhanced safety. For example, when a team member raises concerns about the course of action increases uncertainty for the decision-makers; yet, it may help to reflect on the decision process and find a better solution. This way, increasing uncertainty may have resulted in a safer solution. The main point here is that examined under the lens of uncertainty, stability and flexibility are not two opposite poles but two distinct dimensions (Grote et al., 2018). As such, each has its operating mechanisms and measures: stability-enhancing mechanisms and measures such as standards and routinisation, and flexibility-enhancing ones such as individual and team empowerment. Flexibility- and stability-enhancing mechanisms are considered in the next section, which delves into the concepts of stability and flexibility.

3.4 Stability and flexibility

Stability and flexibility are pervasive concepts in the safety literature, yet their precise definitions are often overlooked, especially in the case of stability. In safety research, flexibility has been defined as the capacity to deviate from standard behaviours (Hollnagel, 2014) or the capacity to respond and adapt to changes and demands (Woods, 2006; Perrow, 1999; Peries et al., 2010). Stability is often approached as the opposite of flexibility, thus in terms of repeatability and fixity (e.g., Hollnagel, 2014). Looking at their meanings in general, the Cambridge Online Dictionary [31] defines stability flexibility as follows:

- Stability:
    - A situation in which something is not likely to move or change.
    - A situation in which something such as an economy, company, or system can continue in a regular and successful way without unexpected changes.
- Flexibility
    - The ability or quality to change or be changed easily according to the situation.

Stability (first definition) and flexibility are presented as opposite concepts, one denoting fixity and the other denoting change. Stability's second definition, however, is closer to endurance, reliability, and predictability, concepts which do not fully contradict flexibility. Keeping these definitions in mind, the concepts are now overviewed as approached in the Resilience

[31] https://dictionary.cambridge.org/

Engineering (RE) and High Reliability Organisations (HROs) literature and compared to traditional control approaches.

In the RE literature, stability is approached in terms of 'dynamic stability'. It relates to complexity theory, in which systems exist far from equilibrium, balancing order and chaos, stability and instability. Resilience is described as '*a productive tension between stability and change*' (Hollnagel et al., 2006, p. 179). In safety management, the goal is achieving and maintaining a condition of stability (Ferreira, 2011) because a system is considered safe when it is stable, namely, when it operates within the safety boundaries (Rasmussen, 1997). However, maintaining stability requires the ability to change and adapt. Flexibility is a key factor in adaptability, representing the system's capacity to restructure itself to respond to changes and pressures (Hollnagel et al., 2006). From this perspective, stability is closer to the second definition of stability presented above, and stability and flexibility are not mutually exclusive; rather, stability depends on flexibility.

Concerning the centralised control approach to safety management, stability appears closer to the first definition abovementioned. As explained earlier in this review, hazard control relies on controls set a priori based on assumptions of how systems and individuals work. Like in RE, the goal is maintaining the system's stability. However, this stability depends on the stability of the behaviours of individuals and system components, achieved by minimising behavioural variability through automation, standardisation, recruitment, training, and so on. Here is where the conflict between stability and flexibility — and between RE and the centralised approach — arises: while the classic approach aims for performance repeatability, the adaptive behaviours core to resilience require performance variability (Hollnagel, 2014; Woods, 2006). In this way, the conflict between stability and flexibility may be understood as a conflict between control and autonomy.

In HRO, stability appears in terms of reliability of performance and outcomes. Similar to the approaches mentioned above, HROs consider a system safe when it consistently produces reliable and stable outcomes, ensuring that safety is a consistent result. Weick and Sutcliffe (2015) postulate that reliable systems' performance must be stable, albeit their working conditions fluctuate and are not always known in advance. Under varying or unknown conditions, reliable performance requires flexibility. Weick and Sutcliffe (2015) argue that stability and flexibility appear contradictory because, traditionally, routine behaviours are regarded as the source of reliability. However, they postulate that the source of reliability stems from flexible behaviours. These behaviours, however, are guided by stable mental models of how to manage the unexpected in a stable (and reliable) manner. Thus, stability and flexibility are interdependent: stable mental models guide flexible behaviours that yield stable outcomes. These mental models, called ‘collective mindfulness’, will be explained further in Section 3.4.2.

In summary, the concept of stability in the three approaches differs. In the centralised control approach, stability implies a state of invariance, permanence, and certainty throughout activities, encompassing both the desired outcome and the activity itself. As such, flexibility contradicts the established mode of operation. Conversely, in RE and HRO, stability is viewed as a dynamic process rather than a fixed state, conveying ideas of reliability and adaptability. Here, stability represents the desired outcome. Flexibility, rather than antithetical, is essential for maintaining stability in a changing environment. Furthermore, while in RE stability depends on flexibility, in HRO stability and flexibility are codependent.

3.4.1 Mechanisms for stability and flexibility: centralisation and decentralisation

This section discusses centralisation and decentralisation as chief mechanisms for stability and flexibility, and the different interpretations of the concepts. Grote (2020), for example, asserts that centralisation enables stability by constraining decision-making autonomy, while decentralisation facilitates flexibility by allowing adaptive decision-making at the frontline. As in this example, centralisation and decentralisation in safety science are often approached in terms of decision-making.

In safety research, definitions of centralisation are often implied rather than explicitly stated. As already highlighted, references to centralisation mostly denote decision-making by top managers and executive teams where the standards and procedures are designed and enforced (McDonald, 2006). Here, centralisation and control are equated. In traditional organisational management research, control is one of the four primary functions of management, the others being organising, planning, and coordinating (Fayol, 1949). Sitkin et al. (2010) define organisational control as any process in which managers influence or direct organisational members to act in ways that align with the organisation’s goals and objectives. Control mechanisms, the fundamental units of organisational control, can be formal (e.g., standards, policies) and informal (e.g., values, norms).

Standardisation is a key control mechanism in centralised systems. It encompasses the routinisation of procedures through protocols, rules, and standards, alongside standardised selection and training methods, work-process standardisation (e.g., supervision, inspection), output standardisation (monitoring and recording outputs), and the automation of routine or complex functions (McDonald, 2006).

Centralisation and decentralisation are also presented in terms of control – whether control is centralised at the top of hierarchical structures or delegated to local actors (e.g., Grote, 2020). Yet, references to local actors' control are again in terms of decision-making powers.

In safety research, the concept of decentralisation has been more concretely defined. For example, it has been defined as the dispersion of decision-making to different business units within the company (Monteiro et al., 2020), the delegation of decision-making to regional authorities (Jia & Nia, 2017), to lower-level managers (Andersen, 2010), or to frontline workers (Grote, 2020). At the frontline, decentralisation, local actors' control, and frontline autonomy are used interchangeably to refer to the operator's decision-making powers.

3.4.2 Balancing stability and flexibility in organisations

Tensions and contradictions permeate both safety and organisational research. The interaction between apparently contradictory elements, such as stability and adaptability (Denis et al., 2001), stability and change (Farjoun, 2010; Feldman & Pentland, 2003), exploitation and exploration (March, 1991) or centralisation and decentralisation (Kanter, 2008) has spurred extensive research. Debates on the importance of resolving the tensions have been long sustained and concepts and models to integrate the contradictory elements have been put forward.

For instance, organisational *ambidexterity* has been researched for decades (Duncan, 1976; Tushman & O'Reilly, 1996; O'Reilly & Tushman, 2013). This concept describes the organisational ability to both exploit (maintain the system stable and efficient) and explore (permit flexibility, autonomy, and experimentation). Brown's and Eisenhardt's (1997) *semistructures* describe a hybrid organisational structure that blends stability in defining responsibilities and priorities with the flexibility to innovate and improvise within ongoing projects; the resulting structure is neither rigid, hindering change, nor so unstructured that it allows chaos. Kanter's (2008) *sameness* contains the idea of coherent practices that make things easier, and that can be disseminated companywide (e.g., best practices and standard business processes), while flexibility is achieved through the empowerment of local business units which make changes to adapt to the local conditions.

In the safety domain, research has highlighted both the need and the incompatibility of concurrently achieving stability and flexibility. The paradox was described by Perrow (1999) concerning 'normal accidents'. He posited that safety requires both centralisation and decentralisation; however, safety-critical systems face a dual challenge. Operators have a local view of the activity; therefore, they can respond independently and creatively to the complex interactions causing failures. However, due to tight coupling in these systems, centralised control of operators is necessary to provide global awareness of the activity and coordinate a prompt response. Tight coupling mandates prescribed steps and unalterable sequences, limiting operator autonomy. Since centralisation and decentralisation cannot be achieved concurrently, 'normal accidents' happen.

Contradicting Perrow's (1999) theory, researchers in HRO pioneer investigations on how to resolve the concurrent needs for stability and flexibility. Two key concepts are put forward: loose coupling (Weick, 1976; Orton & Weick, 1990) and collective mindfulness (Weick et al., 1999).

Coupling conveys the idea of interdependency or mutual reliance among parts. In tightly coupled systems (Perrow, 1999), interdependence and reliance are strong, leading to a high risk of catastrophic failure if one part malfunctions. Loosely coupled systems, on the other hand, exhibit weaker dependency among their parts; although connected and responsive to one another, they do not rely heavily on each other. This *looseness* is the source of flexibility that tightly coupled systems do not have.

In Perrow's (1999) theory, systems are either tight or loose coupled. Contrarily, loose coupling (Weick, 1976; Orton & Weick, 1990) encompasses the idea that any organisation, or part of the organisation, can simultaneously produce stability and flexibility. However, the challenge with loose coupling is that while it makes systems less prone to catastrophic failure, it may also compromise the certainty, consistency, and stability that are essential components of the 'glue' that binds organisations together (Weick, 1976). According to Weick (1976), the tension between centralisation and decentralisation can be resolved by establishing effective mechanisms for loose coupling.

Collective mindfulness conveys the idea of the concurrent maintenance of stable cognitions and flexible behaviours to achieve high reliability. HROs distinguish between two aspects of organisational functioning: cognition and activity. Cognition relates to the collective mindset aimed at remaining alert to detect, understand, and recover from unexpected events. While the activity to deal with the unexpected may vary (is flexible), the cognitive element, the collective mindfulness, remains stable (Weick et al., 1999).

Mindfulness relies on previous experiences. Weick and Sutcliffe (2011) emphasize that in managing the unexpected, the term 'unexpected' refers to events that have occurred before in some form but were not specifically anticipated in their current context. This implies that every unexpected event bears some similarity to past events while also presenting some novel aspects. These similarities form the basis for the mindful process, while flexible, adaptive behaviours address the novel, unexpected elements.

In line with loose coupling (Weick, 1976; Orton & Weick, 1990), organisations have tools available to integrate aspects of stability and flexibility. One such tool is 'flexible rules', a term coined by Grote and Weichbrodt (2007) based on Hale and Swuste's (1998) three types of rules: goal, process, and action. Goal rules only define the goal to be achieved. Process rules provide guidance for achieving the goal within certain conditions. Goal and process rules, therefore, allow decision-making and, thus, flexibility of action. Yet, by specifying the goal to be achieved, the stability of the outcome is assured. Contrarily, action rules are prescriptive as they describe the precise course of action, leaving no or little decision latitude to the rule user.

Although action rules prevail in safety management (Hale & Borys, 2013b), adding flexibility to rules, traditionally used solely for stability, allows adapting the best of each model (standardisation and autonomy) to contextual needs. For example, goals and process rules support *mindful routines* (Grote, 2020, p. 5) when the rule users are experts and highly skilled professionals. Action rules would best suit novice or low-skilled groups (Hale & Borys, 2013b; Grote, 2015). However, as Hale and Borys (2013b) argue, the problem arises because accommodating ideas of flexibility requires a cultural shift by people, organisations and regulators who still operate under a pure control paradigm. Safety culture is discussed in the next section.

3.5 Safety culture

Since the International Atomic Energy Agency (IAEA, 1986, as cited in Cox & Flin, 1998) identified 'poor safety culture' as a contributing factor to the Chernobyl disaster, cultural precursors to major system failures were put on the risk management agenda (Pidgeon, 1998). More recent disasters, such as the nuclear plant accident at Fukushima Daichi in Japan or the offshore oil and gas Deepwater Horizon disaster in the Gulf of Mexico, continue to highlight the importance of safety culture (Kirwan, 2015). But safety culture is not only relevant to catastrophic failure. Research has shown that whether an organisation's safety culture is positive or negative is related to the organisation's safety behaviours and outcomes (Griffin et al., 2016). The concept has become so relevant to safety management that some authors refer to the organisational culture period as the latest stage in the evolution of safety management, following the sociotechnical period (Weigmann et al., 2004).

A simple definition of safety culture is '*the way safety is perceived, valued and prioritised in an organisation'* (Skybrary, 2020). Many other definitions of safety culture have been formulated in over three decades of safety culture research. This section will not focus on what safety culture is or how it is measured[32]. It will present some ways in which it may be utilised and how those different uses may relate to resilience and uncertainty management. Particularly, the section finishes by introducing Weick's (1987) ideas of culture as a mechanism to navigate the tension between centralised control and decentralised action – in other words, between stability and flexibility.

3.5.1 Safety culture as a management and assessment tool.

Journé (2018) coined the term Safety-Culture-as-Tools (SCT) to refer to a set of homogeneous values regarding safety created at the blunt end. They aim to

[32] For comprehensive reviews on the topic, see Guldenmund, 2000, 2010; Weigmann et al., 2004; and Zohar, 2010.

control behaviours and practices related to safety at all organisational levels, from budgeting and resource allocation to adherence to rules or wearing adequate PPE. SCT aligns with the organisation's strategy and, at the individual level, represents the organisational ideals about how safety is created and maintained; therefore, it represents work-as-imagined. A positive safety culture is directly related to adherence to the procedures; contrarily, a poor safety culture becomes a risk factor (Kirwan, 2015). From this approach, safety culture acquires a predictive value and a tool to reduce uncertainty. It can be used as a tool for risk assessment, a mirror to reflect where an organisation stands and how it may improve safety (Guldenmund, 2018). While there is nothing wrong with approaching safety culture as a tool for improving adherence to standardised processes, this approach is only valid as a tool for control, leaving no room for the performance variability required for resilient behaviours.

3.5.2 Safety culture as informal professional culture

Safety culture is not only created at the blunt end. Although performance variability may be seen as a sign of a poor safety culture, adaptability at the sharp end (work-as-done) may encompass the norms and values embedded within professional or occupational cultures. These cultures, which Journé (2018, p. 64) defined as '*the knowledge, values, attitudes and practices created and mobilised in order to "do a good job" in a risky environment',* are located within the organisation's working groups and professional communities. According to Carroll (1998), professional groups have particular approaches to risk and safety control, which arise from their own 'mental models' and 'logics'; these, in turn, guide their safety behaviours. Therefore, the logic and underlying behaviours become part of their professional culture as they result from successfully dealing with a particular type of problem in a particular manner. These mean that the way frontline operators adjust to situational demands and uncertainty may not only reflect here-and-now adaptations but a more profound way to approach risk and safety, which would be embedded in their professional culture.

3.5.3 Safety culture as a stabilising force.

Mearns et al. (2009) emphasise the importance of safety culture in providing direction when operators face scenarios that have not been foreseen and formally determined by the safety management systems. They argue that making a safe decision in these pressured, uncertain situations will depend on safety culture.

Weick's (1987) foundational work highlighted the importance of safety culture in coordinating safety decisions nearly four decades ago, describing culture as a centralising mechanism in HROs. These organisations are characterised by the need to balance strict regulations with the flexibility of decentralised local units capable of adapting to immediate demands. According to Weick, effective decentralisation requires prior centralisation to ensure that individuals across the organisation adhere to consistent decision-making frameworks. This alignment facilitates the coordination of local units operating independently. While standard operating procedures can achieve centralisation, Weick argues that only a robust safety culture enables the necessary improvisation and adaptability in unforeseen situations.

3.6 Chapter summary

This chapter provided an overview of relevant literature regarding the tensions between centralised control and alternative safety management approaches. These tensions lie at the core of efforts to enhance flexibility within controlled systems.

As with other safety-critical systems, current practices in safety management in railways are based on centralised control strategies that aim to ensure safety by maintaining repeated, stable processes and behaviours. This approach, presented in Section 1.2, has made it possible for railways to become ultra-safe industries. Yet, as the complexity and uncertainty of systems and operating environments have increased, researchers have stressed that traditional control strategies alone are insufficient to maintain safe operations (Section 1.3.). For example, it has been argued that an important element behind the success of the centralised approach is the resilience shown by frontline operators who often abandon prescriptions (work-as-imagined) to adapt to the contextual needs (e.g., Hollnagel et al., 2006; Dekker, 2011). Theories and models such as resilience engineering (RE) and high reliability organisation (HRO) have been put forward to provide an alternative paradigm for safety management focused on adaptability rather than control.

The chapter has specifically introduced areas of literature relevant to support the usefulness of stability and flexibility as concepts to investigate ways to increase adaptability in systems that operate under centralised control. Generally, stability is understood in terms of control and centralisation, while flexibility is associated with decentralisation and autonomy. Classic, influential research has depicted these concepts as inherently contradictory (e.g., Perrow, 1999). This review has presented examples from safety and organisational literature, especially from RE (e.g., Hollanagel et al., 2006; Hollnagel, 2014; Woods & Cook, 2003), HRO (e.g., Weick & Sutcliff, 2011; Orton and Weick, 1990), and uncertainty management (Grote, 2015; 2016a) through which the duality of stability and flexibility has been established – they are not necessarily mutually exclusive, they can even be codependent.

Case studies in HRO show practical examples of concurrent centralised and decentralised practices in domains such as emergency management or healthcare, underpinned by concepts such as loose coupling and collective mindfulness. The discussion also touched upon flexible rules (Grote & Weichbrodt, 2007) as a mechanism for loose coupling available to organisations to integrate stability and flexibility.

The chapter concluded with a brief overview of different approaches to safety culture that illustrate how culture can be employed to centrally create stability, as a source of flexibility at the frontline or as a mechanism to integrate stability and flexibility.

4 Methodology

4.1 Introduction

The increasing demands for efficiency and adaptability in railway operations – and thus for higher flexibility – were introduced in Chapters 1 and 2. Any increase in flexibility, nevertheless, must not compromise the system's stability to work within safe boundaries. This Doctoral Thesis is driven by those current needs, aiming to deepen our understanding of stability and flexibility within railway operations. The overarching goal is to identify opportunities for enhancing flexibility in work processes and behaviours while ensuring system stability.

In essence, the examination of stability and flexibility is framed within three main areas:

1. What is revealed about stability and flexibility in the industry standards and regulations as documented,
2. How people involved in the writing and development of standards and regulations discuss their intentions when writing and implementing the standards, and
3. What happens in real-life rail operations practice.

To explore stability and flexibility in relation to those, this research employs three main methods: (1) document analysis, (2) interviews, and (3) case study. Table 4-1 includes an overview of the methods and empirical context in relation to the four studies included in this thesis.

4.2 Research paradigm

Paradigms are conceptual and practical tools that provide a framework from which to solve specific research problems (Kaushik and Walsh, 2019). They are underpinned by different philosophical assumptions about the nature of reality (ontology), knowledge (epistemology), and values (axiology), which guide methodological choices and the interpretation of the results. This thesis takes a problem-centred stance aimed at finding practical solutions to real-world issues; therefore, pragmatism emerges as the most suitable paradigm to frame the research.

Table 4-1 Thesis studies aim, methods, research context and participants.

	Study 1 (Chapter 5)	Study 2 (Chapter 6)	Study 3 (Chapter 7)	Study 4 (Chapter 8)
Study Aim	To explore how standards may provide standards users with the Flexibility needed to adapt to specific contextual circumstances	To provide a description of the rulemaking process and investigate the interplay between control and operational realities	To examine Stability through centralised control and standardisation (centralisation) and Flexibility through local control (decentralisation)	To explore Stability and Flexibility in practice through the everyday activities of rail infrastructure incident controllers
Method/s	Document Analysis Interview data	Interviews Document analysis	Interviews	Case Study using observations, interviews, and documents as data sources
Empirical Context	Online share of EU, UK, and rail industry documents, complemented and triangulated with interview data collected for Study 3	Interview data collected during Study 3 Web content and webinars selected from the RSSB website	Interview study conducted via videocall with people involved in developing rail standards (i.e. rule-makers)	Data collected over 11 day-visits to the network and signalling control rooms at the East Midland Control Centre
Participants	8 rule-makers with diverse backgrounds in industry	7 rule-makers members of the TOM SC[33]	26 rule-makers from a variety of rail organisations and regulatory bodies	Infrastructure incident controllers and signallers.

[33] Traffic and Operation Management Standards Committee (the industry standards committee that manages operational standards and decides on their development and content)

Originating in the United States around 1870, 'American pragmatism'[34] is a philosophical tradition that – in broad terms – understands knowledge about the world as inseparable from action within it, emphasising the link between theory and practice. Epistemologically, pragmatism occupies a middle ground between rationalism (in which interpretations are subjective) and positivism (in which interpretations are objective). It acknowledges that interpretations are influenced by human experiences and context, while maintaining that these interpretations must be tested through practical application and empirical observation (Legg, 2021).

Pragmatism prioritises methodologies and practices over philosophical debates, placing the research question above theoretical considerations (Tashakkori & Teddlie, 2008). The research design and methodology are chosen based on their suitability to address the research question. Framed by this paradigm, the research process remained open-minded and flexible, selecting methods best suited to answer the emerging research questions.

4.3 Qualitative methodology

Although the paradigm followed in this thesis coheres with quantitative and mixed methodologies, qualitative methods were the most appropriate to achieve the research aim and objectives. Justification for their use is given in this chapter for each method.

Qualitative research often focuses on understanding meaning (Hignett & McDermott, 2015). Magnusson & Marecek (2015) advocate for the term "interpretative research" over "qualitative research" to emphasise that these methods aim to understand (i.e., interpret) the meanings people attribute to events and actions, and how they internalise and negotiate these meanings. These meanings are crucial to understanding human action since people respond to and engage with the world as they interpret it (Berger & Luckman, 1966). Qualitative methodologies have the potential to delve deeply into the social world, including everyday life, social processes, and institutions. Additionally, this approach uniquely provides a comprehensive understanding of how things work in specific contexts (Mason, 2002).

[34] First defined and defended by philosopher Charles Sanders Peirce, it was later developed and popularised by his friend and colleague, psychologist William James. (Legg, 2021).

Qualitative methodologies are core to social science research and their uses have grown in popularity within disciplines such as psychology, ergonomics and human factors and organisational research (Hignett & McDermott, 2015; Alvesson & Ashcraft, 2012). In safety research, qualitative methodologies have a long tradition and play a central role in seminar work and the analysis of disasters (e.g., Turner, 1978; Perrow, 1984). They are also crucial in research in real-life contexts in High Reliability Organizations (HROs) (e.g., Weick & Sutcliffe, 2011; Roberts & Rousseau, 1989) and Resilience Engineering (e.g., Lyng et al., 2021; Jonassen & Hollnagel, 2019).

4.3.1 Assessment criteria

Unlike quantitative research, quality criteria for qualitative research are neither well-known nor widely agreed upon (Bryman et al, 2008). The lack of consensus on defining qualitative research may be attributed to the varied philosophical underpinnings and disciplinary traditions from which it has evolved. This diversity is also reflected in the different criteria used to assess its quality (Mason, 2002).

Symon and Cassell (2012) review various quality criteria for assessing qualitative research, noting that early lists aimed for a universal set of criteria based on positivistic assumptions, such as Guba and Lincoln's (1989), which focused on methodological thoroughness. This approach was later challenged, leading to criteria based either on the research's epistemological foundations or on shared understandings of quality. Symon and Cassell (2012) propose a list of quality criteria based on empirical work which advocates for quality goals over methodological principles (Table 4-2). These criteria were used for quality assessment in this thesis for two main reasons: first, the unsuitability of epistemologically based lists for the pragmatic approach of this thesis, and second, criteria such as *theoretical and practical contributions, process flexibility, or the capacity to challenge assumptions,* are well-suited for qualitative research assessment in the context of a doctoral thesis.

Table 4-2 Simon and Cassell's (2012) summary of criteria derived from management scholars and practitioners

Quality output	Making a contribution	New insights
		Practical outcomes
		Creating new problems
	Interesting	Addressing the 'so what' issue
		Matter of personal teste
Quality process	Technical accomplishment	Rigour
		Detective work
	Not linear	Flexible
		Responsive
	Transparent	Systematic
		Theoretically informed
		Epistemologically coherent
	Reflexive	Considering own influence
		Giving balanced account
Quality performance	Logical argument	Logics of discovery
		Consistency
	Recognise limitations	Not going beyond the data
		Crafting a believable account
	Convincing	Rhetorical skills
		Reader's role
		Telling a story

4.4 Research framework

Mason (2002) advocates for a qualitative research approach that rejects the idea of a single, fixed research design in favour of flexibility, exploration, and responsiveness to data. However, she stresses the importance of establishing a preliminary research design at the outset, with ongoing adjustments informed by the evolving research process and context. In line with this perspective, the present thesis adopts an open-ended, iterative strategy with a flexible design, allowing for adjustments and adaptations as the research progresses (Irion, 2004; Hignett & McDermott, 2015).

The research framework here presented was developed to provide a transparent representation of the research process and its evolution. This framework was not completed at the beginning of the process but developed alongside it. The intention is to illustrate the iterative nature of the process and (broadly) disclose how and why design and methodological decisions were made. The initial design decision was to maintain an open and flexible approach. This choice was influenced by the context in which the research began—a time of pandemic upheaval, lockdown, and significant uncertainty. Additionally, it aimed to prevent unnecessary constraints in an exploratory research project with a broad focus and no narrowly-formulated research questions. Consequently, the research strategy involved conducting an initial study and, subsequently, making decisions based on the findings and emerging questions that would help to achieve the research objectives.

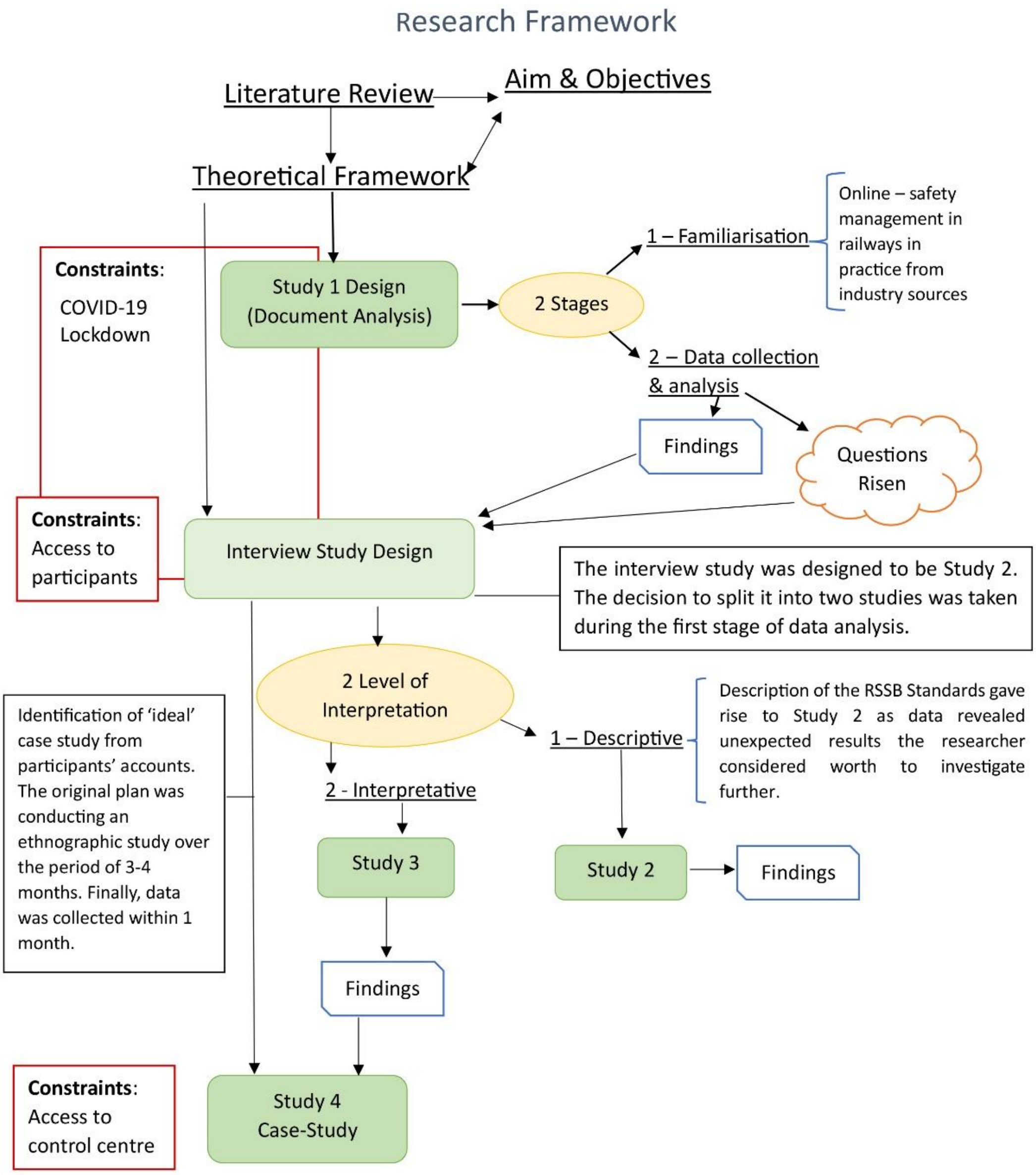

Figure 4-1 Research Framework

4.5 Research Methods

4.5.1 Document analysis

Document analysis was used as a method in three studies within this thesis (Studies 1, 2, and 4). It was the main research method used in Study 1, which mostly utilises documents publicly available online. Lee (2012) suggests that documents serve as enduring repositories containing textual, visual, and audio representations, offering users the flexibility to interpret and utilise their meanings in various ways. As a research method, document analysis holds particular relevance in qualitative case studies, providing comprehensive descriptions of phenomena (Yin, 2003). Documents play an important role in organisational life, especially in the regulatory field, where they contain details of policies, procedures, and rules. The numerous sources of documentary information about organisations include newspaper reports, whitepapers, and tribunal records. This abundance renders documents invaluable for addressing diverse research questions. Nonetheless, Lee (2012) argues that documents have been underutilised in organisational research, possibly due to their accessibility undermining their perceived value or the challenges of managing their volume.

The approach of the rail industry and their organisations to operational management and safety is documented in their regulations, rules, and standards. These documents, therefore, are an excellent starting point to explore rail operations in relation to stability and flexibility. Furthermore, document analysis had added advantages in the context of this thesis. First, most data collection for Study 1 occurred during the COVID-19 lockdown, making online documents an invaluable data source due to their accessibility. Second, conducting a first, well documented study was a good 'presentation letter' to approach industry stakeholders for the subsequent studies. Finally, the abundance of information published online by industry regulators regarding railway regulations made these documents a rich data source. Later in the research process, supplementary documentation from interview participants was also collected, complementing the publicly available information gathered. Details of the sources, types of documents and analytical techniques employed in each study are provided in the respective method sections.

Document analysis was also used for data triangulation in Study 2 (Chapter 6) and to enrich the rule-makers' accounts regarding the rule-making process. Methodological triangulation is a common practice in qualitative research (Bowen, 2009). It involves assessing the consistency of findings from various data collection methods (Hignett & McDermott, 2015). This approach minimises the risk of bias in study findings by combining data from multiple sources and methods, enhancing the credibility of the results (Bowen, 2009).

4.5.2 Interview study

In this thesis, formal and informal interviewing was fundamental to generating the findings and producing the comprehensive knowledge presented. This section presents the interview study designed and conducted for Study 3 (Chapter 7), and the uses of those interviews in other chapters of the thesis. Interviews used in the case study (Chapter 8) and their use in that context is discussed in section 1.5.3.

Study 1 investigated what is evident in industry documents such as regulations and standards about stability and flexibility. The interview study made it possible to explore how individuals developing those standards and regulations talk about their intentions when creating and implementing them. According to Fontana & Frey (2005, p. 697), *'interviewing is one of the most common and powerful ways in which we try to understand our fellow humans*.' They can provide full and rich accounts of people's worldviews and sensemaking, serving as a crucial method for collecting information and gaining an understanding of a wide range of phenomena (Magnusson & Marecek, 2015; Alvesson & Ashcraft, 2012). Interviews are central to organisational studies, being widely recognized by organisational scholars as reliable tools for accessing the inner workings of organizations. While this thesis does not fall within the realm of organisational research, incorporating an organizational perspective has been crucial.

A total of 26 people engaged in the development of rail operational standards, hereafter called rule-makers, were interviewed. They represent various roles within regulatory bodies, infrastructure management, constructors, train operators, manufacturing, and trade unions. Participants' roles and demographics are detailed in the methods section of Chapter 7.

The interview study (Study 3) was designed and conducted as a single study with the purpose of exploring a set the research questions, as presented in Chapter 7. However, the data collected and presented in the interview transcripts were used in other two studies: Study 1 and Study 2. In Study 1[35], the interview data were used to triangulate and discuss the findings. Study 2, which describes the collaborative nature of the making of RSSB standards, developed from one of the questions asked to participants regarding the rule-

[35] Information regarding how the transcript data were used is detailed in Chapters 5 and 6 (Study 1 and 2 respectively).

making process. Table 4-3 summarises the organisations participating in the interview study and the number of participants from each organisation. It includes the number of participants whose interviews were used as data, along with their organizations, across Studies 1, 2, and 3.

4.5.2.1 Sampling

In qualitative research, sampling strategies often emerge organically during the study, guided by inductive logic (Hignett & McDermott, 2015). Despite this, Mason (2002) emphasises their importance. The interviews in this study employed a theoretical or purposive sampling strategy. This involves selecting participants based on their relevance to the research questions, theoretical framework, and evolving arguments. Mason notes that, although theoretical sampling is commonly associated with Grounded Theory, many qualitative researchers adopt this approach regardless of their method.

Table 4-3 Participating organisations and number of participants in each study

Rule Makers' Organisations	**Study 3 N= 26**	**Study 1 N = 8**	**Study 2 N = 7**
ORR	1	1	
RSSB	5	2	4
RDG	1		
RAIB	1		
Network Rail	10	4	
Infrastructure Constructor	1		
Freight Operating Company (FOC) (x2)	2	1	1
Train Operating Company (TOC) (x2)	2		1
Train Manufacturing	1		
Rail Union	2		1

Mason (2002) highlights the significance of determining *what* to sample. In this study, two organisations, the RSSB and Network Rail, were selected. The RSSB writes and maintains the rail standards on behalf of the industry. Network Rail, as the infrastructure manager, is the largest organisation in the industry and develops standards used system-wide. After the interviews commenced, a snowball sampling strategy was implemented, in which participants of interest were identified from existing participants. Snowballing not only facilitated reaching new participants but also revealed cases of interest not initially considered. For instance, the involvement of rail union representatives in the development of rail standards was considered when mentioned by a participant.

An essential aspect of sampling strategy is determining the sample size, which varies based on the study's nature. Saunders (2012) highlights a minimum range proposed by scholars, from 5 (for phenomenological studies) to 35 (for ethnography). For interview studies, the suggested range typically falls between 5 and 25 participants. While data saturation[36] (Glaser & Strauss, 1967) is often used as a benchmark, Mason (2002) critiques its ad hoc nature, suggesting a focus on whether the sample provides adequate and relevant data to address the research question.

In determining the sample size for this study, two key factors were considered. First, participants were *subject matter experts* (Cox et al., 2007). Malterud et al. (2016) introduce the concept of 'information power', suggesting that the higher the quality, relevance, and amount of information the sample offers, the fewer participants are needed. Second, Saunders (2012) highlights the challenge of resource availability. In the context of this study, the timeline for data collection was limited and access to participants was challenging due to the population size and organisational constraints. Considering these factors, a sample size range of 15 to 20 participants would have been satisfactory. However, the researcher continued recruiting participants until data of sufficient depth and richness to address the research question had been collected, resulting in a final sample size of 26.

4.5.2.2 Approach to the interviews

Interviews range from highly structured to unstructured formats. Highly structured interviews, also called 'structured questionnaires,' use closed-ended questions and detailed guides, fitting well with positivist research due to their standardised and easily quantifiable responses. However, this format can limit the exploration of complex issues and encourage conformity, reducing depth and originality (Alvesson & Ashcraft, 2012; Harvey, 2018).

Unstructured interviews, on the other hand, use open questions that allow interviewees to delve into topics they find important. This approach can reveal unexpected insights and novel perspectives but risks straying into irrelevant

[36] Data saturation is reached when gathering of new data fails to yield new insights or theme.

areas. This can lead to significant variations in responses, making it challenging to categorise answers coherently (Alvesson & Ashcraft, 2012).

A middle ground approach was chosen, opting for a semi-structured or loosely structured format. This format aligns with the explorative approach of the thesis and allows for flexibility. The interviews were designed to have a flexible structure, without relying upon a complete script of questions (Mason, 2002). The aim was to obtain rich information relevant to the research questions without constraining the interview within the researcher's ideas and perceptions. Participants were positioned as experts, with the researcher assuming the role of a learner, seeking to gain a better understanding of the topic. This approach allowed issues to be explored in depth and to develop in unexpected ways from the participants' perspectives and experiences.

The interview schedule was organised by topics, containing one to three open-ended questions per topic to encourage participants to delve into the subject. The researcher allowed participants to share freely, probing for additional information and making notes on issues to be explored later. This approach facilitated the follow-up of leads from earlier interviews and the exploration of issues raised by other participants, providing rich data relevant to the research questions. Details of the procedure and an example of the interview schedule are included in the methods section of Chapter 7.

4.5.2.3 Approach to data analysis

The interview data were analysed using Thematic Analysis (TA), a method for identifying themes in qualitative data. According to Terry et al. (2017), although the term 'thematic' was used earlier by qualitative researchers, it gained popularity after Braun and Clarke's influential six-stage procedure in 2006. Despite some criticism, TA remains a reputable and widely-used method of analysis.

The selection of TA for this study was influenced by its flexibility. Unrestricted by a specific theoretical framework, TA aligns with the research paradigm of this study, providing methodological flexibility (Braun & Clarke, 2006; Terry et al., 2017). Additionally, TA allows for rich and detailed analyses of complex data (Trainor & Bundon, 2021). Due to its flexibility, some scholars have criticised it as an 'anything goes' approach (e.g., Labuschagne, 2015). To address this, the study followed Braun and Clarke's (2006) recommendations to be transparent and clearly articulate the paradigmatic foundations, assumptions, and parameters guiding the interview study and data analysis.

The Thematic Analysis (TA) technique used in this study is guided by Braun and Clarke (2006), though not strictly followed. While their six phases may seem like a standardised procedure, Braun and Clarke emphasize that these 'are not rules and should be applied flexibly to fit the research questions and data' (Braun and Clarke, 2006, p. 86). Some authors, such as Symon and Cassell (2012), have raised concerns about the problematic nature of standardising qualitative methods. They argue that the (post)positivist stance of top research journals forces standardised approaches to qualitative research, which may contradict the epistemologies underpinning qualitative methodologies and compromise their diversity and richness.

While Braun and Clarke (2006) advocate for the flexible use of Thematic Analysis (TA), they also highlight the importance of transparency and honesty in detailing how the analysis is conducted. They identify patterns that can lead to poor analysis and provide guidance on producing high-quality thematic analysis, which were considered in conducting this study's analysis. These considerations, together with a comprehensive description of the analysis process are provided in Chapter 7.

4.5.3 Case Study

The document analysis study explores the concepts of stability and flexibility in railway operations as documented. The interview study investigates issues regarding the concepts as experienced and understood by rule-makers. Following these, a case study provides an opportunity to examine stability and flexibility as occurring in practice. Study 4 is a case study exploring infrastructure controllers' activity during the management of incidents. Although the main focus of the study was incident controllers' activity, the activity of signallers was also considered to draw a better understanding of the incident control process.

Case study (CS) is a qualitative approach to research in which the researcher explores a real-life, bounded case over time through detailed, in-depth data collection and integration, using multiple sources of information (Creswell, 2007). According to Rae et al. (2020), CSs are crucial for advancing the state of knowledge in safety science. CS may be used to examine a concrete entity such as an individual or organisation. They also serve to explore something less concrete, such as relationships or, as is the case in this study, work activities (Creswell, 2007).

Stake (1995) distinguishes three types of case studies: intrinsic, collective, and instrumental. Intrinsic case studies focus on the case itself because of its unique interest. Collective case studies examine multiple cases to develop a comprehensive understanding of an issue or question. This case study belongs to the third type, instrumental, as the study aims to provide insight into the broader issue under investigation in this thesis (i.e., increasing flexibility while maintaining the system's stability).

As a method, CS entails a choice of what is to be studied within a boundary of place and time; therefore, a core feature of CSs is that they have clearly defined boundaries (Stake, 2005). These and other aspects of the study design are described in the following section.

4.5.3.1 Design and sampling

The first step in designing the CS as choosing the case that offers the best option to explore the topic of interest. The incident controllers' activity was chosen as a case to study for posing the best option. Either train, freight or infrastructure controllers would have provided a good case to study. However, infrastructure controllers were selected based on convenience since the researcher already had contacts in Network Rail (the infrastructure maintenance company).

Once the case to study was chosen, factors to consider for setting the case boundaries included physical location, people, and timeframe (Simons, 2009). Research is often initially bounded by time and resource constraints, and when deciding the boundaries for this study, these constraints were taken into account. The main constraint was time, so the timeframe was set to the 3 weeks available.

Before deciding on the physical location, researchers must determine whether the unit of analysis will be a single unit (a within-site case study) or multiple units (a multisite case study). Given that this was the first study to investigate incident control through the specific theoretical lenses of this thesis, and due to time constraints, a within-site design was deemed most appropriate. The selected location, Network Rail East Midlands Control Centre (EMCC), was chosen opportunistically. Negotiations with Network Rail for access to a Rail Operation Centre (ROC) were progressing slowly, and with only two months left to complete data collection, no access had been granted. During an interview, a participant mentioned their years of experience working at the EMCC and offered assistance, which facilitated the necessary arrangements for access. Participant recruitment details are provided in Chapter 8 (Section 8.4).

The study design was emergent, reflecting a flexible approach to the research process that allows for evolution from new understandings and adaptation to the unpredictability of real-life contexts. Simons (2009) highlights the importance of design in emergent case studies, noting that while they are open-ended and flexible, they still require structure. Key factors in designing the study include identifying research questions or problems, selecting the methodology and methods, participant selection, and ethical considerations. The research questions were formulated based on the theoretical lenses of the thesis and the findings from the interview study (see Chapter 8, Section 8.2). These questions were broad and served to frame the study and maintain focus during the research process.

In alignment with the qualitative methodological approach of this thesis, qualitative methods of data collection were chosen. Case studies require multiple data sources to gain an in-depth understanding of the phenomena under investigation (Caswell, 2013). The research methods, presented next, were selected for their potential to address the research questions effectively.

4.5.3.2 Methods

Observations

Observation was the main method of data collection in this study. The main set of observations was conducted in the network control room, following the activity of Network Rail incident controllers. Some observations also took place at the signalling control room, shadowing signallers to familiarise with their activity. For details about the observations procedure and participants refer to Chapter 8 Section 8.4.

Observations were used in this study to form a comprehensive picture of the context and producing rich descriptions of the controllers' activity during the management of incidents. In doing so, observations included the context in which the activity developed. Gillham (2000) describes observations as watching what people do, listening to what they say and sometimes asking clarifying questions. Observations have a long tradition in social research and are widely used as a companion method in case study research (Simons, 2009). This method offers the researcher the possibility of understanding how things work in the field, capturing what people do rather than what they intend or think they should do (Brannan & Oultram, 2012; Gillham, 2000).

Robson (2002) highlights two important dimensions to consider in observations: the degree of pre-structure and the researcher's involvement. Pre-structure can be formal or informal. This study followed an informal approach, which is less structured than formal observations. An informal approach does not mean observing without any pre-established parameters; rather, it involves approaching observations without a rigid schedule, allowing flexibility in the type of information gathered and how it is recorded. While this method requires more effort to synthesise and organise the data, it aligns best with the type (instrumental) and design (emergent) of this case study.

The extent to which the researcher participates during observation varies. Robson (2002) describes this participation or role adopted by the observer as a continuum with two poles: at one extreme, the observer fully immerses, becoming part of the group, while at the other, the observer remains a pure observer aiming to be unnoticed (Figure 4-2).

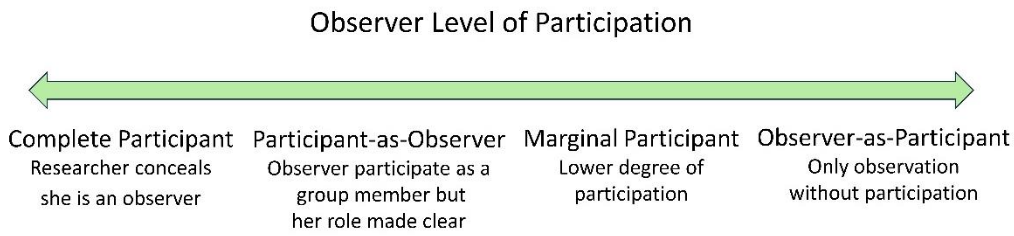

Figure 4-2 Researcher role in observations (Robson, 2002)

In this study, the participant-as-observer role was chosen as the most advantageous to collect rich, in-depth data. One advantage of this position is that the researcher clearly identifies her role, which mitigates ethical concerns while being able to immerse in the group and ask questions about what is observed. Asking questions was vital to form a detailed description of the observed activity because much of the controllers' work during incidents happens over the phone, resulting in large parts of relevant information being otherwise missed.

One problem related to participant observations is the so-called 'observer effect,' where people may alter their behaviour when they know they are being observed. Gillham (2000) argues that, in observations, the researcher acts as the research instrument, and any instrument used will have some effect on the findings. He suggests addressing this issue by considering the probable influence of the researcher's presence. In this study, the researcher observed operators undertaking safety-critical tasks. The observed behaviours were related to how they maintained safety in both normal and degraded situations; therefore, their performance is expected to be similar in the presence of the researcher.

Interviews

Formal and informal familiarisation interviews were conducted with incident controllers and signallers to build an understanding of key aspects of their activity, such as the nature of their role, the work context, the learning process, and the use of rules and standards.

Interviews with incident controllers were always informal [37] . Informal interviewing is a common practice in case study research (Simons, 2009) and has been referred to as 'conversations with a purpose' (Burguess, 1984), 'guided conversations, (Rubin & Rubin, 1995) or 'knowledge as conversation' (Kvale, 1996). Although conducting formal familiarisation interviews would have also been desirable, it was not possible because they are not allowed to leave their workstations for more than a few minutes. An informal approach was a good solution; the researcher was able to ask questions during quiet times and pause the conversation when needed without interrupting their activity.

Familiarisation interviews with signallers were formal. Signallers have regular breaks, and the signaller manager covers for them if they leave their workstations. A total of 11 signallers were interviewed. These interviews served to gain an understanding of key aspects of the signaller's role. Since the observations in the signalling room were conducted only to gain an understanding of the signaller's role and context, the interviews were also

[37] Unlike signallers, whose interviews were formal and recorded, controllers did not sign a consent form for the informal interviews. However, in the 'participant information sheet', controllers were informed of the researcher's intention to hold informal conversations during the shadowing, to which they agreed as part of their participation. They were also informed of their right to decline to answer questions and to stop participation and withdraw their data if they wished to do so.

used to familiarise the researcher with the signallers' roles during incidents. Participants and procedures are detailed in Chapter 8, Section 8.3.

Documents

Documents were provided by the signallers and controllers, consisting mostly of contingency plans in the form of tables and checklists, safety newsletters, and outputs form their incident computer systems. These documents were not formally analysed; rather, they served to familiarise with their activity, as an illustration of the standards guiding their activity and the type of information they manage.

4.6 Reflexivity

I will use this space to explore how my personal experiences, background, beliefs, and attitudes (i.e., 'me') may have influenced various aspects of this thesis. It is important to clarify that this is not an exercise in reflecting on the process itself, but rather a continuation of the reflexive process that has been integral to this research journey. This reflexive approach has been a continuous part of the thinking process throughout each stage of the research, helping me to evaluate whether my choices were made for sound reasons. For instance, I considered whether my preference for interviews over surveys was driven by convenience or by my greater confidence in using that method.

Some of the most significant decisions in this research were heavily influenced by my own perspectives, beginning with the choice of research paradigm, which clearly reflects my pragmatic approach. The 'open' approach adopted, which is not firmly anchored in any single perspective—such as human factors, psychology, social science, or organisational research—also mirrors my diverse background. My qualifications span sports therapy, psychology, and occupational psychology, and I am currently part of the Human Factors Research Group. All these 'lenses' have shaped the approach taken in this thesis. The emphasis on stability and flexibility is also a reflection of my personal experiences, highlighting the need to balance these aspects on stable ground. Additionally, the explorative nature of the thesis and the research questions were influenced by my limited background knowledge in safety science and safety-critical industries. Nevertheless, the choice of methods was primarily driven by the context and what I deemed most suitable for addressing the research questions. For example, I initially considered employing mixed methods, but the project evolved into a qualitative study.

To conclude, I wish to acknowledge the influence of my supervisors throughout the research process. Although I had the freedom to make decisions, I recognise that Study 4 would not have become a case study without their guidance. Originally, Study 4 was designed as an ethnographic study but was subsequently adapted into a short case study due to circumstances beyond my control. When I realised that I would not meet the university deadline for data collection, I was prepared to abandon the study and find an alternative plan. It was their belief in the feasibility and relevance of the study that enabled its continuation, for which I am deeply grateful.

4.7 Summary of the research methods

This chapter has presented the range of qualitative research methods and data sources employed in this thesis. They are summarised in Table 4-4 in relation to the research objective and the studies presented in this thesis.

Table 4-4 Research methods in relation to the research objectives and studies

Objective	Method	Study & Chapter
Objective 1 To describe sources, preconditions and barriers for stability and flexibility.	Document analysis Interviews with rule-makers Case Study	Study 1 (Chapter 5) Study 3 (Chapter 7) Study 4 (Chapter 8)
Objective 2 To provide a nuanced understanding of stability- and flexibility-enhancing tools and mechanisms in relation to operational needs for stability and flexibility	Document analysis Interviews with rule-makers Case Study	Study 1 (Chapter 5) Study 3 (Chapter 7) Study 4 (Chapter 8)
Objective 3 To investigate whether stability and flexibility integrate, and if so, describe how they do	Document analysis Interviews with rule-makers Case Study	Study 1 (Chapter 5) Study 2 & 3 (Chapters 6 & 7) Study 4 (Chapter 8)

5 Study 1 – Exploring flexibility in GB railways regulatory framework

5.1 Overview

Study 1 is a qualitative investigation using documentary and interview data. It delves into the railway regulatory framework, examining the various ways in which flexibility is embedded within standards and regulations to allow the standard user flexibility to adapt to their specific contexts. Five flexibility-enhancing mechanisms are described and critically evaluated.

5.2 Introduction

Ultrasafe industries such as the European railway system (Amalberti, 2001) manage safety within a paradigm of risk avoidance (Amalberti, 2013). This safety model relies on standardisation, automation, and operators with high levels of skills mainly directed to the correct execution of routines to manage normal and degraded situations (Vincent & Amalberti, 2016). Critical to this safety management paradigm is reducing uncertainty[38] by maintaining the system's stability (Grote, 2004; 2009). Centralised control structures and standardisation are typically used mechanisms for stability (Grote, 2020).

Resilience Engineering (RE) highlights the problem of standardisation. One argument is that prescribed work emerges from 'work-as-imagined,' representing how work is supposed to be rather than how it truly is. To cope with the situational realities of everyday operations, frontline operators rely on flexible, adaptive behaviours. This 'work-as-done' is fundamental to maintaining safety (Hollnagel, 2014). Standardisation represents an anticipatory approach that tends to constrain action and may appear at odds with the here-and-now adaptability seen as the foundation of resilience (Macrae, 2013).

The apparent contradiction between standardisation and adaptability often leads to these concepts being regarded as 'hopeless opposites' (Oyri & Wiig, 2022). However, there are examples in the safety literature contradicting this

[38] Uncertainty management and stability are elaborated in Chapter 3 Section 3.3.

understanding and pointing out ways in which standardisation may assist resilience. For instance, Macrae (2013) suggests that standardising basic processes frees up workers' cognitive resources, allowing them to focus on processes requiring adaptations. Grote (2015; 2020) proposes that adaptive behaviours can be promoted using goal and process rules. These rules do not prescribe the exact course of action; they are goal-oriented and provide little or no guidance on how to achieve the prescribed goal. 'Flexible rules' (Grote & Weichbrodt, 2007) demonstrate that flexibility and stability can be integrated within organisational tools typically assumed to maintain stability. Furthermore, flexible rules serve as an example of an organisational tool capable of accommodating various operational needs by providing different levels of flexibility.

The rail industry relies heavily on regulation and standardisation as essential mechanisms for maintaining stability. However, rail organisations and their staff operate in a large diversity of contexts that often require meeting specific needs. This study investigates the regulatory framework of the railway industry in GB. The aim is to explore how regulations, rules and standards may provide organisations and operators with the flexibility needed to adapt to their specific contextual circumstances. The research questions are:

- How do standards and regulations, enforced system-wide, accommodate the diverse contexts in which rail organisations operate?
- (How) Do industry and company standards allow for varying degrees of decision-making for the standard users (e.g., varying levels of flexibility)?

5.3 Methods

5.3.1 Design and data sources

This study takes a multilevel approach to data collection and analysis. Data were selected to allow for three levels of analysis:

- **System level**: this level examines standards that apply system-wide, exploring how these centralised standards may account for local needs and peculiarities.

- **Organisational level**: at this level the regulatory framework is examined within the organisational context, delving into the different types of standards produced by rail organisations. It looks at a) how company-produced standards account for contextual needs and b) how organisations balance central control and local autonomy to adapt to contextual needs while complying with regulations.
- **Individual level**: this level of investigation focuses on how standards are applied by standard users, including rail organisations, constructors, and the workforce. It explores the degree of flexibility operators have in applying these standards.

This qualitative study employs documents as its main data source. It takes an iterative approach to data collection and analysis, and the research design remained flexible, evolving as the study progressed (see Chapter 4, Section 4.5.1. The study was initially designed to address the research question using solely publicly available documents. However, opportunities were pursued to supplement the publicly available data with other sources to enrich the analysis. Consequently, interview transcripts and additional documents provided by the interviewees were later incorporated into the data set. The interview data was also used to triangulate the analysis of the documents.

As a result, the final dataset includes documents and transcript data. The two subsets were collected and analysed in two distinct stages. The first stage (*stage one*) contributed to formulating the initial findings. In the second stage (*stage two*), the additional data served three main purposes: 1) triangulation of the findings, 2) enhancement of detail and richness in the findings, and 3) critical discussion of the flexibility-enhancing mechanisms presented in this study (Section 5.5). The data sources in relation to the two stages are depicted in Figure 5-1.

The publicly available documents analysed in this study were sourced from online publications. These documents encompass written and audiovisual materials produced by the rail industry in GB, the UK Government, and the European. The material included laws and regulations, standards, manuals, guides, and information and guidance on the regulatory framework and safety management systems. The criteria for selecting the online data sources were trustworthiness, relevance, and availability, as summarised in Table 5-1. The sources had to meet all three criteria to be included in the study. The sources and types of documents are listed in Table 5-2. Notice that to maintain the flow and readability of the results in Section 1.4, in-text citations of the documents have been represented by superscripted numbers linked to the references in the table.

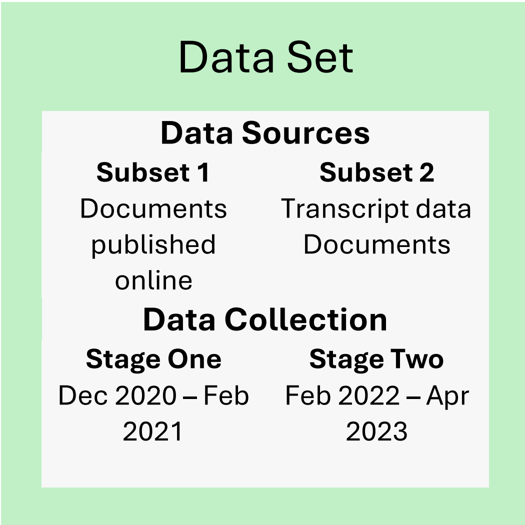

Figure 5-1 Data sources and data collection stages

Table 5-1 Online data sources selection criteria

Criterion	Description
Trustworthiness	The material was produced by an organisation or body with regulatory authority in the UK or EU and published on their official websites (or provided by members of the issuing organisation)
Availability	The content was available to the public or accessible via creating a free account with the institution
Relevance	The material applies or relates to the GB railway industry The material is useful in answering the research question

The transcript data were collected for the third study included in this thesis (Chapter 7) rather than purposely for this study. Eight of the interviews contained data relevant to this study; therefore, those interviews were selected to be added to this study dataset. The interviewees were three women and five men with experience working for the railway industry ranging from 6 to 56 years, and with experience in their current role ranging from 6 months to 36 years. Three interviewees were regulators, one worked for a freight operating company and four worked in infrastructure management.

5.3.2 Procedure and analysis

5.3.2.1 Stage one: publicly available documents

This stage started with a familiarisation phase which purpose was twofold: first, to gain an understanding of safety management from industry sources and second, to start sampling for sources for data collection. Besides using two internet browsers (Microsoft Edge and Google Chrome), two researchers with expertise in the rail transport industry were consulted regarding possible sources of information. The familiarisation phase involved reading broadly across websites such as Spark (www.rssb.co.uk/spark), the Rail Accident Investigation Branch (RAIB) (Rail Accident Investigation Branch - GOV.UK (www.gov.uk) Safety Central (www.safety.networkrail.co.uk), and The European Union Agency for Railways (www.era.europa.eu). During this phase, the researcher gained a broad understanding of safety-related topics such as rail regulatory bodies, safety culture, accidents and incidents investigations, human factors in rail, and so on. It also served to identify the organisations that were the sources of publicly available data: the Railway Safety Standards Board, the UK Government, the Office of Rail and Road, European Union Law, and the European Agency for Railways.

Documents were selected and analysed informed by Bowen's (2009) three steps of document analysis: skimming, reading and interpretation.

Table 5-2 Referenced documents list and sources

Source	Type of Doc	Document Title	Link (if available)
Railway Safety Standards Board www.rssb.co.uk	Audiovisual (Webinar)	**1.** RSSB's Standards Quarterly Update Dec 2021	RSSB's Standards Quarterly Update Dec 2021 - RSSB (videomarketingplatform.co) [Accessed 15 Jun 2024]
		19. RSSB Standards Quarterly Update Dec 2022	https://rssb.videomarketingplatform.co/video/81831824/01:24/railway-standards-guidance [Accessed 15 Jun 2024]
	Web Content (Guidance)	**5.** National Technical Specification Notices (NTSNs)	https://www.rssb.co.uk/standards/types-of-standards-and-how-they-work/national-technical-specification-notices [Accessed 15 Jun 2024]
		9. National Operation Publications (NOPs)	https://www.rssb.co.uk/standards/types-of-standards-and-how-they-work/the-rule-book [Accessed 15 Jun 2024]
		8. National Technical Rules	https://www.rssb.co.uk/standards/types-of-standards-and-how-they-work/national-technical-rules [Accessed 15 Jun 2024]
		10. Rail Industry Standards	https://www.rssb.co.uk/standards/types-of-standards-and-how-they-work/rail-industry-standards [Accessed 15 Jun 2024]
		17. Company & Project Standards	https://www.rssb.co.uk/standards/types-of-standards-and-how-they-work/company-and-project-standards [Accessed 15 Jun 2024]
		15. Safety Management Systems	Safety Management System (SMS) (rssb.co.uk) [Accessed 15 Jun 2024]
		19. How to Apply for a Standard Deviation	How to Apply for a Standards Deviation (rssb.co.uk) [Accessed 15 Jun 2024]

Table 5-2 Continuous

Source	Type of Doc	Document Title	Link (if available)
		20. Guidance to applicants and members of Standards Committee on deviation applications	guidance-deviation-2022.pdf (rssb.co.uk) [Accessed 15 Jun 2024]
		1. Guidance on the Application of Railway Standards	https://www.rssb.co.uk/standards/using-standards/guidance-on-the-application-of-railway-standards [Accessed 15 Jun 2024]
		12. Complying with Legislation	Complying with Legislation (rssb.co.uk) [Accessed 15 Jun 2024]
	Image	Different types of standards and rules[39]	https://www.rssb.co.uk/-/media/Project/RSSB/RssbWebsite/Images/Content-Images/scope-and-force-of-standards-large-image.jpg [Accessed 15 Jun 2024]
	Manuals & Rules	**23.** Train Operations Staff Manual	GERM8000-trainoperationsstaff-Iss-13.pdf (rssb.co.uk) [Accessed 15 Jun 2024]
		22. Rule GERT8000-HB12	Duties of the engineering supervisor (ES) or safe work leader (SWL) in a possession on ERTMS lines where lineside signals are not provided (rssb.co.uk) [Accessed 15 Jun 2024]

[39] The various documents in this table without reference number have been included as sources because they were an important source of information for the overall understanding of the regulatory framework here described.

Table 5-2 Continuous

Source	Type of Doc	Document Title	Link (if available)
	Code	**28.** Railway Group Standards Code	https://www.rssb.co.uk/-/media/Project/RSSB/RssbWebsite/Documents/Public/Public-content/Using-Standards/rssb-railway-standards-code-issue-5.pdf [Accessed 15 Jun 2024]
	Certificate	**21.** Deviation number: 19-004-DEV	(Provided by RSSB)
UK Government www.gov.uk	Legislation	**27.** RIR 2006	https://www.legislation.gov.uk/uksi/2011/3066/contents [Accessed 15 Jun 2024]
		26. ROGS 2006	https://www.legislation.gov.uk/uksi/2006/599/contents [Accessed 15 Jun 2024]
		25. Railway Act 1993	https://www.legislation.gov.uk/ukpga/1993/43/contents [Accessed 15 Jun 2024]
		2. Understanding legislations	Understanding Legislation [Accessed 15 Jun 2024]
	Web Content (Guidance)	**4.** National Technical Specification Notices (NTSNs)	National Technical Specification Notices (NTSNs) - GOV.UK (www.gov.uk) [Accessed 15 Jun 2024]
		6. Railway interoperability	Railway interoperability: National Technical Specification Notices (NTSNs) - GOV.UK (www.gov.uk) [Accessed 15 Jun 2024]
		7. Department for Transport	Department for Transport - GOV.UK (www.gov.uk) [Accessed 15 Jun 2024]
Office of Road and Rail www.orr.gov.uk	Web Content (Guidance)	**3.** European derived railway safety legislation	European derived railway safety legislation | Office of Rail and Road (orr.gov.uk) [Accessed 15 Jun 2024]
		14. Investing in the rail network: Managing safety	Investing in the rail network: Managing safety | Office of Rail and Road (orr.gov.uk) [Accessed 15 Jun 2024]
		14. Safety certificates and safety authorisations	https://www.orr.gov.uk/guidance-compliance/rail/health-safety/laws/rogs/certificates-authorisations [Accessed 15 Jun 2024]

Table 5-2 Continuous

Source	Type of Doc	Document Title	Link (if available)
	Guides	Guide to ROGs	https://www.orr.gov.uk/sites/default/files/2022-12/rogs-guidance.pdf
European Union Law www.eur-lex.europ.eu	Directive	**16.** Safety Management Systems requirements	EUR-Lex - 32018R0762 - EN - EUR-Lex (europa.eu) [Accessed 15 Jun 2024]
European Agency for Railways www.era.europa.eu	Web Content (Guidance)	**13.** Safety Management Systems	https://www.era.europa.eu/domains/safety-management/safety-management-system-sms_en [Accessed 15 Jun 2024]
Network Rail www.networkrail.co.uk	Catalogue	**18.** Catalogue of Network Rail Standards	https://www.networkrail.co.uk/wp-content/uploads/2022/03/Catalogue-of-NR-Standards-Issue-123.pdf [Accessed 15 Jun 2024]
	Standard	**24.** NR/L2/OHS/019	019-Standard.pdf (eppstraining.co.uk[40]) [Accessed 15 Jun 2024]

[40] This standard is not published in Network Rail Official Website (selection criteria 1); however, it is included here because it was facilitated by a member of the Network Rail standards team.

First, a superficial examination of the websites (skimming) was made to start collecting material based on the second criterion, availability, and relevance (third criterion). The second step (reading) consisted of thoroughly examining the content selected to further shortlist the material according to its relevance. Since the study's first aim was to describe the regulatory framework, the first materials selected were those offering rich – yet clear and manageable – information. At this stage, the RSSB website provided much of the data.

As the description of the regulatory framework formed and the different types of standards were identified, material from the bodies producing those standards was selected (e.g., UK Government and EU legislative sources). The descriptive analysis consisted of identifying the main standards groups at the system and organisational levels, describing their main features, hierarchical relationships, rules to their application, and so on. The aim was to develop clear descriptions within the study's scope and overall goal, resulting in descriptions at both system and organisational levels. This iterative process involved moving between sources to fill gaps in information. Once the description of these two levels was complete, sources for analysis at the individual level were selected.

A reasonable data source to explore standards at the individual level is operational rules directed to frontline staff. The rules best matching the three selection criteria were National Operational Publications, published under the name 'The Rule Book' which provide direct instructions for national railway staff. The first search of these documents returned 2319 standards, all meeting the selection criteria. Since all the manuals were similar in structure, the first manual in The Rule Book was selected as a sample. This was the so-called GERT8000/AC, comprising 55 standards and 213 rules. Once descriptions at all three levels were completed, the analysis moved to the third and last of Bowen's (2009) steps: interpretation. Here, the researcher moved from description to explanations in the light of the research question, therefore searching for flexibility-enhancing mechanisms embedded at each level of analysis that may allow organisations and operators to adapt to their specific contextual circumstances.

At the system level, interpretative analysis focused on explaining how standards, centrally decided and with system coverage, may accommodate local idiosyncrasies. This way, the analysis centred on revealing flexibility-enhancing features embedded in these standards and the regulatory regime's structure. At the organisational level, the analysis examined how flexibility may appear in company-specific standards and whether companies had any flexibility in applying centrally imposed standards. At the individual level, the analysis was directed to the rules included in the manual selected, looking for elements that could give the user of the manual decision-making autonomy to adapt to contextual conditions.

5.3.2.2 Stage two: Interview data, new documents, and previous documents update

Data collection in stage two spanned over two years, starting eight months after the initial document analysis described in the previous section finished. This initial document analysis yielded a first set of results. In content and structure, those first results were almost identical to the final results reported here in Sections 5.4 and 5.5. However, the interview and documental data added during this second stage served to triangulate and critically analyse those findings. It also enriched the analysis by adding detail and depth to the descriptions. Note that the update of the findings also included a revision to accommodate the changes in the GB railway regulatory framework brought about by Brexit. The data used for that revision were the same publicly available data used during stage one, which content had been updated by the publishing organisation.

It is important to stress that the interviews used as data source were not purposely conducted for this study but for Study 3 of this thesis (Chapter 7). Although interviews with rule-makers would have been a valuable data source for the purpose of this study, access to participants was very challenging; therefore, the researcher decided to focus on the interview study objectives during the interview time (Study 3). The interviewees also provided the extra documents added at this stage.

The transcript data were analysed deductively in light of the findings. During the initial two stages of the thematic analysis conducted in Study 3 (familiarisation and initial coding), extracts from the transcripts relevant to the initial findings of the present study were selected for further examination. These extracts included supporting or contradictory information, details to enhance descriptions or fill gaps, narratives providing real-world examples of the phenomena described here, and so on. They were utilised for triangulation, enhancing descriptions, critical analysis, and providing real-world context examples, as follows:

- **Triangulation**: When the transcript data aligned with this study's findings, the extracts were selected for triangulation (Appendix I).
- **Enhancing the description:** The data that provided further detail, filled up gaps or shed light on the initial findings, was used to complement and complete the descriptions. Notice that some of this data was purposely prompted during the interviews; if an interviewee's account was relevant to this study, the researcher would ask for more details. For example, an interviewee mentioned that Network Rail has standards to make standards, and the researcher asked whether they could tell her more about it. Then, the interviewee referred to a colour system, and the researcher asked for further details. The documents provided by the interviewees were used during this phase in a similar manner. Completion of this analysis resulted in the final findings presented here.
- **Critical analysis and real context examples:** Again, this analysis was done deductively, but this time the analysis was conducted once this study's final findings were drawn. It consisted of selecting the extracts that serve to critically analyse the findings or provide real context examples (Section 5.5).

5.4 The regulatory framework

5.4.1 System-wide standards (system level)

Analysis at this level revealed three primary categories of standards: UK Rail Legislation, non-RSSB standards, and RSSB standards, organised in a hierarchical structure[1]. These categories contain eight subcategories of standards, some of which can be divided into various types of standards. Figure 5-2 represents the main categories and their subdivisions. While examining every type of standard is beyond the scope of this study, the key features and relationships between the main categories and subcategories are described next.

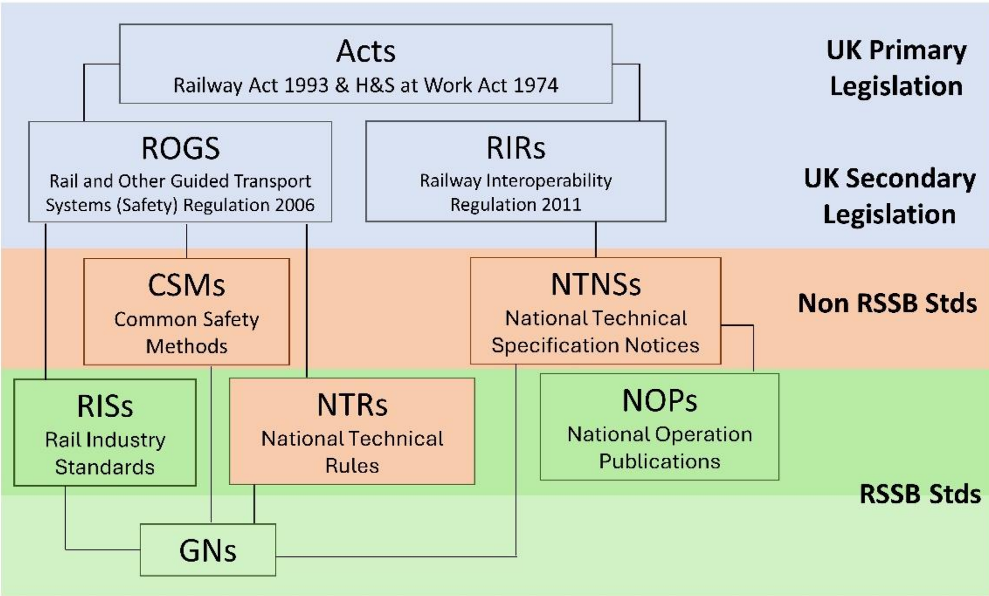

Figure 5-2 Standards: Categories and relationship. Blue and pink: compulsory via legislation. Dark green: mandatory via licencing. Light green: not mandatory. Adapted from RSSB's Standards Quarterly Update Dec 2021 - RSSB (videomarketingplatform.co.uk)

5.4.1.1 UK Rail Legislation

Legislation includes laws and acts that must be complied with; non-compliance is a criminal offence and may lead to prosecution and substantial fines. They are divided into:

- **UK Acts and Regulations**, also called 'primary' and 'secondary' legislation'[2] respectively. Acts are the main laws passed by the legislative bodies of the UK Parliament, such as The Health and Safety at Work Act 1974 or the Railway Act 1993 [25]. They are broad in scope and set the general legal principles. Regulations provide specific details and procedures on how to implement and enforce acts. The most relevant regulations for rail in GB are The Rail and Other Guided Transport Systems (Safety) Regulation 2006 (ROGS)[26] and The Railway Interoperability Regulation 2011 (RIR)[27].

5.4.1.2 Non RSSB standards

This group of standards, directed to support compliance with legislation, replaced the EU Regulation following the UK's exit from the European Union. They reproduce the content of the EU regulations, amended to adapt to the UK context. The two main groups of rail standards in this category are:

- **The Common Safety Methods (CSMs)** replaced the CSMs developed by the European Union Agency for Railways. Now regulated under ROGS, they describe the procedures to fulfil the safety levels, achieve safety targets, and comply with other safety requirements [3], including safety management systems. There are five types of CSMs, three directed to the regulator (regarding licencing and supervision) and two directed to organisations (regarding risk assessment and monitoring).
- **National Technical Specification Notices (NTSNs)**[4,5] are legal standards under the Railways (Interoperability) Regulations 2011. They replaced the EU Technical Specifications for Interoperability (TSIs) and are now published by the Secretary of State on the Department for Transport (DfT) website [6,7] NTSNs define the operational and technical standards to ensure interoperability[5] and to satisfy the 'essential requirements'. These requirements are safety, reliability and availability, health, environmental protection, technical compatibility, and accessibility.

British Standards (BS) and European Standards (EN) are not explicitly developed for the railway system; however, some specified within NTSNs are also applicable to rail organisations for compliance with legislation.

5.4.1.3 RSSB standards

The RSSB produces these standards also directed to support compliance with legislation. Four categories of standards belong to this group:

- **National Technical Rules (NTRs)**[8] are Railway Group Standards (RGSs) [41] made compulsory via the Railways (Interoperability) Regulations 2011 (RIR). They provide controls in addition to National

[41] Railway Group Standards are produced as specified in the Railway Group Standards Code[28] published by the RSSB. They include technical standards and operating procedures that specify what must be done rather than how it should be done

Technical Specification Notices (NTSNs) to ensure that the essential requirements specified in the RIR are met.

- **National Operation Publications (NOPs)**[9] stem from NTSNs, which require rail operators to have a rule book. The Rule Book comprises a series of manuals containing operational rules, which are direct instructions for railway staff relevant to approximately 10,000 frontline operators.
- **Rail Industry Standards (RISs)**[10] are not compulsory by law, but they are still industry-agreed standards and applicable RISs are made mandatory via licencing conditions [11] RISs contain requirements related to subsystems[12] and set rules about their operation or management.
- **Guidance Notes (GNs)**[1] are informative texts detailing the agreed way to meet a requirement. They may stand alone, although they more often appear combined with RISs and NTRs.

5.4.2 Standards and organisations (organisational level)

5.4.2.1 Safety management systems (SMSs)

Safety Management Systems (SMSs) are one of the cornerstones of the railway safety regulatory framework[13]. Railway undertakings (train operators) and infrastructure managers are required to develop and maintain an SMS. The SMS must be certified by the Office of Rail and Road to gain their 'safety certification' or 'safety authorisation' respectively[14]. The purpose of SMSs is to ensure that organisations safely achieve their business objectives and comply with their safety obligations. They serve as a framework for addressing all the risks associated with the organisation's activities[15]. Consequently, they need to be tailored to the specific needs and circumstances of the organisation.

While ROGS 2006 regulates the structure of SMSs, the requirements only specify the areas that must be addressed in a very open manner to ensure that organisations have the flexibility to adapt those requirements to their specific needs. The standard below ((EU) 2018/762)[16], regulating Safety Management System requirements, illustrates their broad, open-ended nature:

> *'Staff, their representatives and external interested parties, as appropriate and where relevant, shall be consulted in*

developing, maintaining and improving the safety management system in the relevant parts they are responsible for, including the safety aspects of operational procedures.'

5.4.2.2 Company and project standards

To control their risks and comply with the law, organisations may incorporate publicly available standards such as Rail Industry Standards (RISs), British Standards (BS) or ISO standards (International Organization for Standardisation)[42] as *off-the-shelf* company standards into their SMS. They may also develop their own company standards[17] to manage risks specific to their activities and local needs. Likewise, standards may be agreed upon with customers and suppliers to manage the risks specific to a particular project (i.e., project standards)[17]. Standards may be agreed upon at the company or project level to:

a) Manage risk in areas not covered by specific laws or industry standards.
b) Complement higher-ranked standards by setting out specific ways to implement those.
c) Impose additional constraints to adapt to local needs or meet business objectives.

It is important to notice that company and project standards must not duplicate existing available standards if they are fit to control for the risks identified by the organisation.

Company standards in large organisations are the most detailed and complex category of standards. Network Rail offers a good example. These standards are the documents that specify requirements and provide guidance to operate the rail infrastructure safely and efficiently[18]. The organisation has developed its own standards framework to classify them based on their function and whether they are mandatory or optional. This way, mandatory standards are divided into three levels: Level 1 includes the policies; Level 2 specifies

---

[42] ISO is an international standard-setting body composed of representatives from various national standards organisations. Both cover a wide range of areas, including product specifications, testing methods, quality management systems, and more. They are not standards specifically developed for the railway system, but they may be used by rail organisations.

"what" is to be achieved; and Level 3 details the "how to" tasks to deliver requirements specified in Level 2. Non-mandatory standards or Guidance Notes provide guidance based on best practice. The standards catalogue also includes guidance on how to challenge the company standards [18]. Standards challenges, derogations and deviations are further described in the next section.

5.4.2.3 Deviations & Derogations

Sometimes, the context where organisations apply standards does not match the conditions the standards were created for, undermining the safety and efficiency aims of the standard. When that happens, organisations can contact the RSSB and apply for a temporary or permanent 'deviation', which allows them to modify a mandatory Rail Group Standard[43] (e.g., an NTR) by setting an alternative provision[19]. A deviation is not an authorisation not to comply with the standard but an authorisation to comply with a specific alternative. The applicant must specify why they cannot comply with the requirement and what they propose as a replacement, which must achieve the same levels of safety. They must also consult with any affected party (e.g., train operators, asset owners, Network Rail, etc.) about the convenience of the alternative[20]. The Lead Standards Committee reviews the alternative and decides whether to grant or not the deviation.

It is important to notice that the committee decides not only based on the suitability of the alternative in terms of its local impact, namely, to safeguard the safety and efficiency of the process; they also decide in terms of the long-term best interests of the railway system as a whole. Deviations increase the variety of practices and processes within the railway system, which may constrain or be detrimental to existing or future compatibility and developments on the system. Consequently, the members of the Standards Committee(s) consider the following question before deciding: *'Is the immediate and local benefit (due to the deviation) worth the cost and impact of increased diversity and possible constraints on the future operation of the railway system as a whole?'* (RSSB, 2022, p. 8).

[43] RISs can be also modified. However, since they are not mandatory by law, their modification does not require a formal 'deviation process' needing only permission but not official approval. Yet organisations may use the same formal document to contact the standard committee to seek advice.

However, deviations may not only be requested for immediate, local benefits but also for testing novel processes, potentially serving as a source of innovation and benefiting the whole system. For example, in 2019, Network Rail was granted a deviation to use fewer workers to go trackside to place the required possession protection (Deviation number: 19-004-DEV)[21]. The organisation argued that the alternative would improve track worker safety and applied for the deviation as a trial to test it. The process resulted in a change in the rule (GERT8000-HB12)[22] as the alternative showed to improve the possession process.

Network Rail itself has processes in place for their standards users to apply for deviations (named derogations) of their standards. They also encourage contractors, suppliers and stakeholders to 'challenge' their standards and propose changes that foster innovation and cost efficiency [18].

5.4.3 Standards and users (individual level)

This level explores the degree of flexibility operators have in applying standards. How a standard is written or formulated conveys various meanings, and the analysis revealed two key distinctions. One distinction concerns the level of detail, here labelled 'level of prescription'. A rule or standard generally provides specific instructions that individuals, groups, or organisations must adhere to. However, the level of prescription can vary, with some standards offering more detailed guidance on how to carry out the instruction while others may provide less detail. In this way, standards can be more or less prescriptive. An example of minimal prescriptive detail was provided in the previous section regarding the SMS regulation.

Another distinction relates to the 'level of obligation' to adhere to the standard. In this regard, a standard may either be an instruction that the user *must* follow, or it may offer *guidance*, leaving it in the user's discretion whether to follow the instruction. It is important to make this distinction because a standard can be very prescriptive while offering just guidance; similarly, it may entail a mandatory requirement but offer very little detail or level of prescription.

While the level of prescription is normally indicated by the degree of detail in the standard's formulation, the data analysis revealed various methods of distinguishing between different levels of obligation. For example, the ISO standards establish that the word 'shall' indicates a mandatory requirement, while the word 'should' implies a 'recommendation' rather than a 'requirement' (Gray & Steward, 2015). In the dataset, this formulation appears in legislation and Network Rail standards, while RSSB standards use 'must' instead of 'shall'. The quote below illustrates this use of wording to distinguish the level of obligation. It also exemplifies different levels of prescription:

> *'You must make sure that precautions are carried out to prevent you or any materials or equipment coming into contact with live CRE shoe gear and associated exposed live train-mounted equipment.*
>
> *You should avoid carrying materials or equipment over CRE.*
>
> *You must not drag objects across, or drop them on, live CRE'*

(GERM8000/train operations staff, 2023, p.77)[23]

This quote is an extract from The Rule Book[9]. The first rule is a mandatory requirement ('you must') that provides some level of prescription regarding what to do but little detail regarding how to do it. The second and third rules in the quote provide very little level of prescription; they are outcome based. However, while one is a recommendation ('you should') the other is a requirement ('you must').

Another method through which the level of obligation becomes apparent is the traffic light colour scheme employed by Network Rail in its company standards. *Red* requirements are presented in a red box and must be complied with and always achieved; variations are not permitted. *Amber* requirements are presented with an amber sidebar. They must be complied with, although variations are permitted subject to approved risk analysis and mitigation. Both red and amber requirements are monitored for compliance, while *green* standards are guidance and are not monitored for compliance. Yet, they should be followed unless an alternative solution produces a better result. Every Network Rail standard includes a full description of this traffic light system and how it should be used. The following quote represents an amber standard. Without the colour code, distinguishing the level of obligation would be challenging, as the use of 'shall' implies a mandatory requirement. This is a Level 2 standard; therefore, it specifies ‘what’ is to be achieved rather than ‘how’ (Level 3). Yet, the standard displays a high level of prescription:

> *‘Working with a warning safe system of work, working shall not be permitted:*
>
> *a) where the total warning time required is more than 45 seconds;*
>
> *b) where there are three or more running lines open to traffic between the site of work and the designated position(s) of safety; or*
>
> *c) at locations where the Network Rail National Hazard Directory prohibits “Red Zone” working.*
>
> *An individual shall not undertake lookout duties for more than 2 hours without an adequate break or rotation from the task.’*

(NR/L2/OHS/019, 2017, p.24)[24]

Although in the rules above, words such as ‘shall,’ ‘should,’ or ‘may’ denote the level of obligation, sometimes rules are formulated in ways that, without the colour code, the level of obligation would be difficult (or impossible) to know. The rules quoted below were also extracted from the same standard:

> *‘The responsible manager is accountable for the preparation of the SWP, and may delegate responsibility for the preparation of the SWP to the planner.’*

(NR/L2/OHS/019, 2017, p.15) [24]

> *‘The responsible manager may authorise the SWP to be implemented repeatedly without their further authorisation where they are satisfied.’*

(NR/L2/OHS/019, 2017, p.16) [24]

The first rule is green-coded, signalling guidance, whereas the second rule is amber-coded, indicating a mandatory requirement. As both rules share a similar formulation, relying solely on the wording might pose a challenge for the rule user in discerning the level of obligation. This raises concerns about relying solely on the text to convey flexibility since flexibility should not result in ambiguity. While flexible rules empower decision-making for the user, ambiguity may lead to confusion. Adding an extra element such as colour coding appears an easy solution to avoid ambiguity[44].

5.5 Flexibility -enhancing mechanisms

The data analysis revealed various mechanisms that allow organisations and operators flexibility to adapt to their specific contextual circumstances, which are summarised in Table 5-3.

Table 5-3 Flexibility-enhancing mechanisms, level of action and brief description

Flexibility-enhancing mechanisms	**Label in this study**	**Level of action**	**Brief Description**
Structural arrangement of the standard framework	*Funnel Structure*	System	Standards categories are arranged hierarchically, narrowing the coverage scope from system to project and adding detail at each level
Possibility to choose among centralised standards	*Off-the-shelf solutions*	Organisational	Organisations have flexibility to select standards from various centralised categories based on their specific needs and preferences
Alternative solutions to existing standards	*Substitution*	Organisational	Organisations can substitute existing standards with an alternative solution

[44] Notice that the colour is not the only clue to distinguish rules hierarchy. It also includes how the colour is inserted to account for colour blindness (box for red, sidebar for amber, dotted sidebar for green).

Table 5-3 Continuous

Flexibility-enhancing mechanisms	Label in this study	Level of action	Brief Description
Level of detail on how to carry out an action	*Level of Prescription*	System, Organisational & Individual	Prescription and obligation are two separate features of rules. This allows for more formulations to align standards to operational needs for stability and flexibility.
Level of requirement to carry out an action	*Level of Obligation*	System, Organisational & Individual	

The first one relates to the regulatory framework structure. As described in the previous section, it includes several categories of standards arranged hierarchically. This hierarchical structure can be depicted as an inverted pyramid or a *funnel*, narrowing from system-wide to local standards (Figure 5-3).

This process typically involves refining and elaborating on the content of the rule to provide clearer guidance or to address specific needs. Thus, standards become more detailed and specific in their content as they apply to a narrower range of situations or contexts (e.g., a company or a project). This *funnel* structure provides system stability because crucial requirements promoting safe and smooth operations are centralised and applied system-wide. It also offers flexibility, allowing standards to be set at different levels to address local needs. Standards at the top of the hierarchy focus on critical safety and interoperability requirements. They are goal-oriented, specifying what must be done but offering limited detail on how to achieve it. Furthermore, standards cannot contradict, replace, or overlap with higher-ranked standards. Instead, they can only address gaps or provide details left unspecified at previous levels. By adding detail, standards can be adapted to local needs and constraints. Note that RSSB standards like RISs have system-wide coverage. However, companies are not obliged to apply all of them; instead, they select those relevant to their context as *off-the-shelf standards* to incorporate into their SMS. This way, centralised standards can cater for local needs.

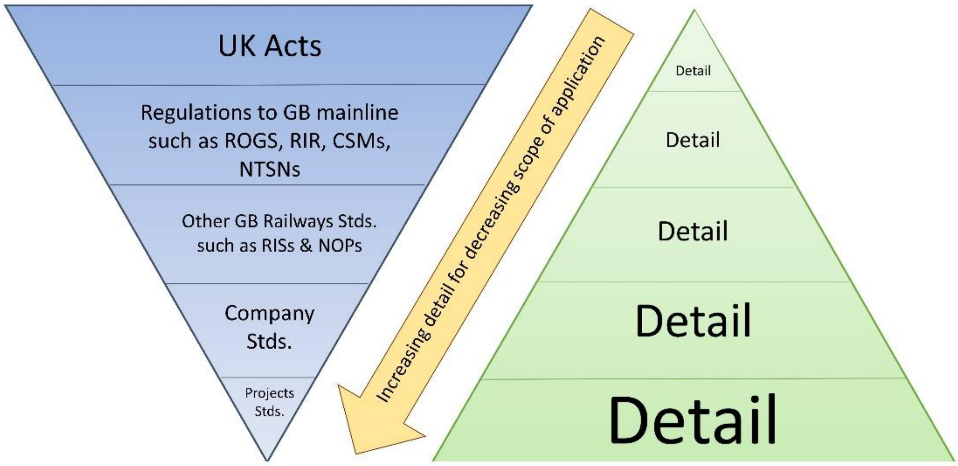

Figure 5-3 Funnel structure: relationship between standards scope of application and level of detail in the standard.

The downside of this standards regime, highlighted by participants during the interviews, is that this framework is rather complicated to understand. As one participant from infrastructure management stated, *'it's so complex people don't understand... that's why people get confused.'* Another participant emphasised the importance of each organisation evaluating the suitability of the different RSSB standards within their unique context—a practice that may not always be well understood within rail organisations. They illustrate their argument with the following example:

> *'When somebody that is not competent in terms of how the regulatory framework works, they might think that everything applies to them because the rule is there... Imagine that there was a rule that says that "if you are in a meeting room and it is a chalk board, you should use chalk to write on it"... Now imagine that you go to that building and ... all you have is white boards, and white boards have marker pens. Obviously, the rule about the chalkboard doesn't apply to you because you don't have that kind of system... there will be some people that feel that they have to comply with the rule ... They'll panic and they will go out there and will buy a chalkboard... that happens in the railways.'* [Participant 103 – Regulator]

Besides selecting the RISs that better suit their needs, organisations can *substitute* RSSB standards with alternative solutions. This mechanism for flexibility comes into play when the applicability of RSSB standards becomes problematic in the context where they must be complied with. Likewise, constructors and suppliers can deviate from company standards. The mechanism allows flexibility and innovation, as novel and better operating methods may be put forward and tested. As explained in Section 5.4.2.3, deviations from central standards are locally proposed but must be centrally approved to a) ensure that safety and efficiency are safeguarded locally and globally and b) the benefits are worth the added diversity and, thus, increased complexity. Increased variety and complexity are problematic aspects of this mechanism for enhancing flexibility pointed out during the interviews. For example, a participant argued that the use of derogations promoted by Network Rail contradicts their efforts to streamline the organisation's standard regime:

> *'if you want to challenge a standard, you can do it through this challenge mechanism. That is the mechanism now for changing standards. It's going to take a long time to get down to 100 business critical rules if you follow that process'.* [Participant 501 – Infrastructure management]

At the individual level of analysis, flexibility was encountered relating to the *level of prescription* and the *level of obligation*. The prescription level concerns the detail regarding how to carry out the instruction: the fewer details, the less prescriptive and, thus, the more flexibility to the standard user. The *obligation* level concerns the level of requirement to carry out an action. Here, standards may be compulsory (either with or without the possibility of *substitution*), recommendations, or provide guidance. Although these two mechanisms were discussed at the individual level, they are encountered at all levels of analysis. Firstly, at the system level, the different levels of obligation are embedded in the different categories of standards; for instance, *non-RSSB standards* are compulsory (refer to Figure 2 in Section 4.5.1). Likewise, Figure 5-3 above shows how the *level of prescription* (i.e., the detail) relates to the regulatory framework structure.

Secondly, at the organisational level, the data showed how Network Rail uses different levels (Levels 1, 2 3 and Guidance Notes) and different colours (red, amber, and green) to indicate the *level of obligation* attached to each standard. Organisations have the flexibility to determine how they incorporate various levels of prescription and obligation into their SMSs to ensure alignment with current legislation and their business objectives. This way, organisations choose the degree of flexibility their standards will afford, as expressed by this participant:

> *'[Network Rail] is moving away a little bit from the ambers and doing more sort of "red this is the outcome and green is how we think you should do it"'* [Participant 500 – Infrastructure management]

Although those developing SMSs and standards know the relationship between prescription levels and degrees of flexibility, several participants pointed out that the challenge lies in determining the appropriate level of prescription to employ:

> *'we get drawn into and have to make judgments on the debates about how prescriptive standards and guidance should be in order to control the risk adequately, but not to impose excessive, disproportionate costs on organisations. I think that's a difficult debate for us'* [Participant 401 – Regulator]

Additionally, a participant acknowledged that high levels of prescription are frequently employed to limit operators' autonomy, but questioned whether the extent of control or autonomy has any tangible impact on safety:

> *'the way that the rail industry have tackled [incidents and accidents] is by layering up more and more and more process... tighter and tighter controls, less and less autonomy, more and more and more central management, and the problem doesn't go away... all the trends are just horizontal. We don't get any better, anything over time. So this is clearly not the right approach... the answer is something different, but it's difficult to know what the answer actually is, because I don't think the answer is to give more autonomy and more freedom of choice, because when we do that, our workforce don't respond in the right way.'* [Participant 505 – Infrastructure management]

5.6 Discussion

Achieving an appropriate balance between stability and flexibility in operations is a fundamental prerequisite for safety and resilience. Investigating the different types and effects of rules and regulations in organisations is a useful way to explore this balance (Grote, 2016b). This study explored the railway regulatory framework at three levels: system, organisational, and individual. The study was set to explore how standardisation and regulation, mechanisms typically used for stability, support flexibility across the levels. The findings demonstrated that flexibility is supported at all three levels of analysis. Five flexibility-enhancing mechanisms were described and evaluated through examples provided by people involved in the standards development: *funnel structure, substitution, off-the-shelf standards, level of prescription* and *level of obligation*.

At the system level, flexibility appears integrated into the structural arrangement, referred to in this study as the *funnel structure*. Designing an effective operational safety framework presents the challenge of finding the right balance between centralisation and decentralisation (Monteiro et al., 2020). In decentralised, flat structures, most decisions are made at the local level, promoting flexibility and adaptation to local needs. Conversely, centralised, vertical structures, characterised by centralised decision-making, lack flexibility and may constrain the ability to respond to local issues (Perrow, 1999; McDonald, 2006; Andersen, 2010). This dichotomous description of structural management emphasises differences within the system but neglects commonalities. The *funnel structure* described here focuses on commonalities and centrally regulates aspects critical for the whole system to run safely and efficiently. Simultaneously, flexibility is not neglected, as details addressing contextual needs are added to standards at the local levels. By filling the gaps left by higher-ranked standards, global and local needs are integrated.

A comparable approach to maintaining the balance between stability and flexibility through standardisation was described by Kanter (2008). In her study of successful global organisations, she explains how these entities uphold high stability through worldwide company standards while remaining agile to adapt to very diverse operational contexts. Kanter concludes that achieving this balance involves permitting local decision-making, provided it aligns with the organisation's global goals and quality standards.

Kanter (2008) also highlights how the centralised model promotes innovation by encouraging local units to make recommendations based on their local experiences. If these recommendations prove beneficial for the organisation's global goals, they become 'best practice'. A similar dynamic is observed in this study concerning *substitution*. Network Rail encourages its standards users to challenge the company standards to find novel solutions.

Similarly, deviations to adapt to local needs may become *good practice*[45]. In this way, the substitution mechanism not only serves as a tool for flexibility but also contributes to industrial learning and improvement. *Substitution* is, therefore a mechanism that provides both stability and flexibility by integrating central and local decision-making. The alternative solutions are decided locally based on the contextual resources and constraints. Yet, these decisions are centrally assessed for their safety and industry convenience. Thus, a formalised (stable) process enables local flexibility, but through review, it is translated back into stability. Furthermore, it may become *good practice,* turning back into standardisation. This way, stability and flexibility not only integrate but also complement and reinforce each other.

The findings also showed how organisations can choose centralised standards as *off-the-shelf solutions* to tailor their SMSs to their contextual needs. All these three mechanisms – *funnel structure, substitution*, and *off-the-shelf solutions* – integrate flexibility and stability and meet two important objectives of these operational models: supporting local decision-making and adaptation while ensuring the reliability and global convenience of the solutions (Grote, 2020; Weick & Sutcliffe, 2011).

The last two mechanisms proposed in this study – *level of prescription* and *level of obligation* – were presented at the individual level concerning frontline operational rules. It is important to notice, though, that they apply to written standards within any category.

[45] Interviewees explained that the term *best practice* is in disuse in the rail industry as it is difficult to judge what is the best way to do something. The term is being replaced by *good practice*.

In accordance with previous research on rules in safety-critical industries (Hale & Swuste, 1998; Hale & Borys, 2013a; Grote et al., 2009; Grote, 2015), the data indicate that different formulations of standards provide varying degrees of freedom to the standard user, which can be employed based on the required level of stability and flexibility. Although prior research has raised questions about whether these contingencies are acknowledged in the practice of rulemaking (Grote, 2015), the findings suggest that they are well understood and utilised by rulemakers within the UK rail industry.

An addition to previous literature is that this study identifies two mechanisms contributing to flexibility within these formulations: the *level of prescription* and the *level of obligation*. The prescription level aligns with the existing taxonomy of flexible rules (i.e., action, process, and goal rules), which concerns the 'how', while the obligation level concerns the 'what'. Furthermore, the level of obligation can be influenced not only by the wording but also by other factors, such as the standards' category or level and the use of colour coding.

Making the distinction between prescription and obligation is important for several reasons. For instance, the degree of prescription does not always indicate the level of obligation. Grote's analysis of flexible rules (Grote, 2016b; 2020) indicates that action rules, as they describe the precise course of action, leave no or little decision latitude to the rule user. However, a Guidance Note (GN) or a Network Rail green rule may prescribe the precise course of action while only providing guidance. In such cases, the standard user has decision-making latitude to do something different. Likewise, whether variations are permitted or not in mandatory rules (as in Network Rail amber and red requirements, respectively) may have significant implications for the planning and implementation of the activity. Therefore, the standard user needs to be aware of the level of obligation.

Grote (2015; 2016b; 2020) suggests that flexible rules help tailor the type of rule to meet specific demands for flexibility and stability. This involves using action rules when stability is required and employing goal and process rules when flexibility is needed. This possibility can be depicted as a dimension with two poles, action and goal, with the prescription level moving along the continuum: the higher the stability needed, the more prescriptive the rule (i.e., closer to the action pole) and the more flexibility is required, the less prescriptive (i.e., closer to the goal pole). Likewise, incorporating varying levels of obligation in standards enables the alignment of standard types with operational needs for stability and flexibility. For instance, red standards may be employed to ensure stability, while green standards provide room for flexibility (Figure 5-4).

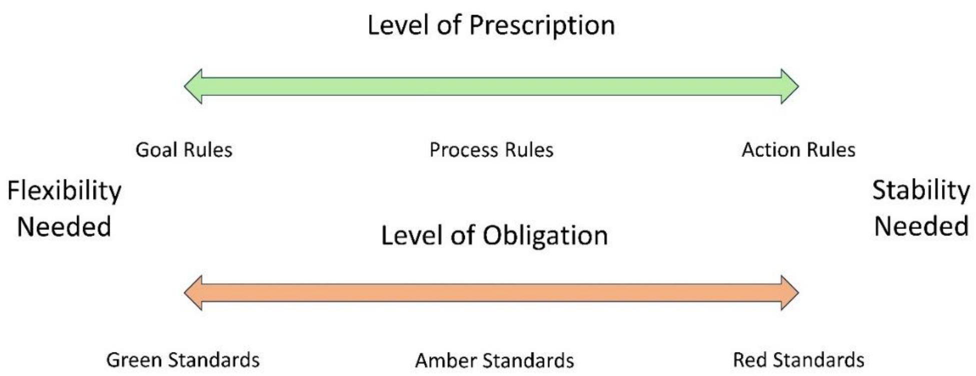

Figure 5-4 Levels of prescription and obligation in relation to stability and flexibility demands

By distinguishing prescription and obligation as separate features of rules or standards, the potential for tailoring rule types to diverse operational demands is significantly broadened. When integrated, prescription and obligation provide a nuanced strategy for meeting operational needs, expanding the range of feasible options. The range of possibilities can be depicted as a 2x2 matrix (Figure 5-5).

Notice that the description presented in this study does not replace the previous classification of action, process, and goal rules. Instead, it introduces an additional aspect to consider. While rules serve as written prescriptions for behaviour (Grote, 2015), it is useful to recognise that varying levels of obligation are associated with adhering to a given standard.

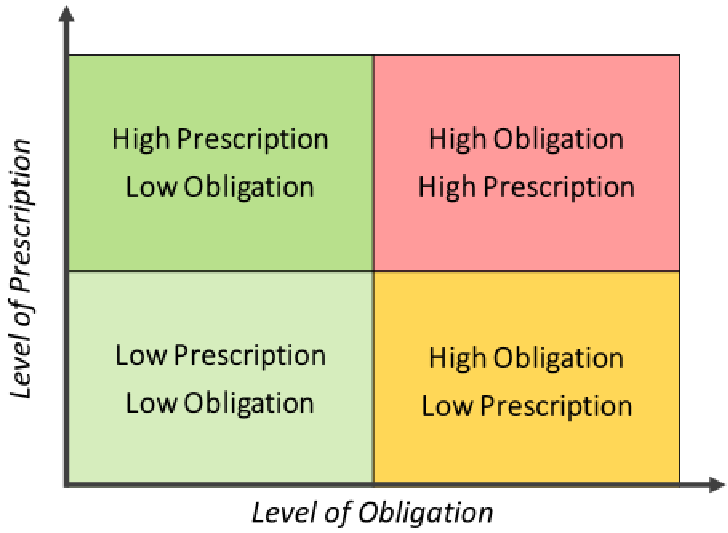

Figure 5-5 Four quadrants of rules flexibility

How those four possibilities correspond to different demands of stability and flexibility is beyond the scope of this study. Nevertheless, a reasonable proposition would be to use rules with high levels of prescription and obligation in situations demanding high stability or red standards (i.e., high level of obligation) with little prescription for processes demanding high stability and high flexibility. Likewise, prescriptive rules (action rules) may serve as detailed guidance when the action or activity is complex but low levels of stability are required. Concurrent needs for high stability and high flexibility might be addressed by employing red standards goal oriented (i.e., high level of obligation and low level of prescription). Finally, encouraging flexibility in situations where stability is not a priority (e.g., activities with low associated risks) by employing minimal levels of prescription and obligation could promote innovation.

5.7 Conclusions

The aim of the present study was to shed light on how standardisation and regulation, mechanisms typically used for stability, support flexibility across the different system levels. Five flexibility-enhancing mechanisms were described, demonstrating that stability and flexibility can be integrated within mechanisms traditionally used for stability.

The following conclusions are drawn from this study:

- The number of standards and the details in them increase as the context narrows from the whole railway system to specific projects to account for contextual needs. Furthermore, to control processes at the local level, organisations can substitute existing standards with tailored ones or off-the-shelf standardised solutions. This way, centralisation and decentralisation may be bridged to accommodate local adaptations while still ensuring the efficiency and safety of the overall system.
- Stability and flexibility may complement and reinforce each other. Centralised (stable) processes enabling local flexibility can lead to the emergence of new practices. These new practices can eventually become standardised and contribute to overall stability within the system.
- Rules serve as tools to constrain or direct actions to varying degrees. While the level of detail in a rule, or its level of prescription, is an important mechanism for constraining action, it is not the only factor. Establishing varying levels of rule observance, referred to here as the level of obligation, also influences the degree of control and flexibility. Since these two features of rules are not mutually exclusive, integrating both provides a more nuanced strategy for addressing operational needs for stability and flexibility.

5.8 Limitations and questions raised

The study examines the regulatory framework within the theoretical context presented in Chapter 4. While there are many theoretical and conceptual lenses focused on regulation, such as soft and hard law, this study does not delve into those specific literatures. Instead, it shows the usefulness of considering regulation in safety management research, particularly given the high regulation of safety-critical industries. This analysis highlights the potential for further connections in future research and takes initial steps in that direction.

This study is limited in the depth and detail of the analysis at the organisational level. For instance, while it provides an overview of flexibility concerning Safety Management Systems (SMSs), it does not delve into an actual SMS document. Further studies could employ a similar approach to investigate how flexibility may be embedded – and therefore enhanced – at this level.

Finally, the introduction of transcript data has facilitated the examination of issues related to integrating stability and flexibility in practice. However, two crucial questions have emerged. Firstly, while describing mechanisms to enhance or constrain flexibility is important, understanding the appropriate degree of flexibility to be applied is equally crucial. Secondly, increasing or decreasing flexibility may not have the anticipated impact on safety figures as commonly assumed. While this could be influenced by how safety is measured, it raises questions worth exploring.

6 Study 2 - Bridging centralisation & decentralisation through collaborative rulemaking.

6.1 Chapter Overview

Study 2 is a qualitative investigation using interview and documentary data. It explores centralisation and standardisation, chief mechanisms for stability, by examining the process of producing rail industry standards in GB. The study provides a description that unveils a collaborative process involving actors from across the industry, in which centralisation and decentralisation are integrated. This collaborative approach may support system resilience.

6.2 Introduction

Centralisation and decentralisation, introduced as chief mechanisms for stability and flexibility in Chapter 3, Section 3.4.1, play crucial roles in organisational and safety management. Decentralisation fosters flexibility and adaptation by enabling decision-making at various levels within the system. Centralisation facilitates organisational control by providing a structured framework through which decisions are made and implemented (Grote, 2020). By centralising decision-making authority, regulators and top management can establish and enforce standards and procedures that govern the actions of organisations and their staff, thus fostering stability. In this context, standardisation is a key control mechanism in centralised systems, enhancing stability.

The limitations of standardisation have been broadly debated in safety research, particularly within the Resilience Engineering (RE) tradition. Dekker (2006) argued that standards are an unrealistic representation of the operational realities. He postulates that an operational system can be divided into a sharp-end and a blunt-end. The sharp-end represents frontline operators, such as train drivers or maintenance workers, who execute safety-critical processes. In contrast, the blunt-end comprises regulators or organisations that support and control sharp-end activities, such as train operating companies or the Rail Safety and Standards Board (RSSB). Control mechanisms, such as rules and standards, are devised and enforced by the blunt-end, which operates removed from the operational context and disconnected from operational realities.

Another argument suggests that standards, which represent an anticipatory approach, often constrain immediate action, potentially hindering adaptive decision-making in response to specific contextual needs. The resilience versus anticipation debate, long held in safety research, revolves around whether it is more effective to prepare for unexpected events by fostering adaptive capacity or to proactively anticipate and mitigate risks beforehand (Wildavsky, 1998).

Hollnagel (2014) refers to standardisation as work-as-imagine (at the blunt end) and as work-as-done to the activity as actually happening at the sharp-end. When work-as-imagine is disconnected from the operational realities and restricts adaptability at the sharp-end, the system resilience is compromised, and thus the system safety (Hollnagel et al., 2006; Shorrock et al., 2014; Hollnagel, 2014). This gap between prescription and practice has been discussed in human factors and ergonomics for decades, for example, referred to as 'imagination versus operation' in the 1940s or 'prescribed work versus realized work' in the 1950s (Shorrock, 2016).

Study 1 (Chapter 5) explored the GB railway regulatory framework. It concluded that, while standardisation is conventionally viewed as a mechanism for stability, it also plays a role in supporting flexibility across different system levels, including the sharp-end. The study identified five ways in which the regulatory framework promotes flexibility, illustrating that stability and flexibility can coexist within mechanisms traditionally associated with stability.

Study 2 delves into the blunt-end activity by examining the development of RSSB standards. The aim is to provide a description of the process and investigate the interplay between control and operational realities. In this study, the terms 'rule' and 'standard' are used interchangeably. Rulemaking refers to the process of either developing a new rule to address an existing gap or changing an existing one, which is the most common practice in the industry. Rule-makers refer to the people involved in rule development. The research questions are:

- How does the process of developing RSSB standards come about?

- Who are the actors involved and what is their role in the process?
- (How) are operational realities taken into account?
- (How) does flexibility and stability merge in the process?

6.3 Method

6.3.1 Design and data sources

This qualitative study utilises interviews and documents as data sources. Out of the 26 participants in Study 3, some questions regarding the issue were asked to eight participants who were members of the Traffic Operation and Management Standard Committee (TOM SC). These participants comprised seven men and one woman, with years of experience in railways ranging from 14 to 56 years. Four participants worked for the Rail Safety Standards Board (RSSB), one for the Rail Delivery Group (RDG), one for a freight operating company (FOC), one for a train operating company (TOC), and one was a member of a rail trade union. The documental data were obtained from the RSSB website and included website content and a webinar (Table 6-1).

Table 6-1 Type and name of documental data used in the study

Type of document	Title & Link
Website Content	How to change standards https://www.rssb.co.uk/standards/using-standards/how-to-change-standards [RSSB, 2023. Accessed: 14 May 2024] How industry agrees standards https://www.rssb.co.uk/standards/using-standards/how-industry-agrees-standards [RSSB, 2023. Accessed: 14 May 2024] Traffic Operation & Management https://www.rssb.co.uk/standards/where-do-we-use-standards/traffic-operation-and-management [RSSB, Undated. Accessed: 14 May 2024]

Table 6-1 Continuous

Type of Document	Title & Link
Website Content	Industry Standards Coordination Committee https://www.rssb.co.uk/about-rssb/groups-and-committees/standards/industry-standards-coordination-committee [RSSB, Undated. Accessed: 14 May 2024] Railway Standards Code https://www.rssb.co.uk/-/media/Project/RSSB/RssbWebsite/Documents/Public/Public-content/Using-Standards/rssb-railway-standards-code-issue-5.pdf [RSSB, 2024. Last accessed: 15 May 2024]
Webinar	RSSB Quarterly Standards Update webinar - September 2021 https://rssb.videomarketingplatform.co/video/ 70732165/ 30:17/explanation-of-limited-change [RSSB, 2021. Accessed: 14 May 2024]

6.3.2 Procedure and analysis

Study 3 interview schedule included the question "*Could you tell me about the process of making a rule?*" As participants elaborated on the process, participants were prompted with other questions such as issues regarding consensus or their roles in the committee as representatives of a particular organisation.

The interviews were transcribed using tidy transcription (Henderson, 2018). This technique maintains only complete words and sentences that convey meaning; repeated words and fillers such as 'you know,' or 'uh' are not transcribed. The transcripts were uploaded into NVivo® software and all the extracts containing information relevant to the rulemaking process were selected and grouped in a node[46] for analysis. The analysis was carried out at the descriptive level, without interpretation; participants' accounts were used literally to form a description of the rulemaking process.

[46] In NVivo® software, nodes are thematic categories or labels that researchers create to classify segments of text within a research project.

Once the description was formed, the researcher searched the RSSB website looking for information to complement the description and fill up the gaps, including information regarding Standards Committees in general and the TOM SC in particular.

6.4 Rail Standards Committees

The rail industry has the authority to make decisions about standards. The RSSB produces the standards on the industry's behalf. These standards, introduced in Study 1, (Chapter 5) are: National Technical Specification Notices (NTSNs), Rail Industry Standards (RISs), Railway Group Standards (RGSs), the Rule Book (RB), and Rail Industry Guidance Notes (GNs). Although produced by the RSSB, these standards are managed by the industry standards committees, which decide on their development and content.

There are seven standards committees (SCs):

- **Control Command and Signalling**: addresses engineering interface issues among railway organisations.
- **Data, Systems, and Telematics**: oversees the change control process for the Telematic Applications and supervises the creation and upkeep of documents facilitating data sharing.
- **Energy**: facilitates the development of electrified railway standards, including electric train interface standards and safety guidance for railway electrification operations.
- **Infrastructure**: the cross-industry decision-making body across the railway industry for standards related to track, gauging, stations, and structures.
- **Plant**: responsible for Railway Industry Standards covering the technical requirements for mobile plant for maintenance and construction of the infrastructure.
- **Rolling Stock**: addresses the interfaces between Rolling Stock and structural systems (i.e., signalling, infrastructure, operations and users).
- **Traffic Operation and Management**: examines the interface between the structural subsystems (signalling, rolling stock, track, structures, and electrification) and the people operating them (signallers, drivers, guards, and trackworkers).

The SCs are supervised by the Industry Standards Coordination Committee (ISCC). This committee oversees the SCs' work and provides direction, advice, and guidance on several areas including the management of standards, issues in British, European, and international standards affecting GB railways, and industry strategies and legislation regarding standards.

The Traffic Operation and Management Standards Committee (TOM SC) is central to operational safety. This committee is formed of members from passenger, freight, and other non-passenger train operators, rolling stock companies, infrastructure managers, owners and contractors, suppliers and rolling stock manufacturers, and the RSSB. The Office of Rail and Road (ORR), Trades Unions and the Department for Transport participate as observers. The committee addresses and oversees issues related to:

- train operation
- signalling and infrastructure operation
- workforce safety
- safety management systems
- the Rule Book and other National Operations Publications
- drugs and alcohol policies
- working hours

6.5 The rule-making process

Contrary to the idea of industry rules being developed in a top-down fashion (Hale et al., 2003), rail industry standards follow a transversal pathway in which the different actors that form the rail system participate. The main steps in the rule-making process steps are summarised below and represented in Figure 6-1:

1. Anyone in the industry can contact the RSSB and apply for a rule change. This is called 'a request for help'.
2. The RSSB assesses the request and decides if the change has merits to be pursued.
3. If the request has merits, they elaborate a 'business case for the change' (BCFC), explaining why the change should be made, the cost-benefit analysis or who will be impacted by the change. Different experts such as human factors specialists, technical specialists, and risk assessors participate in building the business case.

4. The business case is presented to the Standards Committee for assessment, which makes the decision on whether the rule change project progresses.
5. If the Committee decides to progress, the RSSB will draft the new rule and send it back to the Committee, which will approve it for consultation.
6. Although minor changes can be consulted and approved among the Committee members, most rule drafts with wider impact will be sent back to the RSSB to start an industry consultation.
7. The RSSB has a consultation stakeholder register of about 300 organizations registered. They will receive the rule draft and have a period to respond and send comments. The RSSB must respond to every comment received[47].
8. The Committee examines the consultation process and the changes made to the draft. If they agree with the changes, they will approve the draft for publication.
9. The RSSB does the final drafting, printing, and distributing of the new rule.

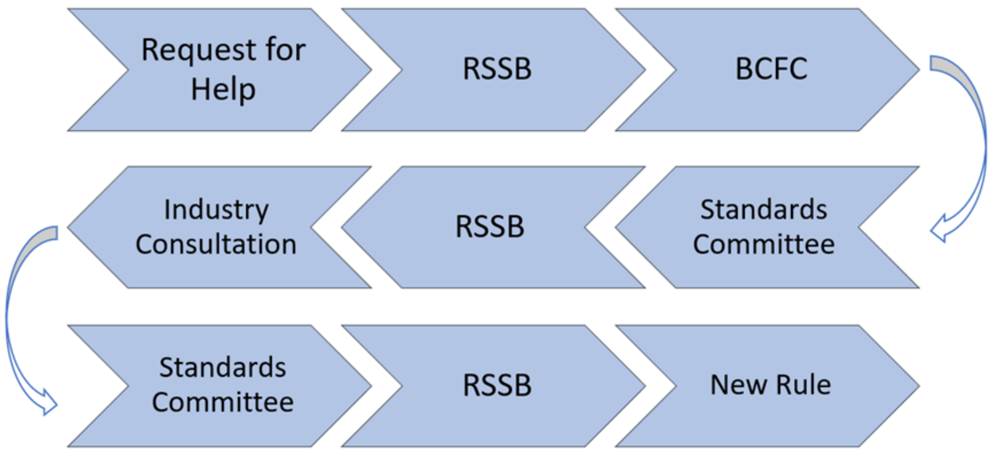

Figure 6-1 GB rail industry standards-making process. RSSB (Rail Safety Standards Board); BCFC (Business Case for Change). Caption: Own source

This description illustrates that rule-making in the GB rail industry is a process a) in which all the different system's stakeholders – i.e., duty holders, industry bodies, regulators, and Trade Unions – are represented and collaborate to produce rules that work for everyone; b) different professional perspectives

[47] More information about the consultation process and changing rail standards is found in the Railways Standard Code link in Table 6-1.

and skills (at a senior level) are part of, and c) that is dynamic and moves back and forth rather than top-down.

The process also demonstrates how central standards (and therefore central control) can be influenced by local practices, triggering innovation and improvement. Rulemaking undergoes a process of centralisation and decentralisation, during which central standards are locally monitored and assessed against local practices. Whenever a standard does not fulfil its purpose, namely guiding activity in a safe and efficient manner, it is reassessed. If an organisation proposes a particular change, this change is examined by the central body, which considers the impact of implementing the proposed change on the safety, efficiency, and financial aspects of the system. However, this 'central' management is mostly distributed rather than centralised, as decisions must be discussed and agreed upon by the different parties that make up the system. Figure 6-2 represents the various stages of the cycle of change and the interplay between local, central, and shared decision-making.

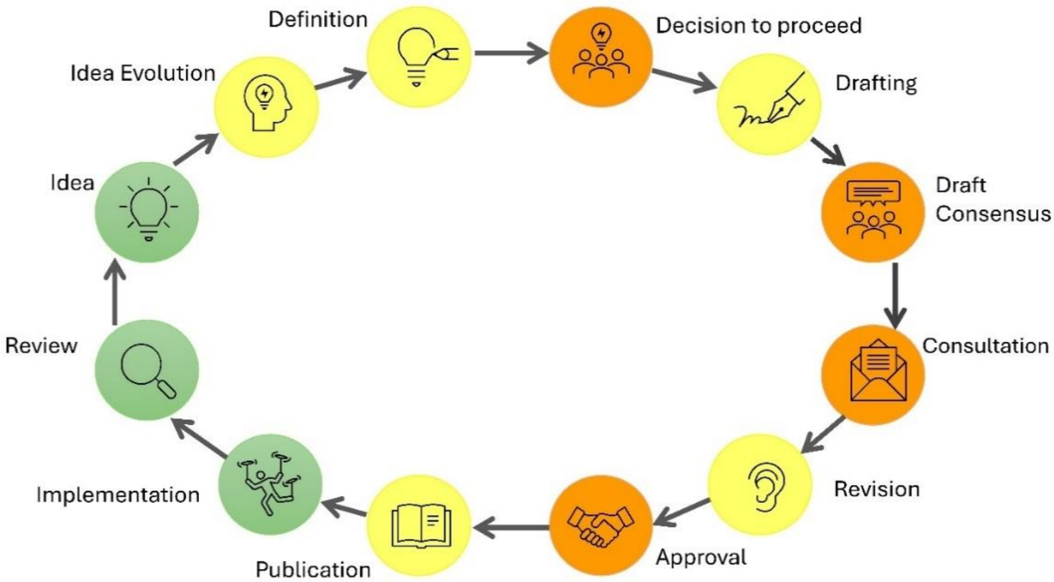

Figure 6-2 Local, central, and shared management of RSSB standards change. Adapted from RSSB Quarterly Standards Update webinar - September 2021

The stages in green and yellow depict local and central decision-making respectively, while the stages in orange represent the integration of centralisation and decentralisation.

6.6 Discussion

The gap between standardisation and actual work has been in the safety debate for decades, being particularly important in the RE tradition. In RE, standardisation is often seen as a potential obstacle to the system's resilience. This study has provided an overview and description of the rulemaking process of railway industry standards in GB. The findings suggest that the often taken for granted dichotomy between blunt-end and sharp-end is not as straightforward as often depicted. The findings also show that central standardisation and local practice can be bridged during the rulemaking process. Furthermore, through a collaborative approach to rulemaking, standardisation may contribute to the system's resilience and bridge the gap between work-as-done and work-as-imagined (Schulman, 1993).

The sharp-end represents frontline operators (e.g., train drivers) and the blunt-end represents those devising and enforcing control mechanisms such as standards (e.g., RSSB and TOCs) (Dekker, 2006). From this follows that regulators and organisations are the rule-makers, while frontline operators are the rule-users. However, this dichotomy does not fully work in all contexts. In the collaborative process here described standards are developed by both rule-makers and rule-users, integrating blunt-end and sharp-end in the process.

The findings also reveal that the central standardisation process is not as hierarchical as often referred to (e.g., Hale et al., 2003; Grote, 2020). The industry ‘owns’ the standards that regulate its activity (RSSB, 2023) and SCs represent the top of the hierarchical structure that monitors, devices and enforces them. Yet, this structure comprises representatives from the different sectors that make up the industry, therefore, authority is not fully hierarchical but rather horizontal, integrating centralisation and decentralisation.

Hale et al. (2003) propose that an optimal rule system should incorporate systematic and frequent engagement of rule users in the process of determining and evaluating rules. Furthermore, involving rule users from across the system with different roles, responsibilities, knowledge, and skills helps to tackle uncertainty. This is because decisions are made by people with complementary skills and different knowledge about the system (Saurin et al., 2013). Uncertainty is also reduced because collaborative rulemaking facilitates a holistic view of the system by bringing together the actors that operate the system's interfacing parts. During rulemaking, these actors assess how changes in other parts of the system may impact their activities and responsibilities. This helps to monitor the effects of changes across the system, providing information critical to maintaining the system's stability.

Likewise, this process maintains some of the advantages of decentralisation, buffering some of the negative effects of centralisation. One such effect is that the stable, repeated behaviours sought by centralisation hinder the flexibility needed to improve and innovate. Another effect of standardising processes and behaviours is that the operational realities faced by the standard users may be neglected. However, in collaborative rulemaking, the operational realities of the system’s local actors are not only considered but are also a source of innovation and improvement brought about by their proposed changes.

Finally, the findings suggest that resilience may be supported through a collaborative approach to rulemaking. The railway is a complex sociotechnical system (CSS) (Ryan et al., 2021), an open system with a wide diversity of connected elements interacting with their environment (Saurin & Sosa, 2013). According to Saurin et al. (2013), resilience is an intrinsic capability of complex systems that can be either supported or hindered by systems design. They put forward six recommendations for the management of CSS, suggesting that the use for the use of the first five recommendations is a means to achieve the last recommendation; that is, to *create an environment that supports resilience*. Table 6-2 summarises the key aspects of Saurin et al. (2013) five recommendations to create such an environment and their relationship with the GB rail collaborative approach to rulemaking.

It is important to notice that, although some of the recommendations represent intrinsic features of collaborative rulemaking, others represent only potentials. For instance, collaborative rulemaking *encourages diversity of perspectives when making decisions* and *anticipates and monitors the impact of small changes*. However, although it *gives visibility to processes and outcomes* and may serve to *monitor and understand the gap between prescription and practice,* this is only fully achievable by a good integration of frontline staff in the process. This integration requires an effort from rail organisations to work with their frontline staff to understand informal practices.

6.7 Conclusion

This study presented the collaborative approach to making rail industry standards in GB. This approach brings together rule users from across the system with different roles, responsibilities, knowledge, and skills to agree on their operational standards, which have the following implications:

- The dichotomy blunt-end versus sharp-end is not always as simple as often portrayed, appearing blurred in this approach in which the rule-users are also rule-makers.
- Collaborative rulemaking appears as a mechanism to integrate centralisation and decentralisation, key mechanisms for stability and flexibility.
- Stability is promoted through central coordination and the holistic view offered by this approach.
- The approach promotes improvement and innovation and takes into account local operational realities, two sought-after effects of flexibility.
- Bringing together diverse actors from across the system reduces uncertainty by providing a holistic view and a variety of expertise.
- The approach has the potential to increase the system's resilience if well implemented. This includes an effort from organisations to incorporate their staff in the process.

Table 6-2 Saurin et al. (2013) recommendations for creating environments that support resilience and their relationship with the GB rail standards-making process

Recommendation	Key aspects	Relationship with rail standards-making process
Give visibility to processes and outcomes	Make visible abnormalities and informal work practices that are part of normal work, and the context that promotes them, as they often contribute to producing expected outcomes.	The rule-making process starts by putting forward rules that are not fit for purpose or informal work practices that contribute more efficiently to desirable outcomes, giving visibility to these practices and the context in which they occur.
Encourage diversity of perspectives when making decisions	Including the diversity of agents that work the system helps deal with uncertainty and complexity. This requires high levels of trust, identification of the most suitable decision-makers, and the reduction of power imbalance.	The rule-making process in GB Rail exemplifies the diversity of agents that can be involved in rules development. Trust and good relationships may be preconditions for including such a diversity of agents, but they are also a product of the agreement process.
Anticipate and monitor the impact of small changes	In complex systems, local optimisations may result in undesired global outcomes. While significant changes are carefully planned, that may not be the case for small changes, which impact might be underestimated.	Since the RSSB and the Committee must approve small changes, the impact of the changes on other parts of the system is anticipated.
Design slack	Introducing slack in the design reduces tight couplings, helping to absorb the effects of variability.	Tight coupling can be reduced through flexible rules, but allowing autonomy brings accountability concerns and requires high levels of trust. A collaborative rule-making process may offer the space to discuss these issues.
Monitor and understand the gap between prescription and practice	Standardised procedures reduce complexity by reducing unanticipated variability. Yet, they cannot cover all possible situations, creating the need to fill in the gaps.	Including frontline staff in the rule-making process promotes monitoring the gap between prescription and practice as work-as-done to fill the gaps is exposed. This requires a culture of trust in which staff can feel confident to openly talk about informal practices, and top management trusts staff to manage the uncovered situations in the first place.

7 Study 3 – Stability and Flexibility in Operational Management: A Rule-Makers' Perspective

7.1 Overview

The present interview study delves into the knowledge and expertise of individuals involved in standards development (here called rule-makers) to further explore stability and flexibility in rail operations management. The investigation includes querying into the factors that contributed to the efficient and safe management of rail operations during the COVID-19 pandemic. Thematic analysis revealed five themes representing how two key mechanisms for stability and flexibility – centralisation and decentralisation – serve railways operations management. The study also presents factors that contributed to operational management during the pandemic crisis.

7.2 Introduction

As discussed in the literature review[48], railways are complex socio-technical systems (CSS). These systems comprise a vast and diverse number of connected technical, organisational, economic, and human components. Furthermore, railways expand across regional, national, and cultural boundaries and, as an industry, the railway system is highly influenced by a complex socio-economic and political context (Wilson, 2014; Carayon, 2006; Lofquist, 2017). Part of these complexities were overviews in Chapter 2, which introduced the railway system in Great Britain (GB). Two important changes affecting the rail industry were introduced[49]:

- Devolution, involving Network Rail (Network Rail) decentralisation of key business functions to the five regions comprising the GB railway network.
- The Williams-Shapps' Plan for Rail (DfT, 2021) aims to replace the current franchise system and establish Great British Railways (GBR) as a single entity to oversee infrastructure ownership, fare revenue, network operation, planning, and fare/timetable setting.

These two changes, somewhat contradictory, involve, on one hand, the decentralisation of infrastructure management and, on the other hand, the

[48] Refer to Chapter 3 Section 3.2.2
[49] Refer to Chapter 2 Sections 2.4.1 and 2.6

recentralisation of key system functions. Centralisation and decentralisation were introduced in Chapter 3, Section 3.4.1, as chief mechanisms for stability and flexibility, respectively. It was highlighted that research often approaches centralisation and decentralisation in terms of decision-making, namely, whether decisions are made centrally or locally (e.g., Grote, 2020; Monteiro et al., 2020; Jia & Nia, 2017). Centralisation is also equated to control, referring to the implementation of decisions made by executive teams, either formally through the standardisation of processes and procedures or informally through organisational norms and values. Likewise, the term "local control" is used to refer to decision-making autonomy by frontline operators or local business units (McDonald, 2006; Sitkin et al., 2010; Grote, 2020).

Influential safety research has treated the impossibility of concurrently achieving centralisation and decentralisation as a key cause of 'normal accidents' in safety-critical industries (Perrow, 1999). Yet, several examples have been put forward in organisational and safety research demonstrating that centralisation and decentralisation, as well as stability and flexibility, can be integrated (e.g., Brown and Eisenhardt, 1997; Kanter, 2008; Weick, 1976; Orton and Weick, 1990; O'Reilly and Tushman, 2013). The rail industry's resilience during the COVID-19 pandemic serves as a practical demonstration of simultaneous stability, ensuring rail operations functioning within the safety boundaries, and flexibility to swiftly adapt to unforeseen challenges.

The current study further investigates stability and flexibility in rail operations, this time from the perspective of individuals involved in rulemaking. It examines stability through centralised control and standardisation (centralisation) and flexibility through local control (decentralisation). The focus is twofold: on one hand, it examines these two key mechanisms for stability and flexibility (centralisation and decentralisation); on the other hand, it investigates operational needs for stability and flexibility through the management of operations during the COVID-19 pandemic. The research questions are:

- How do centralisation and decentralisation contribute to ensuring safe and efficient operations in the railway industry?
- How do centralisation and decentralisation merge or integrate in rail operations to adapt while maintaining safety?

- What are the sources, preconditions, and barriers to stability and flexibility?
- What factors contributed to achieving stability and flexibility in rail operations during the pandemic crisis?

7.3 Method

7.3.1 Design and participants

A total of 26 rule-makers participated in the study. Except for two participants who were interviewed together[50], each participant took part in an in-depth, semi-structured interview lasting between 50 and 180 minutes. The 26 participants comprised six females and twenty males involved in the development of railway operational standards, working for a total of 12 rail organisations. Their experience working for the railway industry ranged from 4 to 56 years, and with experience in their current role ranged from 6 months to 36 years. Their roles and the list of participating organisations are included in Table 7-1**.** Table 7-2 summarises their years of experience in the industry and in their current role.

Participants were recruited and interviewed in three cycles. The first cycle started in October 2021 by contacting the RSSB, seeking collaboration for the research project. A first meeting was held in January 2022 with a contact in the organisation (i.e. the gatekeeper) to provide full details on the purpose and context of the study and to ask for support in identifying potential participants. The gatekeeper introduced the researcher and the study to the first participant, and through snowballing, another four participants were recruited. They were contacted directly via email and interviewed between February and June 2022. Three other participants were contacts provided by the researcher's supervisor.

A second cycle of recruitment started in September 2022 by contacting previous participants who offered their help if further participation was needed. Another seven participants were recruited and interviewed between September and December of that year.

The third cycle of interviews took place between March and April 2023. The recruitment process started 10 months earlier (May 2022) after contacting

[50] These two participants worked in the same team and preferred to be interviewed together.

Network Rail, asking for collaboration in this PhD project[51]. A first meeting was arranged with the gatekeeper for November 2022. The gatekeeper introduced this interview study to various potential participants and provided email contact details to the researcher, who contacted them directly. Several interviews were arranged, and through snowballing, other participants were identified, contacted by email, and recruited. In total, ten interviews with eleven participants were conducted during this cycle.

Table 7-1 Participating organisations and participants' roles

Organisations	**N=**
ORR	1
RSSB	5
RDG	1
RAIB	1
Network Rail	10
Infrastructure Constructor	1
Freight Operating Company (FOC) (x2)	2
Train Operating Company (TOC) (x2)	2
Train Manufacturing	1
Rail Union	2
Participants' Roles	
Train Driver & Union Representative	2
Head of Driver Projects & Assurance	1
Head of Department for Operational Stds (Freight)	1
Senior Operations Standards Manager (Freight)	1
Business Continuity & Emergency Planning Lead	1
Safety & Reliability Engineer	1
HSQES Director	1
Head of Operations	1
HF Specialist Inspector	1
HF Accident Investigator	1
Principal Rail Operations Specialist	3
HF Specialist	1
Director of Standards	1

[51] Network Rail was contacted asking for collaboration in this interview study and the case study presented in this thesis.

Table 7-2 Participants' years working in industry and years in current role.

Range years in the rail industry	N=	Range years in current post	N=
0 – 9	2	0 – 9	16
10 – 19	8	10 – 19	6
20 – 29	6	20 – 29	1
30 – 40	5	30 – 40	1
40 – 50	1	40 – 50	
50+	2	50+	
Range 4 to 56 years Mean = 18 years		Range 6 months to 36 Years Mean = 8	

7.3.2 Procedure

Only one interview was conducted face-to-face, which was recorded using an iPhone 7®. The other 24 interviews were conducted and recorded using Microsoft Teams®. Since participants were geographically dispersed across England, telephone and video call interviewing were two readily available options. Video calling appeared the best option because it combines the advantages of telephone and face-to-face interviewing (Gillham, 2000). Before the interviews, participants received a document with details about the nature and purpose of the research, what they were expected to do, and the measures taken to ensure their anonymity and data protection. Participants were also asked to provide signed consent for participation.

The interviews mostly focused on operational rules and standards, as these serve as tangible tools where stability and flexibility are put into practice. Using practical tools as proxies to investigate theoretical concepts offers several advantages. Firstly, the concepts of stability and flexibility may be too abstract and unfamiliar for the interviewees to engage. Furthermore, studying concepts without a practical instance leaves them decontextualised, without examples or connections to real-world situations (which also makes it harder to apply the findings to real contexts).

While some interview questions addressed the topic of decentralisation, another reason for focusing on rules and standards is that standardisation is a primary tool for control, providing a means to delve into issues around centralisation. Rules and standards are also ubiquitous in railways; every aspect of the operation is regulated. Therefore, these practical tools allow for a holistic approach to railway operations.

The interviews began with three questions regarding participants' backgrounds and concluded by inviting them to add or ask anything they would like to. The main body of the interview schedule was organised by topics, featuring one to three open-ended questions per topic to encourage participants to share their experiences. Topics included general questions about rules and standards, rulemaking, COVID-19 and devolution. Is important to note that not all topics were covered in each interview. For example, not every participant had experience regarding devolution, and some participants had little or no involvement in COVID-19 management.

As participants elaborated on their accounts, the researcher allowed them to share freely, probing for additional information. Sometimes, to avoid interrupting participants' narratives, the researcher would make notes on relevant issues to go back and explore later in the interview. Given the diverse roles, backgrounds, and expertise of participants, the interview schedule was tailored individually. This approach allowed the researcher to take full advantage of the rich and diverse experience of the sample. It also provided the opportunity to follow up on leads from earlier interviews, further exploring issues raised by previous participants. The interview schedule structure with some examples of questions is included in Table 7-3. It also includes examples of the type of probes and follow-up questions employed during the interviews.

7.3.3 Analysis

The interview data were analysed using a Thematic Analysis (TA) technique guided by Braun and Clarke (2006), although not in strict conformity[52]. Braun and Clarke (2006) recommend a flexible approach to TA but underscore the significance of transparency and honesty in documenting the analysis process. The next subsection includes a detailed account of the six stages and steps followed during the analysis. The insights of Braun and Clarke (2006) on avoiding pitfalls and ensuring high-quality thematic analysis were considered during the analytic process (Appendix II).

[52] Refer to Chapter 4 Section 4.5.2.3 for more details about this choice.

Table 7-3 Interview schedule structure with examples of questions

Introduction
How many years have you been doing this job? Could you tell me about your background? What do you do in your job?
Main body
Rules and standards in general Could you tell me about the use of rules in the railway and why they are important? What do you think makes a good, useful rule or standard? What would you say are the limitations of rules and standards? And do you think there are ways to overcome those limitations? Do you think there is a role for rules and standards in increasing the flexibility of the railway? **Rulemaking** Could you tell me about the process of making a rule? In your experience, what are the main challenges of making rules? **COVID-19** What do you think helped the successful management of rail operations during the pandemic? **Devolution** How is devolution affecting your organisation?
Closing questions
Is there anything I haven't asked that you would like to bring up? Is there anything you would like to ask?
Probes and follow-up questions
That's very interesting. Could you give me an example of that? And how do you think that could be dealt with? You said before... could you tell me more about it? And why do you think that happens?

7.3.3.1 Thematic Analysis stages

1. Familiarisation:

The analysis began with the familiarisation stage, involving the transcription of interview recordings using tidy transcription (Henderson, 2018). According to Braun and Clarke (2006), Thematic Analysis (TA) transcripts do not require the same level of detail as other analytical techniques. Tidy transcription focuses on content rather than the structure of speech, maintaining only complete words and sentences that convey meaning. Repeated words and fillers such as 'you know,' 'um,' or 'uh' were not transcribed.

After transcription, the researcher read and reread the transcripts, writing down thoughts, questions, ideas and first impressions. The familiarisation stage was done as soon as possible after each interview and sometimes involved re-listening to parts of interview recordings.

2. Generating initial codes:

The initial analysis of the data involved annotating the transcripts in the margins to paraphrase the main ideas using the researcher's own words. This analysis was purely descriptive and looked at how phenomena happened: for example, who does what, how it is done, what the rules are for, what the operation comprises, and so on. The accounts were broken into units of meaning, which could entail a few words or sentences. As the units of meaning were written, codes (a few words) were assigned to each one, reflecting their semantic or latent meaning. This initial coding was done manually, and the initial code list was introduced into an Excel® spreadsheet.

3. Searching for themes:

The codes in the spreadsheet were sorted and collated into groups. For example, codes such as cost/benefit, increasing performance, reducing costs, and so on, were grouped under the group ‘efficiency’. Another group, ‘relationships’, grouped all codes referring to building good (work) relationships, breakdown of relationships, informal conversations, etc. Potential themes started to emerge. At this point, only the first cycle of interviews was completed. The interviews were uploaded into NVivo® software and no further analysis was done until the new interview data was collected.

After the data for the second interviewing cycle were collected, it was analysed following the three stages described (familiarisation, generating codes and searching for themes). There were only two differences with the previous analysis: 1) the coding and searching for themes were performed using NVivo® software; and 2) when the coded extracts matched an existing potential theme, it was utilised. Consequently, some of the new data were coded deductively using pre-existing potential themes, while others were coded inductively, leading to the emergence of new potential themes. This analytical process was repeated in a similar manner after the completion of the third cycle of interviews.

4. Reviewing themes:

At this stage, there were numerous potential themes. Some of those themes were abandoned because they did have not enough supporting data (e.g., containing only a few extracts or extracts that did not form a consistent pattern). The remaining, stronger candidate themes were then examined individually and in relation to each other. Individually, the consistency of each extract within its respective candidate theme was assessed. Extracts that did not align fully were either recoded into other candidate themes or removed from the analysis. In relation to each other, the themes were examined looking for overlaps or similar patterns, resulting in some themes being collided.

Afterwards, the researcher reviewed each candidate theme in relation to the research question to ensure that it was meaningful to the analytical framework. She printed all the extracts in each theme, reading them again and asking further questions to the data (e.g., what the patterns in the theme really meant in terms of stability, safety or flexibility). These questions aided the researcher in moving from descriptions and considering the stories behind the themes. During this part, mind maps were used to explore further relationships, links, and overlaps between candidate themes. These mind maps helped the researcher in interpreting and making sense of the data and the stories. For example, the relationship between safety and performance or between rules, culture and change started to unveil; overarching themes meaningful to the research question emerged. Again, some candidate themes were abandoned after this review. For example, the theme 'change' contained rich, coherent data telling an interesting story. However, as a theme, it was disconnected from the analytical framework, being not fully meaningful to the research question. Yet, many of its extracts appeared meaningful to other themes and were recoded.

5. Defining and naming themes:

The core or essence of the overarching themes were written down as bullet points along with some representative quotes, which were arranged and rearranged to form a coherent narrative. Subthemes were identified and used to give structure and clarity to the narrative. Finally, themes were ordered to enhance the relationship between them and the storyline they narrate.

6. Producing the report:

The final stage of the analysis occurred during the writing-up of the report. This was a challenging stage because the full analytic narrative was not fully revealed until the themes and subthemes were fully developed as a written report. Then, it was obvious that further refinement was needed, including going back to some of the stories set aside as they appeared to fit better now in the overall narrative. This way, the themes' final reviewing, defining, and naming took place, and the final report was produced.

7.3.3.2 Analysis of COVID-19 related data

As shown in the interview schedule, one of the interview questions approached the management of the COVID-19 pandemic. Data arising from these questions were part of the dataset undergoing TA. However, participants' experiences and perceptions regarding railway operations during the pandemic crisis provided an interesting, illustrative, and practical example of stability and flexibility in action. In a first instance, it was considered to add the analysis of these data as a theme, but this option was discarded for two reasons. Firstly, using one of the interview questions as a theme is one of the pitfalls of TA pointed out by Braun and Clarke (2006). Secondly, using the participants' experiences as a narrative offered a unique opportunity to contextualise some of the present findings within a real case scenario. Furthermore, the narrative also provides an illustrative real example of the industry operating under conditions of high flexibility and high stability, which directly relates to one of this thesis objectives (Objective 2).

To produce the COVID-19 narrative, the extracts from the transcripts regarding the pandemic were collected into an NVivo® node and printed. The analysis was done with the following question in mind: *What enabled rail organisations to continue operations during the pandemic crisis?*

The researcher familiarised herself with the data and generated a set of initial codes, following a process similar to stages 1 and 2 described above. Subsequently, patterns within these codes were identified and grouped to represent the factors aiding organisations in navigating the challenges posed by the pandemic. These factors, along with representative quotes, were organized in a Word® document. Although the TA findings did not guide the analysis of the COVID data, an overlap between the factors and the TA findings became evident. Consequently, a further analysis examined the correlations between the factors and the TA themes. Finally, the factors were presented in two formats: compared to the TA findings and as a narrative with illustrative quotes. Reporting the findings as a narrative, rather than organized by factors, allowed for capturing the interactions and overlaps occurring between factors in a real-world context.

7.4 Thematic analysis findings

The thematic analysis of the data resulted in five high-order themes, all including various subthemes. The importance of centralisation in maintaining a holistic view of the system is captured in Theme 1. Theme 2 gathers issues around local control in terms of decentralisation and here-and-now adaptations. The relationship between safety and performance is approached in Theme 3 and Theme 4 relates to the relationship between rules and culture. Finally, Theme 5 reveals the importance of social processes such as collaboration, good relationships, and trust in enhancing stability and flexibility. The themes and subthemes with a brief description of the latter are summarised in Table 7-4.

Table 7-4 Summary of themes and subthemes resulting from the TA

Theme	Subtheme	Brief description
1 – One system, one whole	*Creating consistency*	Consistent rules and behaviours core to coordination and operational interoperability
	Global problems, global solutions	Centralised solutions to system-wide problems beneficial in terms of cost, reliability, and fairness
	Consequential risk	A holistic view of the system core to managing consequential risk
2 – One system, many contexts	*Locals know better*	Decentralisation devolves control over business functions to regional management
	Dynamic adaptations	Because rules are fallible and contexts unstable here-and-now decisions are needed
	Barriers to autonomy	Issues around accountability and attitudes towards prescription a barrier to flexibility

Table 7-4 Continuous

Theme	Subtheme	Brief description
3 – The system is performance focused	*Safety is a quality of the system, not an end*	Rules and standards are made for performance; safety is embedded
	Safety is a precondition to performance	A high-performing system must be safe since incidents and accidents impact performance
4 – Rules and culture	*The culture is in the rule*	The organisation's approach to safety culture can be conveyed in the rules and could be changed by changing the rules
	Fair culture	Fair culture is key to increasing flexibility in rules and standards (and thus in processes and behaviours)
5 – Social processes	*Rail groups*	Inter-organisational collaboration has an important function in maintaining a holistic view of the system. Good relationships enhance collaboration
	Trust	(Mis)Trust mediates in people's attitudes towards rules and flexibility. Interprofessional trust important for flexibility

7.4.1 Theme 1: One system, one whole

This theme encapsulates a clear pattern appearing across the data: the crucial role of centralisation in taking a holistic approach to the management of rail operations. The data showed various reasons why holistic management is important, which are presented within three subthemes.

7.4.1.1 Creating consistency

> *'We have an awful lot of interfaces between different systems in the railway industry. The infrastructure is managed by one company. The trains are operated by a range of other different companies. Then you have various different contractors and other organizations who get involved in that mix as well.... wherever you get an interface between two of those*

organizations, it's really important that everybody knows how that interface is managed... to get the whole thing to work properly it's really important that everybody knows what they're supposed to do, and that everybody's behaving consistently'. [Participant 101 – Regulator]

The quote above represents a persistent pattern found across the data. Establishing consistency throughout the system appeared as paramount to rail operations management. Interfaces are pervasive in railways and consistent performance plays a pivotal role in coordinating activities at those interfaces. While organisations can coordinate their operators and processes through company or project standards, centralised standards are core to coordinating activities across the many system interfaces. This coordination not only arises from the prescriptive aspect of standards but also from the predictive one: standards both guide the users' behaviour and tell them how they should expect others to behave. Furthermore, the process of creating centralised standards provides descriptions of how the system components and actors interact, which in turn act as the blueprint of the entire operation:

'We have a set of standards that cover the operation of the whole system... how it works and how we work it'. [Participant 101 – Regulator]

Maintaining consistent processes across the system is also core to interoperability. Operational interoperability may be described as the capacity to sustain efficient operations across system boundaries. Several participants highlighted the relationship between system-wide consistency and achieving effective operational interoperability. Consistency appears to assist interoperability by facilitating cognitive processes such as the capacity to manage, remember, and apply information, this way minimising the chances of error:

'It's a lot easier if you just have to remember one thing, than if you have to remember a different thing for wherever you are.' [Participant 601 – Train driver]

Many of the examples highlighting the detrimental effects of losing consistency and interoperability arose from accounts relating to the decentralisation of the Network Rail function, the so-called devolution, and the subsequent possibility of fragmentation:

> *'If someone goes from one area and working into another area, do they have to relearn a whole set of processes? Is it the safest way? Is it the most efficient way? Is it the most cost-effective way? You've got all of these things and, how do you manage the competencies?'* [Participant 500 – Infrastructure management]

> *You've got a national contractor... [They] potentially have to apply different rules depending on where they are geographically. First risk is that they apply the wrong rule. It immediately gives rise to a hazard which can, of course, lead to an incident.'* [Participant 105 – Regulator]

Participants elaborated on the advantages and disadvantages of devolution, with some participants expressing a favourable view while others showed their resistance. The one common point of agreement, nevertheless, was the importance of avoiding fragmentation by maintaining a holistic view of the system:

> *'With Devolution you get an element of fragmentation which brings risk... Rail is a highly interconnected system and if you've got breakdowns in communication between the various actors within the system then, potentially, you've got safety risks, and that's why you need a sort of overarching view of this across all of the different operators, owners and local government bodies'.* [Participant 105 – Regulator]

7.4.1.2 Global problems, global solutions

Every organisation encounters challenges when operating their business and must devise solutions to overcome them. In rail organisations, where staff bear safety-critical responsibilities, the need for solutions to control risk is regulated by law. One instance is addressing human factors like fatigue. Although every organisation has leeway to manage the issue, the problem is common to every rail organisation; for example, train drivers' fatigue management is common to all train operating companies (TOCs). Centrally standardised solutions (i.e., central standards) are cost-effective for organisations since they can use the centralised standard, such as a fatigue standard, rather than having to invest in its development. The benefits are not only in terms of cost-efficiency but also reliability since they are developed and tested by human factors specialists. The next quote regarding custom marks[53] illustrates this argument:

> *'you don't have to reinvent the wheel every time a situation occurs... before, organisations had to spend a lot of time, money, resources in setting up a process to create new signs and by having a standard... they can just follow the process... So there is a huge benefit on harmonizing practices'.* [Participant 103 – Regulator]

Notice that standardised solutions are not necessarily the same as centralised solutions. A centralised solution is something agreed to be used (or imposed upon) by all the organisations in the system. A standard is a tested, reliable solution but is not necessarily used system-wise. While both are reliable and cost efficient, only centralised solutions facilitate operational interoperability, as highlighted above.

The benefits of industry standards are even greater for smaller organisations that may have fewer resources. For example, a participant mentioned that *"very few railway companies have human factors specialists"*. Therefore, the advantages are not only at the financial level, but it has an element of fairness by facilitating resources equally. Furthermore, centralising certain functions is crucial to prioritise collective interests over individual ones, as this participant explained:

> *'Any organisation is not going to fund R&D unless that organisation is going to benefit. And there are a few things where it needs one organization to do something for the benefit of another organisation. And naturally, that wouldn't happen even though it may be the right thing to do and a good idea."* [Participant 105 – Regulator]

Rail organisations are obliged to operate safely, being responsible and accountable for the management of the risks associated with their activity. Yet, the data revealed that the rail industry as an entity seems to perceive a societal responsibility to fulfil. Examples from the data include the protection of railway staff, the people and goods that they transport, the environment, the infrastructure and the tax-payer money. The next quote refers to personal

[53] Custom marks are the signs at the platforms that indicate the train driver where to stop.

track safety, a provision every company whose staff works on or near the track must include in their safety management system. The participant reflects on an accident that cost the life of a rail worker. It highlights the industry's feelings of responsibility to provide solutions to risks that affect system-wide:

> *'there is no standard for that... everyone has done something differently. And that's a gap. That's not to say what they're doing is unsafe, but whether I'm walking around the railway depot in Scotland, or walking inspecting a train in York... the principles are the same... We, as an industry, we have no standard for that... the risks that people should be aware of when wandering around dangerous locations on the railway. And this person was crushed to death between two trains.'* [Participant 201 – Regulator]

7.4.1.3 Holistic view of risk: consequential risk

This theme so far has elaborated on the importance of maintaining a holistic view of the system to rail operations. Much of this global view is provided by centralised standards. Yet, the data revealed a contradictory pattern showing that centralised standards may not always promote that holistic view and adversely affect operations. This is related to the management of primary and secondary risks.

Industry standards are centrally developed based on hazard control for primary risks, namely direct risks restricted to the local context. Although as discussed earlier many standards control and coordinate the activity at interfaces, they neglect the impact those controls may have somewhere else in the system. This 'emergent' risk is called secondary or consequential risk, and the industry is directing efforts to its understanding and management:

> *'Historically, the railway's response when something happens: stop running trains. We're now at a point where if something happens we won't stop running trains because the risk of stopping running trains is actually greater than the primary risk of the failing in the first place. And that's a journey that we're on, and that we need to continue doing. And it's a reason why some of the stuff that's written in standards as a control for a primary failure is bonkers.'* [Participant 201 – Regulator]

Participants' examples of consequential risks emerging from cancelling or delaying trains include detraining [54] and risks related to platform overcrowding[55], including increased risk of slips, trips and falls, staff assaults, etc. In the next quote, a participant gives a good explanation of this shift, using an example of a study on the failures of the train radio system. The quote exemplifies the emphasis some participants placed on taking a holistic approach to risk management:

> *'Traditionally, we would have treated [the radio system] as a safety critical piece of equipment and we'd take the train out of service at the earliest opportunity... We looked then at the risk that the radio is mitigating... And we looked then at the wider picture and found that the secondary risk was actually greater than the risk that we were mitigating in the first place... And that analysis we did there was based on the whole system risk.'* [Participant 105 – Regulator]

The data shows that keeping trains running to managing consequential risk requires an increase in flexibility. The more flexibility there is, the more important it becomes to maintain a holistic view to understand how those flexible actions may impact the global operation:

> *'My point of view as a train driver was, I was worried about my train, that train, those passengers... if you're gonna step it up and use degrees of flexibility and discretion, I think you need somebody who can see and understand, "OK, if I do this or if I don't do this, these will be the impacts". And for me, the only people really placed to do that are the control teams, who have that wider view of the network as a whole.'* [Participant 301 – TOC]

The quote above illustrates another aspect of holistic management found in the data: a holistic approach implies going beyond the 'tangible' part of the

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[54] Detraining refers to a passengers' behaviour in which they force open the doors and leave stopped trains before they arrive at the platform.

[55] Note that most passengers' fatalities occur at train stations. A passenger is a person on railway infrastructure who intends to travel, is in the process of travelling or has travelled. The last fatal train accident registered in GB was 4 years ago due to the derailment at Carmont in August 2020, in which one passenger lost their life. In the same 4-year period, 12 passengers have lost their lives at train stations (ORR, 2023; available at https://dataportal.orr.gov.uk/statistics/health-and-safety/rail-safety/).

operation to include other aspects that play a key role. One of the most salient aspects found in the data is the management of people's *worldviews* about how the system works, what are the risks and what is their role and the role of others in managing those risks:

> *'we've done the analysis and we have basis on engineering judgment and these analyses. Then the operator, they have to take the risk of running the train... and then say, "oh no, there's a brake failure. We have to stop the train". Whereas we, as the train manufacturer would say, "well, actually, it's perfectly safe to operate in this scenario... there's nothing wrong with operating the train"'* [Participant 701 – Train Manufacturing]

Other examples found in the data of the factors playing a role include competence management, power relations or motivations to use new technologies:

> *'The more flexibility you have, the better... but it results in a shift in that decision making... from the driver who, traditionally, we focus on training and competency elements, to our control teams. And we're probably at a stage where there might be a bit of a gap between the levels of training and competency we put into our control teams versus the level of training and competency we put into our train drivers.'* [Participant 301 – TOC]

The management of consequential risk exemplifies the criticality of maintaining a holistic view of the system because local action may have global repercussions. Centralised standards play a critical role in operational management; however, their focus on primary risks may have knock-on effects that hinder safe operations. Much of the impact of secondary risks appears to be buffered by the work of control teams, which is explored in Chapter 8. Yet, as one participant stated, consequential risk...

> *'is a fascinating area, and I think one that there's a long way to go, but essentially, our standards are bound by the railway system, so we need to take a whole system view.'* [Participant 105 – Regulator]

7.4.2 Theme 2: One system, many contexts

Despite the importance of taking a holistic approach to rail management, the data analysis also showed the significance of local control to adapt to the context. Local control involves a degree of autonomy or flexibility to deviate from the centrally established ways of operating. In the interviews, local control appears in three main ways: devolution (i.e., decentralisation), standards variations and derogations, and dynamic adaptations (i.e., here-and-now decision-making to adapt to contextual needs). Variations and deviations were discussed in Chapter 5 Section 5.4.2.3 and will not be further explored here. This theme elaborates on participants' perceptions and attitudes on devolution, dynamic adaptions, and potential barriers to increasing local control.

7.4.2.1 Locals know better

Devolution refers to the decentralisation of Network Rail, which involves a permanent shift of control in which regional management takes ownership and control over many of the business functions. Under this arrangement, the managing directors of the regions have decision-making powers and are responsible and accountable for their specific area. Participants' attitudes towards devolution were mixed. On one hand, participants generally recognised the advantages of local control, which they justified by citing the contextual disparities among regions. They pointed to variations in local risk profiles, resources, customer bases, and business requirements, among others, and stressed that managing these contextual factors requires local knowledge that people at the centre lack:

> *'if you are truly to operate in a region with all of your customers, the only way to do that is to know your region and the way your region needs to operate. And I don't think people in the central functions can know that.'* [Participant 501 – Infrastructure management]

> *'one of the points of devolution is let the region talk to their own people... They should do it because they know their own people. That's the point of devolution is deal with your people, both your stuff, both your passengers, your neighbours, because you understand them, you're closer to them, you know them.'* [Participant 503 – Infrastructure management]

On the other hand, participants considered the potential risks associated with operating a fully decentralised system. Various participants suggested that without a centralised Technical Authority to harmonise practices, the system's complexity would escalate, introducing new challenges for operating companies, constructors, and frontline operators. Some even questioned the feasibility of complete decentralisation:

> *'you can't have interoperability across five regions if you all have a different procedure for doing that. You will still have to have national standards'.* [Participant 501 – Infrastructure management]

Devolution and interoperability challenges were introduced in Theme 1 (Section 7.4.1.1). Beyond issues of interoperability, one participant stated that *'from a cultural point of view, [devolution] is entirely detrimental.'* They expressed concerns about how devolution is already causing fragmentation in the organisation's core values and pointed out the danger that it entails:

> *'someone told me, "oh, you're using the old core values". I said, "no, I'm not using the old core values, these are the current ones". They thought, and they said, "oh, yeah, because in [region] we've got different ones". How is this allowed?!'* [Participant 503 – Infrastructure management]

> *'On my opinion. There is no alignment to anything central, to any central culture, to any central authority. It's really dangerous.'* [Participant 503 – Infrastructure management]

7.4.2.2 Dynamic adaptations

This subtheme encapsulates a recurring pattern in the participants' narratives regarding local control: the unstable, dynamic conditions in which the railway operates, and the imperative for flexibility to swiftly respond and keep the system going. Participants cited numerous disruptive events[56] the system encounters, portraying dynamic adaptations as a normal part of the system's operation:

[56] Disruptive events refer to events that disturb the smooth running of the system. They may be due to extrinsic factors such as weather conditions, or intrinsic such as breakdowns or decreased resources (e.g., staff).

> *'If you consider just what we do as the rail industry, though, today really heavy rain out there, next thing we know, flooding, tree falling down, the timetable is falling apart, we've got to adapt. So we reschedule trains, we rescheduled drivers, we reschedule guards, we look at crewing.... We're very well versed in reactionary contingency management. Whenever something goes wrong, we have people in the business that know what needs fixed, know what needs to change.'* [Participant 302 – TOC]

The successful resolution of a disruptive event rests on individuals' ad hoc decisions to rearrange organisational resources and readjust the plan. However, these decisions are not purely improvised. Most disruptive events are unexpected concerning when and how they occur, rather than what they entail. In other words, they often happen at unforeseen moments and the specifics of how they unfold may vary, but they are anticipated. Consequently, rail organisations maintain standardised contingency plans to address most disruptive events. Yet, these plans are only a starting point, and the ability of individuals to effectively manage the unique aspects of each event remains paramount.

Dynamic adaptations are also core to everyday operations when rules fail. Participants' perceptions of the fallibility of rules are unanimous. They acknowledged that rules cannot cover every scenario and, sometimes, safety depends on frontline here-and-now decisions to deal with the situation:

> *'you can't always have a rule for every situation. So sometimes staff are going to be faced with situations where they have to make a decision.'* [Participant 101 – Regulator]

From the narrative, this type of failure seems to occur occasionally, and frontline decisions appear to play a central role in maintaining safety. However, participants also pointed out another way in which rules fail, involving a mismatch between the resources required to accomplish the standardised process and the actual resources available. In the narratives, this failure appears more common in relation to infrastructure maintenance. This is illustrated by the following quote in which the participant holds a conversation with a site work supervisor:

> *'I wanted to know, in the standard, how many people did it need take to pick up a 30 foot piece of rail ... And he [the track supervisor] said to me, "well, it depends how many people you've got at work ... if there's four of you, it will be four. If there's eight of you, it will be eight ... we just pick it up and get it done" ... Then I had to say "no, what does it say in the standard?" And he didn't know what it said in the standard... obviously from a safety point of view, this is a nightmare, because if it's four people every time, then they're going to get injured.'* [Participant 505 – Infrastructure management]

7.4.2.3 Barriers to autonomy

A salient obstacle to autonomy revealed in the data is the issue of accountability, which manifests at various levels among local actors. For instance, within Network Rail, the Technical Authority serves as the central body responsible for formulating standards. These standards are signed off by the standards owners, who bear accountability for the effectiveness of risk control associated with the standards they endorse. As one participant articulated, concerning outcome standards:

> *'will the standard owner want to take that risk on if they're the ones that are the accountable people at the end of the day?'* [Participant 500 – Infrastructure management]

Additionally, under devolution, regional managers are held accountable for their respective regions. This accountability may result in heightened risk controls aimed at ensuring safety within their designated region. Consequently, this may limit the autonomy of constructors, as explained by one of the participants:

> *'the route managing directors in Network Rail for the various routes are accountable and responsible for their particular regions. Therefore, that's why they would put additional controls and procedures etcetera in place, irrespective of what the technical authority do. So that makes it, for us, as an infrastructure contractor, we have many clients, so we don't just have technical authority, we have all of the route managing directors as clients in the devolved regions. That makes it challenging.'* [Participant 702 – Infrastructure management]

Accountability is identified by participants as an important barrier to frontline autonomy. Autonomy encompasses making operational decisions and appears recurrently associated with concerns about the potential consequences of those decisions; therefore, is often linked to frontline resistance to embracing increased degrees of freedom:

> *'people are scared of having to make decisions, using common sense. They'd rather just follow a handbook or a standard'.* [Participant 302 – TOC]

Accountability as a barrier to autonomy does not diminish the importance of accountability; setting accountabilities is a crucial function of centralised standards and procedures. Instances in the dataset emphasise the critical role of well-established accountabilities and responsibilities in interface coordination at the organizational and operational levels. Some of these instances are presented in Theme 1. Yet, those are accountabilities set a priori rather than the product of a process in which an operation goes wrong, and someone is made accountable (i.e. blamed) for the outcome. This issue is further discussed in Theme 4 regarding fair culture.

Beyond concerns about accountability, frontline operators, such as train drivers, harbour other motivations for their reluctance to use more flexible rules to gain more autonomy. One significant reason is their trust in the existing rule-based framework, coupled with a profound sense of responsibility towards the passengers they transport. This is illustrated by the following extract from a formal train driver's account:

> *'[rules] were fairly black and white: "you do this in this situation. You do that in that situation". That's it. And, if it says that you should be doing this, then you should be doing this. There's no ifs, no buts, that's just the way it sits. I would fiercely resist anybody who was trying to push it if it was outside of that framework. Because the training I had received, and the ethos that I've been given is that I was the one who was accountable, I was the one who was responsible for the safety of that train and all the people on it. And these are the rules and regulations that will keep you safe, "do this and you will be fine" so that's what you do, you go off and you do that because you believe that's entirely the right thing to do.'* [Participant 301 – TOC]

Participants' narratives imply that this positive attitude towards prescription generalises among train drivers. Two participants even mentioned that the drivers' recruitment process includes psychometric testing in which their attitude towards rules is measured. Given that train drivers are the only frontline operators interviewed in this study, this positive attitude towards prescriptive standards can only be suggested for these professional groups. Yet, the data indicates that individuals' positive and negative attitudes towards prescription and flexibility respectively, serve as a barrier to increasing autonomy. While in the data attitudes about the value of autonomy are mixed, these appear to be influenced by individuals' beliefs about the system, the rule user, and the reasons behind allowing flexibility:

> *'that's a flexible rule, but it places a lot of emphasis and all the reliability on the driver. So it's whether, from a human factors point of view, should you make that easier for the driver and just have a maximum speed set? "Don't drive more than 10 miles an hour". That type of performance, on a long straight line, naturally, the industry wants them to be able to drive as fast as they think they can.'* [Participant 401 – Human Factors Specialist]

> *'the rule it's the rule until it's not the rule. There are lots of derogations to rules... sometimes it's done purely about cost. It's done purely for that, because it doesn't suit a company to put resource somewhere else'* [Participant 601 –Train driver]

These quotes show that negative attitudes towards increased local control are often linked to the perception that greater flexibility is solely focused on improving performance. This belief seems an obstacle to a more flexible approach, as clearly articulated by this participant:

> *'I think it's going to be a process to get us to a more flexible, responsive decision-making space... Anything which starts to tilt the balance and can be perceived as being purely about performance, without adequately being explained as to how it also protects safety in the same breath, is going to be challenging for the industry. And I think that's a cultural shift'.* [Participant 301 – TOC]

7.4.3 Theme 3: Safety and performance

The interviews revealed a recurring pattern related to the persistent efforts from the industry and rail organisations to keep trains running – which is not surprising since its activity is rail transport. There are many instances across the dataset that stress the industry's focus on performance. While in some participants' accounts this performance focus appears positive (e.g., as an industry talent or skill), in others, it appears less so and linked to financial motivations. As issues related to performance, cost, efficiency, and other factors appeared in the narratives, a question that arose during the data analysis was whether flexibility appeared to be associated with performance and efficiency, while stability was linked to safety (a question also coherent with research in safety and trade-offs[57]).

7.4.3.1 Safety is a quality of the system, not the end

> *"You are not really thinking about safety. You know that's part of it. If you buy a telephone, you know it's not going to explode in your desk and you're going to have a hazard in there. I think the same is with standards. We develop them, with safety embedded. The main reason we will develop them is because it makes sense, because it reduces cost, to make them compatible with all the processes, with all the needs. Safety is embedded."* [Participant 103 – Regulator]

The primary purpose of the railway system is the transportation of people and goods, and operational standards are developed to manage the operation. Safety is part of the operation, but it is not the operation. Therefore, while safety risk assessment is an integral and crucial part of standards development, their primary objective remains to (safely) guide the operation. Since safety is embedded in the standards, the revision of standards is often directed at increasing the efficiency of the process[58]. Naturally, industry standard alterations undergo a risk assessment by the RSSB Health and Safety team. As one participant clarified, they need to be satisfied that the change *'is no less safe. It doesn't have to be more safe... we must demonstrate this to be no less safe'*. This participant further explained that

[57] Examples are Grote (2020) safety versus autonomy, Hollnagel (2009) efficiency-thoroughness trade-off (the ETTO principle) and Dekker (2004) safety versus performance.
[58] Note that participants also explained that standards may be revised after accidents and change in the light of their failure to control the hazard, thus with the purpose of increasing safety.

enhancing the safety controls of an already safety-effective standard does not justify a change if it negatively impacts efficiency:

> *'we want to introduce something which is more rigorous than what we do at the moment, because we think that'll be safer. But when you evaluate that idea... you do realise is that this actually prevents operations as flexibly as they are now, and therefore you're actually introducing constraint which would probably cost money... it's an impact on performance and having considered it, you end up by saying "well you might see some benefits but these benefits outweigh these benefits."'* [Participant 102 – Regulator]

This participant's narrative is similar to those of others whose main role is the development of standards. Their narratives imply that the process is approached as a balancing exercise, in which the safety properties of the standards must be maintained, but the ultimate goal of the change is to improve performance.

7.4.3.2 Safety is a precondition to performance

Consequential risk, introduced in Theme 1, underscores the connection between performance and safety, illustrating how a decline in performance can affect safety. The present subtheme underlines this relationship in another direction: high performance is not possible without safety. This finding appears both explicitly and implicitly in the narratives along with various examples illustrating the severe consequences of accidents on operational performance:

> *'you don't get a high performing system unless it is safe. They have to go hand in hand... if you aren't protecting your safety, if you aren't looking after and preventing incidents at all levels, you will find that your performance goes through the floor anyway.'* [Participant 301 – TOC]

Furthermore, safety is also a precondition for financial sustainability. Incidents and accidents incur substantial financial expenses, including infrastructure damage, harm to third-party properties, and environmental repercussions. The tragic loss or harm to human lives also incurs significant costs, as one participant pointed out. Accidents can also lead to substantial disruptions to rail traffic with subsequent financial implications, which this participant's narrative of a train accident evidences:

> *'Nobody got hurt but massive disruption. Massive economic disruptions... Something on the West Coast Main line, the flagship line for the country, where a lot of the traffic goes, passenger and freight traffic. If you have a bad one [accident] on that that blocks that line for a couple of weeks, then that's a massive economic impact as well.'* [Participant 801 – Human Factors Specialist]

Poor safety records may result in legal prosecution and negatively impact the organization's reputation, staff retention, and customer attraction. The link between safety and business sustainability becomes even more pronounced within freight organizations. One participant pointed out that safety is '*a selling point*' and their customers now *'really look for a safe operation'*. They noted that people who were previously employed in the freight industry are now transitioning to roles within customer organizations to challenge safety aspects in contractual agreements. The participant provided several examples stressing the significance of safety for the freight business, which are effectively captured in the following quote referring to a derailment of a freight train:

> *'[The train] caught fire, and also spilled huge amounts of aviation fuel into the water course. So the Environment Agency for Wales were there, the fire brigade, obviously, and the line was closed for nearly six months. Six months. The disruption and the cost, it's still ongoing now... [the customer] tankers there with a huge fire, an environment issue, and there's their tankers, with [the customer's name] written on the side on fire'*. [Participant 303 – TOC]

Saying that safety is a precondition for performance does not deny, nevertheless, the existence of trade-offs between safety and performance. While the regulator's claim above, indicated that they go hand in hand when writing the standards, participants mentioned other ways in which efficient performance may be prioritised over safety (e.g., by cutting numbers of staff). Eventually, a tipping point may be reached, resulting in a 'loss of safety' (i.e., an accident) and subsequent adverse consequences on performance. Some participants expressed concerns that this might be already happening in the industry:

> *'There's a lot of pressure to cut costs, have fewer people. And the whole way that the industry is funded and led is changing... we do get feedback from managers that they are seeing the impact of this. These things are quite performance driven. These changes... it's cost cutting, not necessarily about safety.'* [Participant 105 – Regulator]

7.4.4 Theme 4: Rules and culture

The topic of culture appeared recurrently in the dataset. A clear pattern found regarding culture is that adopting a more flexible approach to operations should be accompanied by a cultural change and a shift in the approach to standardisation:

> *'It would be quite a large culture change, culture shift I think. The company would have to be ready for that. I think it would be quite a large sort of say "actually we're going to not tell you how to do things anymore, we're just going to tell you what we want". It would be quite a large sort of jump.'* [Participant 500 – Infrastructure management]

7.4.4.1 The culture is in the rule

Whether owing to learning, new knowledge, good practices or new technologies, participants explained that updating rules is constant in the rail industry. However, standards are simultaneously the object of change and vital tools for change. Some participants argued that the industry is so dynamic because they are used to following rules; due to the frequent changes in rules, individuals are used to adapting their actions from one day to the next. The relationship between rules and culture and the possibility of changing culture by changing the rules emerge from the data, appearing possible if the new rules align with the organisational (or industry) values, as explained next.

In Theme 1 it was discussed that centralised standards are core to coordinating behaviour, and behavioural coordination may create a shared understanding and purpose:

> *'everybody uses the same basic rulebook, and therefore everybody has the same basic understanding... the more people practice the same kind of things, the more you're all going in the same kind of direction.'* [Participant 504 – Infrastructure management]

However, rulemakers appear to be aware that culture reflects a shared belief rather than a shared behaviour. As one participant suggested, a set of written rules followed by operators may not clearly signal that belief:

> *'Do they just comply to the rules because they must and they cut corners as soon as no one looks at them? Or do they really own them and believe in them and then do them because they choose to do them?'* [Participant 503 – Infrastructure management]

From the train drivers participating in this study, it appears that owning the rules is the widespread conviction in their professional group, an ethos that is embedded during their training:

> *'these are the rules and regulations that will keep you safe, "do this and you will be fine" so that's what you do, you go off and you do that because you believe that's entirely the right thing to do.'* [Participant 301 – TOC]

Another train driver provided a clear account of the instrumental role of rules in shaping cultures, suggesting that *'the culture is in the rule.'* The full significance of this statement unfolds throughout the narrative of their experience, tracing the driver's journey from a time when rules predominantly governed safety during emergencies and degraded situations. They explained that during normal operations, the prevailing *'culture was not to lose time'*:

> *'When I learned to drive, if you were doing less than 50 mph [when arriving to the platform], you get told off because you were seen as losing time. But that was the culture'.* [Participant 601 – Train driver]

Rules carry two distinct meanings: one is explicit (indicating what they prescribe), and the other one is implicit (indicating what they entail). While the explicit meaning conveys standardised behaviours, the implicit meaning –

which the participant referred to as *'the unwritten part of the rule'* – may convey organizational values. Over time, if the two meanings align effectively conveying both, normative behaviours and organisational values, a formal (new) culture may take root. Yet, this is a slow process that the participant noted...

> *'has taken 20 years, but the culture of train drivers has certainly evolved.'* [Participant 601 – Train driver]

The data suggests that for a change in culture to occur, other organisational processes, such as training and accident investigation, must also align with the values underlying the desired culture. This suggestion is developed in the next subtheme.

7.4.4.2 Fair culture

As a safety-critical sector, the rail industry and its organisations have established processes for investigating accidents, incidents and not adherence to rules and regulations. The approach to these investigations is registered in the organisations' safety management systems. Fair culture refers to an investigative approach focused on learning from accidents and incidents rather than assigning blame. Although referred to as *culture,* because it reflects organisational values, it is a company standard:

> *'It's not called a standard, but it is in itself a standard. It's a process.'* [Participant 503 – Infrastructure management]

Participants explained that this process reflects whether an organisation's culture is based or not on blame. They agreed that fair culture is (or should be) about identifying what went wrong rather than who went wrong. This way, the industry and the organisation can learn about the systemic causes underlying the incident. Some disagreement, however, was found regarding whether fair culture can be fully based on no blame, with some participants emphasising that this approach is about the fairness of the process:

> *'It can't be a no-blame culture because there has to be boundaries. People have to understand that rules, procedures, etcetera are in place to protect people, so if people break rules, we need to understand that, but it can't be no blame, it has to be what we call fair culture, so we treat everybody with fairness and respect.'* [Participant 702 – Infrastructure management]

The data analysis also showed that fair culture plays a crucial role in fostering flexibility. Participants advocating for a more flexible approach agreed that an increase in flexibility requires the use of more flexible rules. In turn, the use of flexible rules must be embedded within a fair culture to empower organisations and their staff to accept greater control over their activities. The issue of fear of being blamed for an operational decision being a barrier to increased autonomy was explored in Theme 2. Due to this fear, a fair culture is pivotal to the acceptance of flexible rules.

The interviews revealed that the uptake of fair culture by rail organisations is mixed. For example, while a participant stated that they ‘*are specifically no blame’* another participant asserted that their organisation ‘*function on blame culture’*. The data analysis revealed resistance to fair culture at different levels, from senior management to unions, as illustrated in the following quotes:

> *‘as you talk about fair culture, people automatically go to the worst end where there's potential disciplinary action.’* [Participant 702 – Infrastructure management]

> *‘There are leaders who think we just need to stop, we just need to get rid of anybody who keeps breaking the rules... But there's a reason why he did it... we give them no choice with our processes and procedures and with the pressure that we put upon them.’* [Participant 506 – Infrastructure management].

> *'The person who's in charge of Fair Culture... he's tried to change [the current blame culture] and it's been blocked by the unions.’* [Participant 503 – Infrastructure management]

Unfortunately, the participants' narratives lack sufficient detail to draw conclusions about the reasons for this resistance.

7.4.5 Theme 5: Social processes

This theme elaborates on the significance of social processes to operations management. The focus is on collaboration – which in turn is assisted by good relationships – and trust.

7.4.5.1 Collaborative groups

Something that stands out in the data is the variety of intra- and inter-organisational groups operating in the rail industry. These groups bring together people and organisations that share the same activity or which activities interface. Some examples are Standards Committees, the Operations Standards Forum, the Train Operators Subgroup, the Freight Operators Subgroup, and various groups that bring together train operators and Network Rail. One participant also mentioned the Local Resilience Groups, that bring together the emergency services, local authorities, the environment agency, utilities, health services and transport providers, including rail, to have a shared understanding of risk and response to incidents.

Collaboration between organisations through these groups plays an important role at different levels. Beyond its importance in rulemaking (refer to Chapter 6), interorganisational collaboration has a function in the system's learning and improvement by fostering communication, discussion, intelligence sharing, and conflict resolution:

> *'We have a regular meeting with Network Rail. It's called a Level Two safety meeting... We will discuss any issues we have... or any sort of conflict... We also have an operators forum, TOSG ... we go along to that with representatives from passenger operators, freight operators and Network Rail, and we will share best practice about incidents we've had. We'll discuss any infrastructure issues".* [Participant 303 – FOC]

These quotes exemplify not only the role of these groups in learning and improvement but also in maintaining a holistic view and managing interfaces. As discussed previously, holistic management and coordination are particularly important in decentralised systems and organisations. As the following quote illustrates, these groups may serve to address some of the problems brought about by decentralisation, provided they are efficiently established:

> *'I've been setting up a Network Rail, the HSE collaboration group. And what that does is you look at all of the regions, because all the regions have their own sort of groups of health and safety professionals and managing directors that work on*

various topics, but it's very disparate, there's a lot of duplication, so we're bringing that all together to have a bit of oversee, making sure that we're connecting the right people on various subjects'. [Participant 702 – Infrastructure management]

The data also implies that maintaining good relationships among group members is key to their good functioning. These good relationships appear to enhance collaboration, although the other direction is equally plausible, where good relations are fostered by collaboration:

'the OPs standards community is a very tight group of people... We all know each other personally... We have a shared email address to the whole group, we can just email everybody to say "I'm looking at this standard, this is causing me a problem. How do you do it?" Usually within a matter of minutes, some people would come back... This is a really tight knit community that shares that type of information'. [Participant 302 – FOC]

Maintaining positive relationships within rail groups is of particular significance in the case of rail industry standards committees such as the Traffic Operation and Management Standards Committee (TOM SC). As detailed in Chapter 6, this committee holds a central role in standard development. Since standards necessitate consensus approval from committee members, cultivating positive relationships seems a key factor in reaching an agreement, as this participant explained:

'I might find myself placing a sustained objection in the Standards Committee. I think I've only ever had to do that once or twice in the 10 years... more often than not, through good relationship management and conversations outside of the committee... all those issues have been addressed. When you do get to a position of sustained objection, it's usually because there's been a breakdown in the relationship'. [Participant 201 – Regulator]

7.4.5.2 Trust

Trust (and mistrust) is a social process that appeared important to increasing flexibility in rail operations at many levels. Several indications of the trust and flexibility connection have already appeared across some Themes. For example, train drivers' trust in the current prescriptive, rule-based approach to safeguarding safety may act as a barrier to the uptake of flexible rules (Theme 2, Section 7.4.2.3). The issue of the importance of train drivers' trust in engineers' professional judgment in the management of consequential risk was highlighted in Theme 1 (Section 7.4.1.3). In degraded scenarios, train drivers may have to delegate operational decisions to controllers, which also requires interprofessional trust:

> *'you have to trust the person who's telling you what to do... And we've got regular issues where they've told the driver to do something, which actually they shouldn't have told them to do. But they're very performance focused and to keep the railway running, etcetera.'* [Participant 601 – Train driver]

The last sentence of this quote also exemplifies another way in which trust, or mistrust in this case, appears important. Several participants showed mistrust regarding the reasons behind efforts to increase flexibility and the mechanisms that enhance flexibility, such as derogations, portraying flexibility as performance-focused, perhaps at the expense of safety:

> *'there will be forces that will generally resist [flexibility] on the fear that it introduces the possibility of performance before safety sort of approach.'* [Participant 301 – TOC]

> *'people will say, "I know that there's that standard, but I can't comply with it", and they get a derogation. You're simply cheating the system'.* [Participant 501 – Infrastructure management]

The interviews show that an increase in flexibility demands trust among the various stakeholders and, as this participant pointed out, across the business levels:

> *'it requires a huge amount of trust across all levels of the business, not only those at the frontline who are getting the direction, those who are having to make the decision, and those who are at the very top, who are fully accountable from a legal perspective'* [Participant 301 – TOC]

The narratives imply that trust must operate in two directions to support autonomy. The first direction is a top-down dynamic involving the trust in frontline operators by senior managers and standards owners. The second direction is bottom-up and involves frontline operators feeling empowered:

> *‘trusting people and training them sufficiently, and giving them the right support tools in place to be able to manage within that framework... to be able to make that judgment themselves within the context of the situation they find themselves...it's about empowering people... that's hugely challenging to do and requires a lot of trust’* [Participant 301 – TOC]

> *‘If we've got a very autocratic leader, you can get the situation where they're not really reflecting empowerment in the right way, and they're often focusing on who went wrong rather than what went wrong... they then also are stopping feedback and honest conversation because the trust isn't there.’* [Participant 506 – Infrastructure management]

From participants’ accounts, it appears that frontline empowerment requires giving them the necessary tools and resources (e.g., competence, flexible rules). It also necessitates a fair culture environment in which they feel confident to both make mistakes and speak up. The following quote is an extract from a senior manager and illustrates how trust must work in two directions and the important role played by a fair culture:

> *‘Trust. It's everything for us. We employ people, we pay people good money. So therefore, if we can't trust them to do a good and safe job, then something's going badly wrong. But it's just having that confidence to put your trust in somebody... you've got to give that element of trust to people and they've got to know that. We as a senior management team trust our people, it's quite as simple as that. And yes, there are occasions where that trust is broken, but again, that's where fair culture comes in. What we're asking people is be open and honest with us, tell us what's happened... They always come out eventually, but this is a fair culture environment and that builds trust, by people knowing that they can speak openly and honestly and they'll be treated fairly.’* [Participant 702 – Infrastructure management]

7.5 High stability and high flexibility in action: the case of COVID-19

7.5.1 Setting the context

Under normal circumstances, railway operations are subject to rigorous regulations. In this industry, every activity related to the movements of trains is regarded as safety-critical. Strict controls are implemented not only to facilitate efficient but also safe operations. However, when the COVID-19 pandemic struck, the industry had to navigate dual sets of strict regulations: those normally regulating rail operations and those imposed by the government to manage the pandemic. Particularly challenging was that these two sets of regulations often conflicted, rendering rail regulations difficult to comply with. Furthermore, government COVID-19 regulations changed continuously, increasing uncertainty in an already uncertain context. The industry had to operate under a high-flexibility mode to adapt to a) a highly uncertain, unstable context and b) new regulations often incompatible with their own regulations. Simultaneously, the situation required maintaining a condition of high-stability because, due to two concurrent safety-critical concerns (rail operations and public health), the system had to operate within unusually narrow safety boundaries:

> *'It was pandemonium. If you consider we had to almost review everything we did and we had to take the health and wellbeing advice in with that as well, the distancing, you're vulnerable, you're extremely vulnerable. What people couldn't do, the continual shifting advice from government on "right wear a mask, don't wear a mask, 2 meters, 1 meter, screens needed, screens not needed". There was a constant sort of shifting landscape that I had to continually review as well. So you used to log on in the morning and see what advice had been given the previous night so you could then decide if anything you already dealt with needed amended or rules needed changed.'* [Participant 501 – Infrastructure management]

Despite the upheaval, the industry not only managed to keep trains running, but it also took advantage of the reduced number of people in stations and the decrease in train traffic to do extra maintenance work. What did help to maintain high stability in such a changeable context? How did flexibility come about in a double-regulated context? In other words, what facilitated work in an operational context that required of high-stability and high-flexibility? Delving into participants' experiences and perceptions, the analysis of data revealed five influencing factors that were labelled as:

- Groups/Collaboration
- Centralisation
- Relationships, trust, and shared goals
- Things managed as usual
- Risk assessment

Despite that the data were analysed inductively (the results from the thematic analysis were not used to guide the analysis), these five factors overlap with some of the findings included in the themes and subthemes, as shown in Table 7-5. Besides being categorised and presented in the table, the factors are presented within a single narrative. This serves to stress that, when contextualised in practice, the factors are not fully independent and often work in relationship with each other. The narrative is illustrated with quotes from participants' accounts. The factors alone or in relation to the findings are in italics.

Table 7-5 Factors in relation to main thematic analysis findings

COVID-19 Factor	**Factors Brief Description**	**(Sub)Theme Correlation**
Groups/Collaboration	Previous and newly formed collaborative groups key to providing a holistic view of the problem, cross-learning, problem-solving and response implementation	Collaborative groups Holistic management Consistency
Centralisation	A central body (Rail Delivery Group – RDG) core to holistic management through the coordination and guidance of collaborative groups, and by providing global principles to the global problems	Holistic management

Table 7-5 Continuous

COVID-19 Factor	Factors Brief Description	(Sub)Theme Correlation
Relationships, trust, agreement, and shared goals	Good relationships, trust, and a sense of common purpose vital to prompt agreement and efficient collaboration	Social processes
Things managed as usual	Before COVID, the industry was used to combine standardised, routine processes and behaviours with the ability to adapt to eventualities as they arise.	Dynamic adaptations
Risk assessment	Safety was embedded in every operational decision to keep the system running. Continuous risk assessment was core to dynamic adaptations and fostering staff trust.	Safety embedded Dynamic adaptations Trust

7.5.2 Adapting operations to the COVID-19 context

> *'when COVID came about a couple of years ago, my professional head of rail operations had to be moved into a different group that was going to work on how they were going to be doing some emergency COVID work and training... they have to be together and put together rules or how they were going to manage the risk of COVID transmission, and you cannot just do that in isolation, you also need occupational health experts, and you need to have lots of people coming together'* [Participant 103 – Regulator]

The role of *collaborative groups* appeared pivotal in navigating the challenges posed by the pandemic. In addition to regular groups, new ones emerged within and across different organisations (intra-organisational and inter-organisational groups, respectively). These groups took various forms, including those comprised solely of safety professionals, intra-organisational groups with diverse professionals from various departments, cross-industry groups involving professionals from different fields, and groups formed by distinct agencies, such as the Resilience Forums[59]. These groups appear to have had a crucial role in providing a *holistic perspective* on the issue, fostering cross-learning, enabling discussions and knowledge exchange, coordinating and implementing strategies, and providing support among different agencies. They also played a role in ensuring a *consistent approach* across the industry, consistency that was key to maintaining an *optimal relationship with the unions*:

> *'making sure we got a consistent approach across the industry for all kinds of things. Sick pay, provision of face coverings, our approach to testing, we were really keen to make sure that no one was an outlier or went rogue and did something that everybody else wasn't doing, because that would cause problems with trade union relations. We did that kind of piece of work for consistency in industry.'* [Participant 901 – TOC]

It appears that the unions undertook an active role to ensure that rail staff's wellbeing was safeguarded, with COVID measures and changes in normal processes being *agreed* between unions and organisations along the way. *Risk assessment* – which in normal circumstances is vital in safety-critical industries – took an even more important function in this highly uncertain and threatening environment. Considering that many controls in place to manage operational risks were not now appropriated, that the virus was importing new risks, and that the government advice and regulations were frequently changing, risk assessment became both a flexibility-enhancing tool and a warrantor for *good relations*:

> *'Everything was risk assessed. Without a shadow of doubt, even the decisions we made were risk assessed. So "if we didn't do it, what was the consequence of not doing it? And if we did do it, what's the risk of doing it?" Everything had a risk assessment. It was signed off by the trade unions, which I think was very important. We had engagement with the unions very early. We never made signallers sit in signalling panels alongside each other. We had to create new desk arrangements and everything*

[59] Some groups, such as the Resilience Forum, were already well-established groups, but their collaboration increased during this crisis.

> *like that for them... We just signed all of that off with the unions to say "this is safe work site, it's been risk assessed"'.* [Participant 501 – Infrastructure management]

Good communication, collaboration, trust, good personal relationships, and a *shared sense of purpose and direction* were crucial *social processes* for navigating the crisis. These factors appeared important across all relational levels: between regulators and organizations, among organizations themselves, and between regulators, organisations, and rail staff through the unions:

> *'It required the industry and the regulator to work very closely in a collaborative and very open, trusting way that people would just have to speak their minds, and then find common ground and bounce ideas off each other to work out what was the best solution for society as a whole'.* [Participant 401 – Regulator]

> *'It was because we had all the same purpose, same sense of purpose, same collective accountability and responsibility. No one was trying to make money or commercialise this. Everyone was trying to keep the railway running, keep people's jobs, keep people safe, passengers and employees. Because we all had the same reason for being on that call every day, it was effective.'* [Participant 501 – Infrastructure management]

A *central body***,** the Rail Delivery Group (RDG), *coordinated collaborative discussions* and provided *national principles* that rail organisations could use as a framework to work within. It also provided guidance and assistance with planning. They put together a series of what a participant called '*assumptions of reasonable worst-case scenarios'*, such as: '*Consider the fact that you might have to defer medicals because people might not be able to attend medical appointments*'. Those assumptions helped organisations to work out *contingency plans* to manage those (which often became real) worst-case scenarios. Other contingency plans that had been devised for other crises played an important role as they were reviewed and used in this context; for instance, contingency plans to deal with an influenza epidemic. These included plans to control influenza contagion and to operate with 20% of the workforce on sick leave (approximately the proportion impacted by COVID). This capacity to make contingency plans transferable is a good example of the general *adaptive capacity* of the industry, which was portrayed as a key factor in the successful management of the COVID crisis:

> *'We're very well versed in reactionary contingency management. Whenever something goes wrong, we have people in the business that know what needs fixed, know what needs to change. It was exactly the same in the pandemic, "we cannot carry out driver training because we can't get through the cab? Right, okay, let's look at plan B."'* [Participant 301 – TOC]

Therefore, although the exceptionality of the situation is well acknowledged throughout the narratives, the industry's success in adapting and managing the crisis appears as natural and unsurprising:

> *'I think probably just down to the way that we have the ability to adapt what we do quickly to changes, because even without the Pandemic, we are quite reactive as an industry. Something will happen, we need to change something, we just find a way to do it, we go out, we put the rules and we change it. We have a history of being adaptable'.* [Participant 302 – FOC]

This extract points out the role of rules in managing change. The use of other industry and organisational tools regularly available to adapt to contextual constraints, such as deviations and derogations, was also crucial. However, success may not only rely on the industry's capacity to adapt; it may also rely on the *routine nature* of rail operations and the *clear boundaries* and red lines within which organisations and frontline staff operate:

> *'I think it's because we have routines, much of it didn't change. Obviously, the environment in which we were working changed, there were things that couldn't take place, but the day-to-day operation was... I think what helps is that regimentation where they know that forever conditions, whether it be night, day, raining, pandemic, they have to complete a task in a certain manner.'* [Participant 303 – FOC]

7.6 Discussion

This interview study explored issues around stability and flexibility in railway operations management through the experiences of people involved in rulemaking. Two key mechanisms for stability and flexibility were used as practical tools to frame the exploration: centralised control and standardisation (centralisation), and local control and autonomy (decentralisation). The data was analysed using Thematic Analysis and the findings were presented within five higher order themes.

Centralisation plays a crucial role in the holistic management of risk and the operation (Theme 1). Holistic management is core to establishing consistency throughout the system. Participants argued that consistent processes and behaviours are important at various levels. Interfaces are pervasive in railways and consistent performance is needed to coordinate activities at those interfaces. Consistency also supports interoperability by facilitating cognitive processes such as managing, remembering, and applying information. This enhances safety by minimising the chances of error for individuals and organisations that work across system boundaries, such as train drivers and infrastructure contractor companies. Furthermore, consistency offers economic benefits, as it saves resources by eliminating the necessity to relearn processes.

The economic benefits of centralisation discussed by participants were encapsulated within Theme 1 (Section 3.4.1.2). While participants highlighted cost reduction as a benefit of standardisation, they did not mention the cost and resource intensity associated with flexibility when discussing its disadvantages. This pattern mirrors the safety literature on adaptation and resilience, where economic costs and benefits are typically not considered. This omission is not surprising, as cost-benefit analysis traditionally falls within the realm of risk management. However, budget cuts and financial pressures significantly impact system and operational management, with many demands stemming from the need to increase efficiency. Therefore, in reality-based safety science (Rae et al., 2020), it would be logical to consider (at least broadly) the economic aspects of flexibility.

A problem with standardisation that is gaining importance in practice is consequential risk. Traditional hazard control focuses on localised (primary) hazards, but the industry is beginning to explore and measure the impact of (local) hazard control on other parts of the system. In complex, tightly coupled systems, small local changes can have significant system-level effects (Cilliers, 1998; Remain et al., 2015). This effect is at the core of the need for adaptation in complex systems (Hollnagel et al., 2006). Although adaptations are often directed at correcting small variations (Hollnagel, 2014), they may also introduce small changes. The impact of local adaptations receives limited attention in research (Perry & Wears, 2012). In practice, the co-dependence between stability and flexibility is evident. As participants explained (Section 7.4.1.3), the more flexibility to adapt, the more conditionalities are introduced, and the more important it becomes to maintain a holistic view to understand how flexibility may impact the global operation.

Returning to standardisation, the analysis suggested its potential to both change and establish culture (Theme 4). The findings revealed that organisational values may be embedded in company standards and thus spread across the system. Conveying organisational values through operational rules and standards is particularly useful in decentralised systems or organisations because values can act as a stabilising force (Weick, 1987). If standards can convey organisational values, it implies that a cultural shift could be supported through new standards aligned with the organisation's new direction. As participants stressed, a cultural shift is needed if the rail industry is to accept an increase in flexibility, making these findings particularly important. These findings also illustrate how standardisation can have the dual function of providing stability and facilitating change.

Similarly, the findings reveal the potential dual function of collaborative groups in enhancing both stability and flexibility. On one hand, they support stability by maintaining a holistic view and improving coordination in decentralised systems. On the other hand, they facilitate system learning and improvement by fostering communication, discussion, intelligence sharing, and problem-solving. Collaborative groups were also central to the industry's adaptive response to COVID-19 (Section 7.5). Altogether, inter-organisational collaboration enhances stability while fulfilling two important functions of flexibility: learning and improvement, and adaptation.

Flexibility and adaptation at the system level often (if not always) incorporate stabilising elements such as contingency plans. This was evident when referring to dynamic adaptations (Section 7.4.2.2) and COVID-19 management (Section 7.5). However, flexibility alone is more likely to occur at the frontline level to address the fallibility of rules or lack of resources (Section 7.4.2.3). Numerous studies have demonstrated the importance of resolving issues related to accountability and trust to enhance frontline flexibility, findings supported by this research (e.g., Reason, 1997; Snook, 2002; Grote, 2015; Dekker, 2011).

However, accountability issues often focus on frontline operators being blamed for the consequences of their decisions. These findings also highlight the significant impact of standard owners' and regional managers' accountability in allowing flexibility for frontline operators. If these managers are held accountable for the failure of standards to control risk, they tend to create or enforce detailed, prescriptive standards, significantly reducing flexibility.

7.7 Conclusions

This study has identified and discussed factors contributing to the safety and efficiency of railway operations relating to centralisation and decentralisation. It has also pointed out barriers to flexibility. The following conclusions are drawn from this study:

- Centralisation is key to gaining a holistic view of operations and their risks, playing a crucial role in operations' safety and efficiency.
- One of the roles of holistic management is ensuring operational interoperability and avoiding fragmentation.
- Consequential risk evidences the importance of a holistic view and highlights the limitations of standardisation in providing it.
- Standardisation may have a role to play in both changing and establishing culture. This appears particularly important in decentralised systems or organisations.
- There are 'tools' available to the industry and its organisations that can provide a bridge to integrate central and local control, such as collaborative groups and a unified culture.
- Safety and performance may be approached as mutually dependent. Likewise, safety may be approached as an integral part of the operation rather than an external element that may be added.

7.8 Limitations and questions raised

This study benefits from a varied sample comprising participants from diverse roles and organisations, allowing for a good exploration of viewpoints on the issue within the railway industry. Yet, it is subject to limitations. The sample's broad representation results in certain role categories being underrepresented; for instance, there is only one participant from manufacturing and two train drivers. This restricts the depth of insights gleaned from each specific perspective, thereby limiting the extent to which the findings can be applied to the profession more broadly. Nevertheless, since the aim was to capture their perceptions within their common role (rulemaking), the diversity of roles and organisations is well suited to the explorative nature of the study.

Building upon these initial findings, further research could extend this investigation to focus on different roles. This would contribute not only to a more comprehensive understanding of the issue under investigation but also to a better understanding of the diverse worldviews and (sub)cultures operating within the railway industry.

8 Study 4 – Balancing stability and flexibility in practice: managing the unexpected

8.1 Overview

The case study presented in this chapter (Study 4) explores stability and flexibility in practice through the activity of rail infrastructure incident controllers (ICs). Data were collected within the network and signalling control rooms at the East Midland Control Centre (EMCC). While the focus was primarily on the activities of incident controllers, the pivotal role of signallers in ensuring stability was also examined. Using data from observations, interviews, and documents, four main functions of the IC activity and some underlying functions were identified. The findings revealed various sources of stability and flexibility, which are here discussed.

8.2 Introduction

Where (or by whom) safety is controlled is a key topic in safety research, as discussed throughout the literature review in Chapter 3. Control often refers to where safety decision-making is placed, or in other words, who makes safety decisions. The Resilience Engineering (RE) tradition often approaches control as a dichotomy between decisions made at the blunt end and decisions made at the sharp end (e.g., Hollnagel, 2014; Dekker, 2006). At the blunt end, safety decisions are anticipated based on knowledge and forecasts of how the operation may unfold. These safety decisions are implemented as ‘soft’ or ‘hard’ barriers such as standardisation and automation respectively (Reason, 2000). At the sharp end, safety decisions are situational, occurring as adaptations to the immediate context and situation.

Much of RE research in practice investigates safety at the sharp end by examining frontline contextual adaptations (e.g., Jonassen & Hollnagel, 2019; Pariès et al., 2013). Similarly, research in the High Reliability Organisation (HRO) tradition mostly focuses on the sharp end, often on frontline team adaptations operating within the immediate context in which incidents occur (Weick & Sutcliff, 2011). However, not all here-and-now decisions to adapt to unforeseen situations occur in the context in which the contingency happens.

Frontline here-and-now adaptations typically control only the primary risk (i.e., the direct risk in the local or immediate context). This is also true for rules and standards, which mostly focus on controlling hazards related to the local context of the process or activity. Study 3 (Chapter 7) highlighted the issue of *consequential risk* [60] and the knock-on effects on system safety and performance when adhering to rules in specific situations. The study findings also underscored the crucial role of rail network control teams in managing consequential risks and other escalating contingencies by dynamically adapting to the conditions. Despite being removed from the immediate context where incidents happen, these teams make real-time decisions to manage the situation as safely and efficiently as possible. This feature of the rail controller's role was highlighted by Farrington-Darby et al. (2006) in the first large naturalistic study of rail network controllers in the UK. Farrington-Darby et al. (2006; 2009) called attention to the cruciality of social interaction in the controller's activity while demonstrating the validity of qualitative methods based on ethnography to understand it.

The present study investigates stability and flexibility in practice through the everyday activities of rail infrastructure incident controllers. The aim is to describe how *dynamic adaptations* unfold in these control teams. As argued in Chapter 7, resolving disruptive events depends on individuals' ad hoc decisions and flexibility to adjust resources and plans[61]. The role of controllers is critical in these *dynamic adaptations*, which, rather than being purely improvised, develop from standardised contingency plans.

Although the study focuses on the role of infrastructure incident controllers, it also provides an overview of the Rail Operating Centre (ROC) and its control team, including signalling control and train operators. The role of signalling control is particularly crucial to incident management, as it upholds the safety-critical aspects of the process. Therefore, the study also delves into the activities of signallers in relation to those of incident controllers. The research questions are:

1. What is the role of the incident controller in incident management?
2. What are the different actors involved in incident management?
3. What are the sources of stability and flexibility supporting the incident controller activity?
4. How do flexibility and stability merge in their everyday activity?

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[60] Refer to subtheme *Holistic view of risk: consequential risk* in Chapter 7 Section 7.4.1.3.
[61] Refer to subtheme *Dynamic adaptations* in Chapter 7 Section 7.4.2.2.

8.3 Method

8.3.1 Initial industry contact

Network Rail was approached for collaboration in this doctoral research project in May 2022. The overall project was presented to the gatekeeper, a contact of the researcher's supervisor, via email. The aim was to gain Network Rail's collaboration for this case study and the interview study presented in Chapter 7. In August 2022, Network Rail agreed to collaborate, and a meeting with the gatekeeper was scheduled for November that year. During this meeting, the key aspects of the case study were discussed, and the gatekeeper agreed to contact the Rail Operation Centres (ROCs) deemed suitable for conducting the study.

Communication continued between the researcher and the gatekeeper over the following months, but confirmation from any of the ROCs was not forthcoming. In April 2023, during an interview for Study 3, the interviewee offered to help introduce the project to the managers at the East Midlands Control Centre (EMCC), where they had worked for several years. They facilitated the introductions via email, and a meeting with the signalling and network control floor managers was arranged for the following month.

8.3.2 First visit to the site

A first visit to the EMCC took place in May 2023, accompanied by the gatekeeper. This visit served to meet the managers face to face. The managers had received in advance the study information sheet explaining the purpose and process of the study, and these were further discussed during this visit. Additionally, the visit served to familiarise with the EMCC context and to meet some of the staff. The managers agreed to participate, although formal consent was pending approval from the unions. Once the unions confirmed their agreement, formal consent was obtained, and the researcher was able to apply for and receive ethical clearance from the university to start data collection.

8.3.3 Data collection

Data collection began in July 2023 and lasted for 11 days. It was conducted in both the network and signalling rooms, with more days spent in the network room. Table 8-1 shows the total days and hours of data collection on-site and in each room.

Table 8-1 Site access during data collection

	Control	Signalling	On-site
Total days	8[62]	4	11
Total time	2865 (48h)	960 (16h)	3825 (64h)

8.3.3.1 Network control room

After the initial visit, the first day of data collection in the network control room (hereafter the control room) allowed the researcher to further familiarise herself with the work context, environment, and the various roles of personnel and organisations present. During this time, she created control-room layout diagrams, drawing the positions of different controllers and the equipment on their workstations. An Incident Controller (IC) volunteered to be shadowed, providing insights into their role and the dynamics of their activities. After that day, a routine was established where the researcher would return on days when at least one of the ICs she already knew was present. She would be introduced to new controllers if necessary and would sit at a station alongside one of the controllers.

As explained in Chapter 4, observations were informal, and the researcher adopted the role of participant-as-observer. This approach allowed the researcher to conduct observations without a rigid schedule, aiming to build rapport and immerse herself as much as possible in the controllers' activities. While the participant-as-observer role seeks acceptance as part of the group, the degree of acceptance can vary. In this case, the group acceptance of the researcher exceeded expectations, and after only a few visits, they started calling her the 'new trainee'. Although the researcher only observed when they were busy, the ICs explained their actions between calls, kept her informed on the progress of incidents, and demonstrated how they used the system.

During quiet times, informal interviews in the form of conversations allowed for further questions about their activities, their journey to becoming controllers, their previous experiences, listening to 'controllers' stories[63],' and

[62] One day was shared, with the researcher spending half a day in each room.

[63] 'Controllers' stories' included narratives of past incidents, stories about people and other railway roles (often about signallers and track maintenance staff) or jokes shared by the group. Hayes (2018) suggests that storytelling is a key factor in professional identity construct. Weick (1995) argues that shared stories and narratives are key to make sense of information and events.

going through contingency plans and checklists. Although the initial observation sheets noted only key points without detailing what or how to observe, these were soon abandoned to fully embrace the rich information shared by the controllers. Data were captured in the form of field notes, which included direct observations, responses to questions and visual representations among others (see Table 8-2). The incidents were noted chronologically as they developed, recording every observed action step by step. Any gaps in the recorded information were filled in as much as possible after the incident was resolved. Documents and incident system (computer) outputs were also collected in printed and electronic (emailed) formats. Each day, the data were supplemented with additional notes and reflections about the day written afterwards.

8.3.3.2 Signalling control room

The data collected in the signalling control room (hereafter the signalling room) mainly comprised interview data obtained through familiarisation interviews with signallers. Eleven face-to-face interviews were conducted, each lasting between 19 to 44 minutes. The participating signallers were two women and nine men, with experience in the role spanning from 2 to 34 years. Three participants held managing positions. Participants were invited via email, and those interested in participating contacted the floor manager, who coordinated the scheduling and sequence of participation.

The interviews were conducted and recorded in accordance with the university's ethical guidelines. The interview schedule was organised around specific topics but kept open and flexible. Participants were asked to discuss their roles in general and the challenges they face. To understand the signallers' roles during incidents, they were asked to describe a particularly challenging possession or event. They were also encouraged to talk about what helps make their work easier and their experiences working under strict operational rules. Prompts such as 'Why do you think that happens?', 'How do you think that can be changed?', and 'Please tell me more about it' were used to gain a richer understanding of their safety-critical role in the incident control process.

In addition to formal interviews, data collection in the signalling room encompassed informal observations and conversations aimed at gaining some understanding of the dynamics of signaller activity. The researcher sat alongside volunteering signallers, gaining insight into the particulars of signal operations at their workstations, their modes of communication with other personnel, the types of information utilised during the signalling process, and the methods by which they acquire it. The data collected here also comprised room layout diagrams marking the positions of the workstations and the equipment on them. Data were also supplemented with after-the-day notes and reflections.

8.3.4 Data sensemaking

The two sets of data collected (control and signalling room) were treated separately. Data collection yielded information from various methods and in different formats (Table 8-2), which needed to be organised before analysing it in light of the research question. The initial data organisation involved first, collating the different data outputs into one dataset. Then, through data reduction (Simons, 2009), the data relevant to the research question were selected, and data that were not fully coherent or incomplete, such as several incident management records, were removed from the dataset.

Sensemaking in this study was framed by Wolcott's (1994) work on transforming qualitative data into meaningful findings (Table 8-3). Wolcott discusses three ways to transform the data: Description involves paying attention to what is going on and remaining close to the data as it was recorded. Analysis involves examining the data and moving beyond descriptions by exploring how things work. Interpretation goes beyond the factual to understand what lies underneath. Wolcott emphasises that these categories are not discrete, sequential, or mutually exclusive. The researcher may integrate them, move between them, or choose one over the others. In this study, the three categories were used, often blended, during the process of data transformation. This process was conducted four times (here referred to as cycles), one for each research question.

Table 8-2 Data collection method and output

Room	Data collection method	Data collection output
Control	**Observations** **Informal interviews** **Documents**	Field notes of direct observations and incidents management, responses to questions, drawings and visual representations, field notes of technologies used, incident computer systems outputs, contingency plans, after-observations notes and reflections.
Signalling	**Observations** **Formal interviews** **Informal interviews** **Documents**	Interview transcripts, field notes of direct observations, responses to questions, drawings and visual representations, field notes of technologies, after-observations notes and reflections, and safety newsletters.

Table 8-3 Sensemaking framework based on Wolcott (1994)

Category	Looking at	How
Description	What happens	Data literal meaning
Analysis	How it works	Data coding/info flow diagrams
Interpretation	What can we do with it	Data through theoretical lenses

The first cycle served to draw a description of the ROC context and to address the different actors. *Description* involved reading through the data and selecting information regarding the building, context, room setup, people, their respective roles, etc. These data were then transformed into a narrative, maintaining its literal meaning.

The second cycle addressed RQs 1 and 2, focusing on the role of ICs in incident management and the actors involved. This cycle involved description, analysis, and interpretation. The incident management data (i.e., the field notes from observations of ICs during incident management) were examined line by line, with descriptive codes assigned and the actors involved noted (Table 8-4). Diagrams illustrating the actors and information flow were created. Patterns were then searched for across the codes and grouped into labelled categories; for example, 'info from signaller', 'info to team', and 'info from Google' were grouped under the label 'information'.

Table 8-4 Incident management data first coding example

Data – Incident management fieldnotes	**Code**	**Actors**
– IC1 listening on the phone and taking handwritten notes, asking the signaller if he took the driver's details	Info from signaller	IC1 Signaller
– As IC1 receives the information repeats back to make the other controllers aware	Info to team	IC1 External/Unknown Other ICs
– IC1 takes the radio to talk to MOM and sends him there to sort out the fault in the barrier	Mobilising resources	IC1 MOM
– IC1 checks the area in Google maps	Info from Google	IC1

In addition to observed actions, the incident management data included explanations and conversations with the ICs, which were used to understand what was happening (*description*) and to organise the categories meaningfully. Through description and analysis, the researcher formed a comprehensive picture of the incident management process, which was then examined in light of theory and previous findings from this thesis (*interpretation*).

The third cycle addressed RQs 3 and 4 (sources of stability and flexibility, and how the two concepts integrate) and involved both description and interpretation. In this cycle, the researcher examined the two datasets guided by these questions. The signalling room data outputs, including the transcripts from the familiarisation interviews[64], were transformed through description[65]. In examining the datasets, particular attention was given to data regarding rules, contingency plans and the like. Interpretation was conducted

[64] These interview recordings were transcribed using tidy transcription (Henderson, 2018) as described in Chapter 7 Section 7.3.3.1.

[65] The aim was to understand how the activities in the signalling room support the ICs' activities, and how the roles compare, rather than gaining a comprehensive understanding of the signallers' activities. Therefore, no analysis was conducted.

through the theoretical lenses of this thesis and its previous findings, including those produced in the first and second cycles described above.

8.4 Network Rail East Midlands Control Centre (EMCC)

The EMCC, in Derby, is a two-story building that provides signalling and network control over 350 route miles of railway across the East Midlands region. Unlike other control centres, where signallers and controllers share space, the EMCC signalling control and network control rooms are on distinct floors.

At the time of this study (July 2023), the signalling room was undergoing renovations. The room is a large open space in which light is kept low. There are six signalling workstations, four double (for two signallers) and two single-managed, two large shift signalling manager desks, a stand-up desk and a desk containing the documents and forms used in the everyday signalling activity. There is a large walk-in filing closet occupying the far end wall where the completed documents and forms are filed.

In the room, the stations are arranged emulating the flow of trains along the system; this way, when a train disappears from a signaller diagram appears in the nearby signaller diagram screen. This arrangement facilitates communication between signallers which areas of control interface. The office environment is friendly and slightly noisy due to the different alarm systems that frequently go off in the stations.

The control room is a spacious, well-lit open area. It is shared between Network Rail and East Midlands Railway (EMR), a train operating company. Additionally, there is a British Transport Police (BTP) station, although police officers are not onsite 24/7. Desks are arranged so that controllers can be seated close to those with whom they need to interact frequently, thereby facilitating the flow of information (see Figure 8-1). In the right corner near the door, there is a seating area. On the left, separated by glass, there is a meeting room and the Network Rail duty managers' office.

The environment in the office is friendly and lively but not noisy. Controllers typically share most information regarding incidents from desk to desk, although it is not uncommon to see them visiting a colleague's station in person. They appear to have a friendly relationship with EMR staff and often engage in cheerful conversations with each other. Most communication with

EMR controllers is facilitated through the train running controller (TRC), who sits back-to-back with them and works in close collaboration.

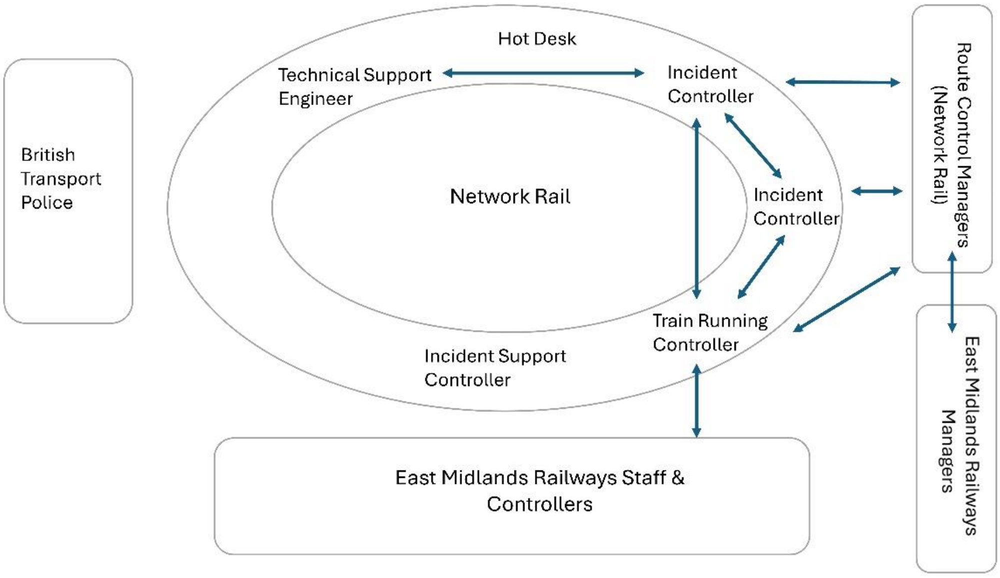

Figure 8-1 Control room layout, roles and information flow

8.4.1 Network Rail control team

The Network Rail control team comprises signallers and different types of controllers and support staff. The different roles are summarised in Table 8-5. Controllers work 24/7 in a 12-hour shift without breaks. They have their meals at their stations and, when they are not busy, they may leave the room to stretch their legs or get themselves and others a cup of tea. If they leave the room, they are covered by another incident controller. Signallers also work 24/7 but with various shift patterns and with 2-hour breaks every four hours. When signallers leave their stations, they are covered by the manager signaller.

Table 8-5 Network Rail controllers' roles and brief description of their responsibilities

Role	Brief description
Route Control Manager (RCM)	Oversee the control team and work closely with TOCs and other Network Rail managers during major disruptions. Together, they coordinate response at the area's boundaries and deal with delay attribution disputes.
Incident Controller (IC)	Plan and coordinate the response to all infrastructure and operational incidents in their area of control. Also involved in the execution of planned infrastructure repair and maintenance.
Train Running Controller (TRC)	Work closely with the ICs, and in liaison with TOCs whose services run in the route and other control centres. Together, they identify potential disruption and initiate early action to minimise train delays and manage train services during times of disruptions.
Technical Support Engineer (TSE)	Work closely with ICs. TSEs analyse the data from the performance sensors on the track, which send alarms with potential faults in the system. TSEs judge whether each alarm is an error of measurement or a potential fault that needs a team to check it and fix it if necessary.
Incident Control Support (ICS)	Assist ICs in the everyday management of contingencies and planned work
Chief Signaller Manager	Signalling team management. Work closely with TOCs and other Network Rail managers during major incidents.
Signaller Shift Manager	Oversee and coordinate the activities of signallers.
Signaller	Control the movement of trains across the network by operating the signalling system. They have a vital role in ensuring safe access to maintenance staff when working on or near the track.

8.5 Managing incidents: the role of the Incident Controller (IC)

Incident Controllers (ICs) are involved in managing any incidents that may disrupt normal rail operations, which encompass the safe and efficient running of both freight and passenger trains. Safe operations not only include the safety of passengers and rail staff, but also of members of the public, the infrastructure, and the immediate environment. The range of incidents that ICs handle is vast, including infrastructure malfunctions, train breakdowns, trespassing incidents, level crossing issues, suicides, and so on.

Railways are complex, tightly coupled systems in which local failures may result in disruptions, not only in local and regional areas but also in larger parts of the system. The role of the IC is to resolve failures as quickly and efficiently as possible, thereby controlling disruptions and minimising knock-on effects. Although the timing and scale of the contingencies that ICs deal with are often unpredictable, they emphasise that their role has a degree of predictability. As one IC commented, "*Failures and disruptions are predictable. Knock-on effects are predictable too; it's about seeing the big picture and how to minimise the damage.*" This implies understanding how failures occur, the immediate and local consequences, and the potential global, network-wide effects.

Figure 8-2 uses a real-case incident to graphically illustrate the IC's role during incident management. The figure depicts an incident where a barrier at a level crossing broke, preventing a train from continuing its journey. The signaller informed the IC about the incident, who then began preparing the response. The IC's goal (blue boxes) is to resolve the issue as quickly and safely as possible. Safety is the main factor to consider. Train traffic safety was managed by the signaller from the moment the barrier failed (1), and there were no concerns about problematic disruptions since no train was expected to pass for over an hour. The IC searched for the MOM (Maintenance Operations Manager) that could arrive the quickest (2) and discovered that it would be at least an hour before the maintenance team could reach the site. This raised safety concerns about the passengers on board, including vulnerable passengers and the risk of attempts at detraining (i.e., self-evacuation).

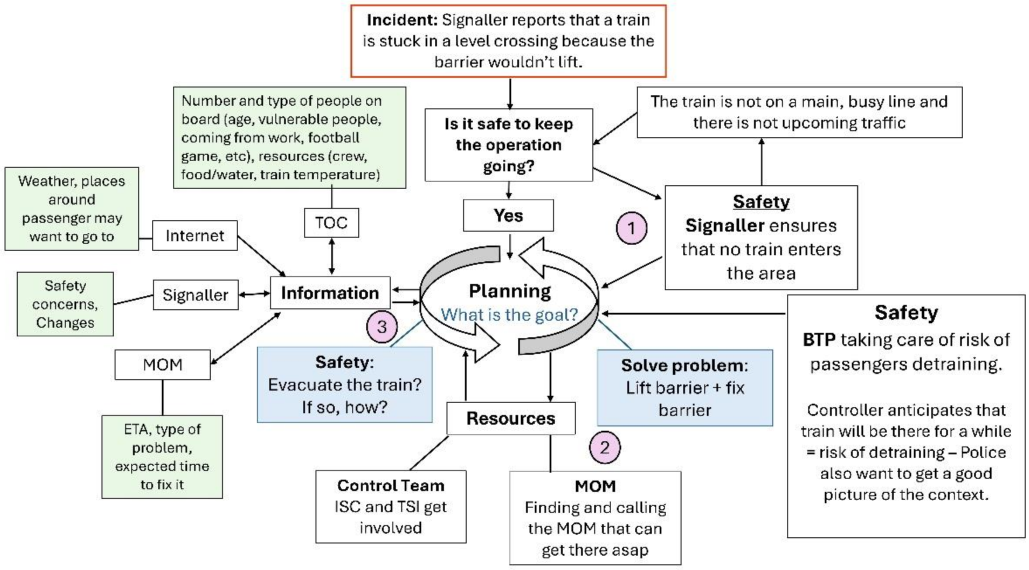

Figure 8-2 IC Incident management in a real-case scenario. The blue boxes represent the IC goals; The green boxes represent examples of the information gathered.

To plan a safe resolution of the problem, the IC needs to get the team to fix the barrier to the place and to ensure that passengers will be safe if left onboard. This requires a high cognitive activity, involving mental processes such as gathering, assessing, and communicating information, decision-making, and problem-solving (3). Cognitive activity occurs individually and collaboratively within the IC team and with other teams they interface (e.g., Train Operating Companies (TOC) controllers, Permanent Way maintenance teams[66] (PWay), signallers, etc.). These cognitive activities are supported by standards such as operational rules and procedures, contingency plans, and learned routines developed within the IC team.

Four IC functions were identified as critical to the management of the incident:

1. Embedding safety
2. Planning and coordinating the response: dynamic adaptations
3. Supporting the team and other stakeholders: teamwork
4. Spreading the information: creating collective awareness

[66] Permanent Way or PWay refers to the structures that form the track bed; It includes the track itself, the sleepers, the ballast, and the subgrade. Controllers at EMCC used the abbreviation PWay to refer to the engineers and maintenance staff in charge of their maintenance and repair.

Notice that these do not represent an exhaustive list of the IC functions, but four broad function categories observed when shadowing the ICs.

The rest of this section is organised as follows: the four observed functions are outlined next, using illustrative examples from the incident depicted in Figure 8-2; then the functions are made explicit in Table 8-8 using another real-case scenario; finally, the core underlying processes of those functions are highlighted and depicted in Figure 8-3. Both Figure 8-2 and Table 8-8 include the Signaller's function, which will be overviewed in section 8.6.

8.5.1 Incident Controller observed functions

8.5.1.1 Embedding safety

Although the safety-critical role in managing incidents is placed on the signaller and the role of the controller appears directed to the system's performance, controllers explained that, when managing an incident, safety is non-negotiable. ICs were clear and affirmed that '*protecting lives is the priority*' and their decisions are based on that premise.

With each new incident, the first query ICs need to resolve is whether it is safe to continue operations. If the answer is no, traffic comes to a halt. Decisions about whether to stop the traffic are mostly made in agreement with the signaller manager. Said that, since warranting the system's safety is the signaller's main responsibility, decisions to bring traffic to a halt will be made solely by the signaller if s/he considers that the situation requires it. Safety decisions are taken throughout the process. For instance, in Figure 8-2, decisions about safety also involved whether evacuation of the passengers was necessary to ensure their safety, and to involve BTP to control the risk of passengers detraining (self-evacuating).

8.5.1.2 Planning and coordinating the response: dynamic adaptation.

ICs work with incidents that happen in a context from which they are removed; therefore, they need to construct a mental model of the situation to effectively plan and implement their response. To form those mental models, they largely rely on the information they gather throughout the process drawing from various sources (Table 8-6), some of which provide real-time updates (e.g., a MOM) and others offering asynchronous information (e.g., Google Maps views). Gathering rich, updated information is vital to coordinating the response.

The process of gathering information must be continuous due to the dynamic nature of the context, which is subject to change due to expected and unexpected events. Additionally, the flow of information itself is dynamic; it is not always linear (it may not reflect the sequence of events), not always accurate and certain information may take time to emerge. Consequently, controllers must constantly collect and evaluate both local and global information related to the event, the broader context, and the available resources, reconstructing their mental models in response to changes in the information landscape.

Table 8-6 Observed sources of information and methods of communication used by the IC

Observed Sources of Information	Observed Methods of Communication
Response Team: • MOM – Mobile Operation Manager • S&T – Signalling and Telecom • PWay – Permanent Way maintenance team **Control Team:** • IC – Incident Controller • ISC – Incident Support Controller • TSE – Tech Support Engineer • RCM – Route Control Manager • TRC – Train Running Controller **Signallers and Signallers Managers** **BTP** – British Transport Police **Police** **EMR** (East Midlands Rail) team (the train operating company (TOC) on site. **GSM-R Recordings** of conversations (GSMR automatically records every conversation) **Train Station Staff** **CCTV cameras** (level crossing and trains forward CTTV)	• **GSM-R** – (Global System for Mobile Railways) – the European Radio System for Railways communications • **Radio** (mainly to MOMs) • **Regular phoneline** • **Level crossing phoneline** • **Email** • **WhatsApp** (e.g., updates, pictures, videos) • **Face-to-face** (from desk to desk or going to other's desks)

Table 8-6 Continuous

Observed Sources of Information	Observed Methods of Communication
Incident computer systems, used by Network Rail (Network Rail) and TOCs/FOCs (Freight Operating Companies) controllers: • Fault Management System (F2000) (also used by infrastructure constructors) • Incidents Alerts • CCIL – Control Centre Incident Log **Internet** (e.g., Google Maps, weather forecast, level crossing description, postcodes, etc). **Live trains timetables** **Signallers control screens** (see Table 8-9)	

As controllers gather and assess new information and reconstruct their mental models, they adapt the response plan. This dynamic adaptation implies a continuous and flexible response to changing circumstances, enabling controllers to maintain the system's safety and functionality after a failure.

The mental models forming the basis of dynamic adaptation encompass not only an understanding of current events and appropriate responses but also considerations of potential future scenarios. For example, this concept is illustrated in Figure 8-2, where controllers gather information about both the internal and external context of the train. They use this information to anticipate various factors, such as the likelihood of passengers self-evacuating and the risks associated with leaving passengers on board for an extended period (e.g., elderly passengers on a hot train without access to drinking water). Accordingly, controllers flexibly respond and adjust their strategies to address immediate changes, pressures, and resource availability, while also preparing for and anticipating possible future challenges.

8.5.1.3 Support the team: teamwork

ICs operate as a part of a team, which functions within a larger network of individuals and teams participating in the management of incidents. As previously mentioned, incident control activities heavily rely on cognitive processes such as gathering, assessing, and communicating information, decision-making, and problem-solving. Distributing these tasks within the control team enhances the efficiency of the overall control process. For example, in the incident above the Incident Support Controller (ISC) and the Tech Support Engineer (TSE) stepped in promptly to assist the IC. Therefore, while it may appear that controllers are working in isolation during a specific incident, incident control entails a distributed cognitive activity.

Many controllers emphasised the importance of sharing information among the team members and being up to date with developments in other stations. Knowing what is going on in each station allows them to help each other whenever needed, to promptly take over a colleague's incident if required or to work together if the incident escalates in complexity. For this reason, they remain attentive to ongoing events and have established routines to facilitate this information sharing. For example, when they talk on the phone, they usually start the conversation by saying who are they talking to (e.g., 'Hello BTP') and repeat new or relevant information aloud [67]. Non-verbal communication is also utilised within the team; for instance, making eye contact signals to another team member that a current phone or radio conversation is relevant to them, while nods or thumbs up confirm receipt of a message.

Except for one IC with a police background, all ICs participating in the observations came from various rail operational backgrounds, including PWay, S&T, TOCs and signalling. This diverse mix of backgrounds and experiences enables ICs to seek clarification from one another when in doubt, collaborate on finding solutions collectively, and gain insights into the rationale behind certain actions taken by ground staff. It is common to observe controllers engaging in discussions regarding potential causes of issues or determining the most effective response strategies. One IC emphasised that...

[67] This observed routine is a well-established communication strategy within team undertaking safety-critical activities.

> *"It is important to be able to ask when you don't know, and to know who to ask. Everything that happens in rail has happened before, so you just need to find the person with the experience to know"*

8.5.1.4 Spreading information: Creating collective awareness

The control team operates within a network that includes TOCs, signalling, BTP, and Network Rail response teams (MOM, S&T, PWay). These teams also need to maintain awareness of real-time activities, their development, and potential outcomes to form the mental models necessary for dynamic adaptation.

This IC's function involves disseminating information to ensure all parties are aware of the situation (i.e., collective awareness). For example, as shown in Figure 8-2, BTP required information about the passengers and the train context to plan accordingly. The train operating company, EMR, needed timely updates on the progress of the MOM and an estimated time for problem resolution. Additionally, EMR needed to ascertain BTP support availability to minimise the risk of passenger detraining. Accurate information about the situation and available resources was crucial for EMR to plan its response and minimise disruptions.

Creating collective awareness is also central to minimising the risk of knock-on effects across the system. Incidents in one area can lead to delays that have the potential to escalate and cause (major) disruptions in other areas. ICs must make Network Rail and TOCs controllers in the bordering regions aware of: a) the incidents occurring in the IC region, and b) whether these incidents have the potential to cause serious disruptions in their regions. To do this, ICs enter every new incident into the Incident Alert system (Table 8-6), providing a brief description of the issue and a code. This code consists of a letter (D, C, or A) indicating the level of risk, paired with a number from 1 to 4 denoting the estimated delay in minutes that the incident may cause, as shown in Table 8-7. Since all controllers in the railway system have access to the Incident Alert system, they can anticipate the potential impacts of incidents in bordering regions and proactively initiate a response.

Table 8-7 Coding system for incident alerts

Level of risk	Estimated delay in minutes
A – Safety related incident with potential to cause staff fatality / serious injury. **C** – Safety related incident (e.g., may cause derailment or SPAD) **D** – Non safety related incident but likely to cause delays	**1** – Likely to cause more than 2000[68] **2** – 1001 to 2000 **3** – 500 to 1000 **3 Potential** – 400 to 500 affecting high-traffic areas **4** – 0 to 400

Through this system, ICs create collective awareness not only within the parties operating in their region but also across the system. For example, ICs in the EMCC control the Bedford area, which interfaces with the St. Pancras area. If a D4 incident (i.e., likely to cause 300 minutes of delays in Nottingham) occurs in the Bedford area, EMCC ICs would code the incident as D3 Potential. This is due to its likelihood of escalating when crossing into the high-traffic St. Pancras area. This alerts St. Pancras area controllers to the potential risk, allowing them to initiate a response before disruptions occur, thereby minimising the risk of knock-on effects. Although the coding follows a set rule, determining how to code incidents is based on experience and learned on the job, and it relies on the controller's estimation of the minutes of delay.

[68] This refers to the total number of minutes delays expected from adding the delays of all services related to the incident.

Table 8-8 Incident Controller observed functions: ensuring safety (Safety); planning and coordinating the response (Information and Response), supporting the team (Teamwork), and spreading the information (CA). Maintaining stability function (Stability) also included with the source of stability in italics.

Incident / Issue	**Function**
At 12.30 pm, a lorry knocked off clean the barriers, which went down to the side of the track. The missing barrier appears in the system as 'failure'. Signs have been put to danger. The incident was reported to the signaller by the truck driver. The signaller reports to the IC.	**Stability –** The *automated system* detected the failure and set the lights to red. The *signaller* initiated the response by taking care of safety-critical actions (lights to red / at danger and ensuring no train access to the affected section of the track) and contacting the controller to report the incident. **Information** – IC1 listening on the phone and taking handwritten notes, asking the signaller if he took the driver's details – writing down the details **CA** – As IC1 receives the information repeats back to make the other controllers aware. **Response** – IC1 takes the radio to talk to Lincon MOM and sends him there to sort out the fault in the barrier. **Information** – MOM is on his way expecting about 70 minutes to arrive at the place. **CA** – IC1 informs the TRC (sat next desk) → **Teamwork** – TCR to work with TOC to minimise service disruption. **Response** – IC1 calls PWay on the phone. **CA –** IC1 makes two more calls to report and to tell them that the MOM is on the way. **Information –** IC1 checks the area in Google Maps and gathers information about the crossing using the ABC railway guide online. **CA** – IC1 Makes another call, passes the postcode to the person at the other end and informs them that MOM are on the way and that one barrier is missing **CA –** EMR Route Duty Manager walks nearby, and IC1 calls him to let him know about the incident **CA / Information –** IC1 makes another call, and passes the train driver number to them and the incident reference number. IC1 asks if they have assistance there and tells them that they will call the BTP **Teamwork** – IC1 talks over the desk with the second IC (IC2), who now is working with him on the incident. IC2 is with the BTP officer onsite (at the control room station), they are looking at something on the officer's phone.

Table 8-8 Continuous

Incident / Issue	Function
Issue: IC cannot get hold of Lincon BTP	**Teamwork** – IC2 ask the BTP officer whether he can get hold of the BTP in Lincoln because he is calling but no one is answering. **CA** – BTP in Lincoln finally answers the phone and IC2 passes them the information about the incident, the truck driver and the truck company. IC2 says that they wanted to let them know in case they get informed by the public and because someone may want to cross[69]. **Teamwork / CA / Stability –** *BTP* call the *ambulance* and *fire services* to let them know about the risk.
Safety issue: Someone from the truck company is waving the traffic through the level crossing[70]. BTP has no resources to respond.	**Information** – BTP calls and informs that a driver has reported that someone from the truck company is waving the traffic at the level crossing and that BTP has no resources to respond. **Response / Stability** – IC2 calls *Lincolnshire Police* asking for support as BTP in Lincoln has no enough staff to respond. The police agree to send support. **Information** – IC1 calls the MOM to ask for an update. **Teamwork / CA** – The RCM is on the phone with BTP who are asking for an update on the incident. **Information** – Lincolnshire Police calls IC1 to let them know they are on site and taking care of the issue **Information** – PIC (PWay) phone IC2: S&T just arrived and that will try to refit the displaced barrier. MOM is also onsite.

[69] IC explains to researcher that signallers are the first one to know – signallers are usually the ones reporting to control – and they are taking care of the situation from the first moment. Since the signallers are taking care of the critical part, IC explains that he prefers the first call to be to the responders (MOM, S&T and PW) because they will be the ones to fix the problem. Then, he calls/informs the rest (TOC, BTP, etc) to let them know what happened, that the people to take care of it are in their way and how long it will take them to get there. He explains that other ICs may call the TOC or BTP first.

[70] Waving traffic through at a level crossing is a hazardous behaviour and is strictly prohibited. It constitutes an offense for all parties involved, including the transportation company and the drivers crossing, as they are not allowed to pass a red signal at a level crossing, regardless of whether barriers are present or not.

Table 8-8 Continuous

Incident / Issue	Function
	Information – Another call from the PWay team about the barriers and the truck driver. **Teamwork** – PW will leave BTP to interview the driver. With that information, once the incident is sorted out, Network Rail's legal department will take care of the incident to arrange accountabilities, insurance, etc. **CA** – IC2 to BTP to give the registration of the truck and the latest update (the MOM has spoken to the police on site. The police told them that the truck driver reported that he was following a van, the van reversed, and the truck got stuck in the crossing). [71] **Information** – MOM to IC2 with an update: BTP is onsite. Barrier back to auto-control with the signaller. **Information** – MOM to IC2: All is repaired and in order. **CA** – IC2 goes to the EMR Regional Duty Manager to let him know that all has been sorted and is back to normal. **Information** – MOM calls IC2: All has now been fully tested and they confirm that is back to normal. It is 15.05, two and a half hours after the incident was reported.
Incident closure (1505h)	IC1 finishes filing in the CCIL, F2000 and Incident Book.

[71] Information about the incident from IC2 to researcher: The response teams (MOM, S&T and PW) are on site trying to fix the barrier. Meanwhile, a level crossing assistant (LCA) is onsite and s/he is changing the barrier from automatic to manual control. This means that the barrier will not come up and down automatically; the signaller in charge of the level crossing will call the LCA to lift / down the barrier manually every time a train passes. The LCA will be there until the system is fixed and put back to automatic. The incident happened because the truck crossed the track following a white van. The van stopped and started reversing to get into a side lane, which stopped the truck over the crossing. Meanwhile, the barrier started to come down and got caught up on the truck. When the van cleared up the way, the truck went forward causing the barrier damage and some damage to the traffic light wig-wag (the metal piece around the traffic light). IC2 shows the researcher pictures of the incident that the response team has uploaded to the WhatsApp group.

8.5.2 Incident Controller's functions underlying processes

The descriptions of IC function reveal that dynamic adaptations to manage incidents occur at three levels (Figure 8-3), with the IC playing a role in each:

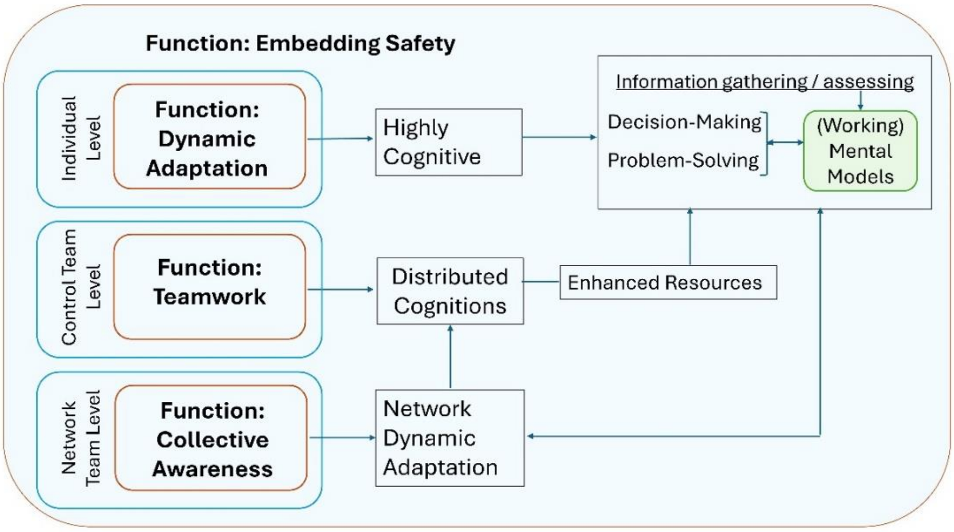

Figure 8-3 Incident Controller's functions, levels and underlying processes

- At the individual level, the IC adapts to respond as events develop. This activity is highly cognitive and requires mental models of what (is the current (fluid) situation), how (to respond) and potential (future scenarios). Skilful gathering, assessment and communication of information is vital to constructing those mental models, core to decision-making, problem-solving and planning processes.
- At the control team level, cognitions are distributed, enhancing the effectiveness of the adaptation process. Each IC is a resource in terms of time (reduced by having more people working on the incident), experience, knowledge, and manpower (as any team member can step in and help or replace another team member). This way, teamwork facilitates the cognitive process underlying the adaptation (information-related processes, decision-making, problem-solving and so on) as well as the response coordination.
- At the network teams level, each interfacing team plays a specific role in managing the incident, contributing to the system's dynamic adaptation to the eventuality. The IC plays an important role in providing information for those teams to form their mental models of the situation. Likewise, interfacing teams' members often participate in processes such as decision-making and problem-solving together.

8.5.3 The role of rules and routines in the IC's activity

The work of controllers is regulated and guided by a variety of operational standards and procedures, including National Operational Procedures (NOPs) and Network Rail company standards and contingency plans.

Most Network Rail operational standards observed are characterised by allowing ample degree of freedom in decision-making. The modules and manuals containing the standards are brief and many of them have a simplified version, such as a one-page diagram, table, or checklist. Checklists are widely used by controllers. They include several actions presented in sequential order, often phrased as '*Controllers ensure that the following actions have been followed.*' These actions are outlined without much or any detail about how to execute them or a specified order, and not all actions listed are necessary in every instance. ICs assess the situation and have the flexibility to decide when and how to proceed based on the context. An IC explained:

> *"You know the goal and, as you get the information, you start planning what is the best thing to do in that scenario, what you should do first. You don't follow the process as in the manual, you know what the goal is, and you think on your feet."*

Simplified procedures, such as checklists and tables, also help to save time when quick decisions are necessary and there are multiple reasonable options. Decisions often need to be made swiftly for safety but also for efficiency. For instance, delaying decisions can result in longer intervals before the next train can be dispatched, leading to time escalations (which can result in considerable delays if there are, for instance, 20 trains to set out). Contingency plans are also utilised to resolve conflicts, such as those between two TOCs requesting access during disruptions.

Although operational standards for controllers are not prescriptive, ICs also work under the "*rules of others"*. For instance, when signallers activate a red light following a prescription, controllers are bound by that action. However, having flexible rules allows them to navigate around such constraints. As one IC mentioned, they have the autonomy...

> “to think out of the box and, when a situation does not match what is on the rules, we can risk assess and come with the best solution to keep the operation going.”

Unlike signallers or train drivers, ICs do not undergo *formal* training before assuming their posts; they learn the procedures by shadowing other team members. More importantly, they learn the routines that ensure efficient incident management. They learn the golden rule – safety first and then performance. They learn how to gather and assess information, make decisions, maintain awareness of open incidents’ development, communicate with the team and others, and so on. Despite the dynamic nature of their roles, their activity is based on these routines, which they *informally* acquire as a part of the team.

According to one of the controllers, processes have significantly improved in terms of efficiency, but it comes to the skills of the controller to make the process efficient. They provided the example of suicide incidents and how they now typically reopen the line within an hour or shortly thereafter. While the standard protocol outlines the people the IC needs to contact, it does not specify the order; however, it is ‘*common sense*’ to call the ambulance first (prioritising lives), followed by the police (ensuring safety), and then the operational staff (RIO and MOM). Typically, the person who answers the call and opens the incident will coordinate team activities; however, experienced teams like the observed often self-organise by remaining aware of each member's actions and determining the best next steps (as shown in Table 8-8).

ICs resolve most incidents without referring to the procedures because many of the incidents they deal with occur regularly. However, they emphasise the value of having procedures in place because they cannot remember everything, so they rely on the manual when encountering unfamiliar incidents or to double-check specifics. They may also use checklists to ensure that all necessary steps have been taken. However, it seems that what they call ‘*common sense’* – which appears to be informally learned as part of training – is often more important than strictly adhering to the rules. For example, an IC mentioned that while the Rulebook states that trains should not be stopped for deer, they would ignore the rule and stop if the deer were a large stag because ‘*it is common sense*’.

Finally, despite that the controller activity is mostly learned informally within a local group, controllers explained the importance of having consistency regarding their activity across the system. This was discussed during an observation in which a TRC was at the EMCC covering another area which had insufficient staff for the day. As the routines and the technologies are the same across areas, there is flexibility to adapt to staff shortages. The controller emphasised that by having a standardised method of work they can move from area to area, cover for others, or help with incidents occurring in other areas '*because there is consistency*'.

8.6 Maintaining stability: The signaller's safety-critical role

Signallers control train movements across the network by operating a complex system of traffic lights and other equipment. Their primary responsibility is to ensure the safety of trains, maintenance staff, and members of the public in the area they control while aiming to make train movements as efficient as possible to minimise delays. The signalling control system is highly automated and prepared to fail safely. Failures show instantly in the signaller station, which enables them to rapidly initiate the response to maintain the system's safety. Signallers also take an active and important role in line blockages and possessions[72] during rail maintenance work, as ensuring the safety of workers is a crucial aspect of their safety-critical role.

Signallers control the movements of trains using diagram screens, which show and control the lineside and traffic lights. Each workstation has several diagram screens comprising the area of control at that station. These diagrams represent the tracks and the location of trains in real-time, as well as the position of line blockages and possession.

Besides the diagram screens, signallers' stations are equipped with a GSM-R (Global System for Mobile Railways) through which signallers communicate with train drivers, a phone, CCTV cameras offering real-time views of the level crossing, and screens displaying other real-time information about the segment they control and beyond (Table 8-9).

[72] Line blockages and possessions are areas of the track undergoing maintenance or repair works. Possessions involve the closure of the track undertaking the maintenance work to train traffic. Line blockages are used for smaller works, and the maintenance staff gets on the track between trains.

Table 8-9 Digital systems sources of real-time information available to signallers

System	Description
SDCR – Siemens Digital Conflict Resolution	Displays live information of all the trains that will pass through the signaller area in the next two hours. This includes path booked, train ID, origin and destination, arrival and departure time in the signaller station, platform, line and stops.
TRUST – Train Running System on TOPS[73]	Records details of train running as compared with schedule; it registers the delays, the issue that caused the delay and 'who' caused it
Full diagram screen	Shows the whole picture of the network in the area of the signaller (e.g., East Midlands). They can click on any train in the network and the route booked for that train lights up. If they double-click on the train, it opens the train information in TRUST.
Siemens Fault system	Displays reported faults in the system within the area they control (one for each station).

When something goes wrong in the system, signallers are typically the initial point of contact in many operational rules and procedures, so they can manage promptly the safety aspect. They are often the ones to first communicate the incident to the controllers. Their role in gathering and spreading information is also significant. Usually, they are the interface between train drivers and controllers, as well as other parties, such as staff at the train stations or members of the public at level crossings.

During emergencies or incidents, signallers and controllers work together to develop plans; the controller proposes the strategic plan, while the signaller devises a plan that warrants safety and is feasible within their area. Once agreed upon, the signaller implements the plan. They may implement emergency procedures, such as stopping trains, putting the lights to danger or diverting traffic. Like controllers, they must adapt their response strategy as the incident develops. However, they work under a strict set of rules and protocols.

[73] TOPS stands for Total Operations Processing System.

8.6.1 The role of rules and routines in the signaller's activity

In their safety-critical role, signallers must adhere to strict regulations outlined in The Rule Book, published by the RSSB. During interviews, signallers emphasized the importance of strictly following these operational rules to ensure safety. For example, they mentioned the rigorous protocol during the initial phone call with the PICOP[74] to coordinate a possession setup. Adhering to the rules is crucial to ensure accurate information regarding possession limits and duration. Signallers also noted instances where maintenance teams deviated from protocols, either for convenience or due to lack of knowledge, highlighting the risks associated with such behaviour.

Learning the standards and procedures regulating their work is vital for signallers and is a core part of their training. Signallers complete 12 weeks of extensive classroom and location-specific training. After the formal training period, they are yearly reassessed in an ongoing cycle of competence assessments to ensure that their skills and knowledge of the standards remain up to date.

Signallers emphasised the importance of rules for safety and coordination but also highlighted shortcomings in The Rule Book. Some commented that the manuals and certain practices need updating, contain too many rules, the wording is sometimes complicated, and some rules do not make sense. Additionally, access to The Rule Book is limited to print copies, and modules lack simplified presentation. Signallers believe that involving them in rulemaking could improve rules' relevance and effectiveness.

Signallers' rules are highly prescriptive regarding safety; however, rules afford flexibility in terms of efficiency. For instance, specific instructions dictate when a light must be red, but signallers have discretion in choosing which track to route a train through to optimise traffic flow efficiently.

Prescriptive rules do not necessarily dictate every aspect of a signaller's actions and aspects like social interactions remain uncodified. Examples given during the interviews are handling non-compliant PICOPs or discerning when a PICOP does not understand what they are repeating back to the signaller (required to ensure they have the information needed). How rules are

[74] Person in charge of the possession.

interpreted plays a critical role in the effective application of the rule, as one signaller noted...

> *'we all have the same Rule Book, but we all interpret it slightly differently. There's lots of times when you can be doing your rulebook correctly, but you're not doing it very well on a personal level with how you deal with people.'*

Interpretations do not only play a role at the individual level but also at the local or regional level; despite that signallers' rules are standardised across the system, their interpretation may vary between areas, as a shift manager highlighted:

> *'once a year, all the trainers would get together from around the country to discuss the new rules [] and that's when I first really noticed the different interpretations of everything around the country.'*

Two reasons for the different interpretations were identified from the signallers' accounts. First, signallers learn the rules during their training, but the training practices themselves are not standardised:

> *"[training] is very different from area to area. And the problem with that is that we do get signallers moving from these areas in and about. We get a signaller coming from the northeast here, he has the basic same training as everybody else, but the interpretation is, out of some of the rules, is different to what we teach. It can be quite challenging."*

Another reason identified is that local practices may influence the interpretation of rules. In signalling boxes with only one signaller and limited technology, manuals contain more rules, and are generally more prescriptive. However, in ROCs with larger teams and modern technologies, signallers' manuals are less restrictive, and there is greater reliance on practices agreed upon locally to cover the grey areas in the manual:

> *'If something's a bit subjective, say, trespasses, where you think "well, technically, I don't have to caution for that, but I don't like the sound of it, so I think I will." You've then got another opinion,*

at least in your SSM. And it can... Yeah, it helps with the grey areas, and there are a lot of grey areas in the rule box still.'

Signallers also explained how local, informal practices may ingrain and guide decision-making processes and practices as these are *'how we do it here.'*". For instance, in the EMCC, signallers utilise a second document for possessions not included in The Rule Book; yet, it is followed as strictly as a regulation, despite disagreements from managers who view it as redundant work adding to their workload:

'There is no reason at all why we have a second sheet of paper at all. And that maybe plus 15, 20, 30 minutes work extra on everybody's shoulders every night. [...]. Over the course of the year, you can end up with 1,500, 2,000 extra hours' worth of manpower, for the sake of replicating one piece of paper to another'.

Local practices appear to be an important part of the everyday activity of signallers and, from the data collected, these seem to be directed to reinforce safety rather than efficiency.

8.6.2 Comparing controllers and signallers' rules and routines

Table 8-10 outlines the distinctions in the main features of rules utilised by controllers and signallers, as well as the roles these rules serve in their respective activities.

As summarised in Table 8-10, the rules used by controllers and signallers align with their respective roles. Signallers bear the primary safety responsibility and adhere to strict protocols during incidents. These protocols are formally taught during training and regularly assessed for proficiency. However, the accessibility of rules could be improved.

Controllers' rules are also well suited to their activity, which requires flexibility of action to continuously adapt to the situation. Their rules are mostly flexible (e.g., goal and process rules) and directed to guide and assist their activity rather than to impose constraints. Furthermore, the simplicity and presentation of the rules are well-suited to their function.

Table 8-10 Differences between features and function of rules in control and signalling activities

Rules	Controllers	Signallers
Overall Goal	Flexibility for dynamic adaptation	Stability to maintain safety
Role	Supporting the cognitive activities underlying the adaptations (e.g., cognitive processes such as memory (often act as a memory aid), decision-making, planning, etc, by giving options, road-mapping possible scenarios and solutions, setting goals, etc). Allowing decision-making autonomy Saving time (e.g., when multiple options are available, lack of time to discuss solutions or get to an agreement (conflict resolution), etc.)	Hazard control during normal and degraded situations by setting precise parameters of action Ensuring safe coordination of the train–maintenance staff interface
Type of rules	Mostly flexible – goal and process rules	Mostly prescriptive – action rules
Accessibility	User-friendly, accessible online, often simplified as diagrams, tables, or checklists	Not user-friendly, sometimes complicated wording and with many variations for each scenario. Rules hard to find when needed and not simplified formats; only presented as full standards and only on print.
Quantity (as expressed by participants)	Not too many/not many	Too many
Learning process	Learned informally on the job	Learned formally during the training period and reassessed yearly
Usefulness (as expressed by participants)	Useful tools to facilitate their work and aid memory and decision-making	Vital tools for coordination at interfaces and for establishing the foundations of their activity

Since this study aimed to investigate controllers' activities rather than signallers, a direct comparison of their routines is not feasible. However, the data revealed an intriguing difference. Controllers rely on learned routines, which are fundamental to effective operation during incidents, individually and as part of a team. Rather than through a structured program with a set duration, as seen with signallers, controllers' routines are learned 'informally' within the local group, where they gradually assume more responsibilities over time. Despite the informal nature of this training, the data suggests that these learned routines maintain consistency across regions, unlike the formally trained routines of signallers. Interestingly, while it may be assumed that prescriptive rules would lead to less variation, it is the flexible routines of controllers (guided by flexible rules) that could exhibit greater stability across the system, according to participants' accounts.

8.7 Stability and flexibility in the incident control process

8.7.1 Integrating stability and flexibility

These findings show that stability and flexibility in practice do not only coexist but are also codependent. The main source of stability is the signaller, who provides the safety-critical function that allows the IC to act flexibly. In turn, the role of the signaller is supported, firstly, by a highly automated system prepared to fail safely and, secondly, by strict rules and regulations controlling their activity. Occasionally, other actors, such as BTP and ambulance and fire services, also deal with safety-critical aspects of the process, being a further source of stability. These external sources of stability support flexibility and dynamic adaptations in the control room; controllers can think creatively and improvise solutions while safety is being taken care of. Likewise, IC's flexible behaviours are also supported by flexible rules and procedures that are a source of both stability and flexibility (Grote & Weichbrodt; 2007). On one hand, they provide stability since they set safety goals and indicate ways to achieve them; on the other hand, these rules allow decision-making and, thus, flexibility of action.

The routines ICs learn during the training are another vital source of both stability and flexibility. These may be compared to HROs' concept of 'collective mindfulness'. Collective mindfulness conveys the idea that flexible behaviours are guided by stable mental models of how to manage the unexpected in a stable manner. Stability and flexibility are this way integrated:

stable mental models guide flexible behaviours that yield stable outcomes (Weick & Sutcliffe, 2011; Weick et al., 1999). In the control room, the behavioural patterns ingrained during the trainee period appear to become stable mental models of how to perceive, understand, and manage the incident in a stable manner, while being flexible to adapt to the situation.

Notice that these stable mental models differ from those referred to in Section 1.3.1.2 regarding dynamic adaptations. Those are 'working mental models' core to planning and coordinating adaptations that are not stable; they are a representation of the situation that changes as new information arrives and the plan and response develop.

8.7.2 Flexibility and empowerment

In a similar vein to stability being identified as a prerequisite for flexibility, these findings indicate that both team and individual empowerment are essential. Here, empowerment refers to granting incident controllers the authority and resources necessary to make decisions. A core resource is information. Controllers must make real-time decisions within a context from which they are physically removed. These decisions must effectively manage both local and global effects; accurate and comprehensive information about the local and global context is indispensable for informed decision-making. Additionally, flexible rules provide a valuable resource, given their alignment with the demands of the controllers' roles (working under prescriptive rules would hinder rather than facilitate the flexibility required in their role). Finally, the team itself emerges as a crucial resource, offering a diverse range of skills, knowledge, and manpower. Altogether, resources and authority to plan and implement the response are crucial to effective flexibility of action.

8.8 Summary of the findings

This case study investigated stability and flexibility in practice by observing the activity of rail incident controllers (ICs). ICs have a key role within a network of individuals and teams participating in the management of rail incidents. Four primary IC functions were identified as contributors of the IC activity to the overall management of incidents, contributions that happened at three levels (Table 8-11).

Table 8-11 Summary of IC functions and levels of contributions

Level	Function	Description and underlying process
Individual	***Embedding safety***	Critical to their activity is ensuring that safety is embedded in the decision-making, planning process, and response.
	Planning and coordinating the response: *dynamic adaptations*	This function is highly cognitive and requires ongoing gathering and assessing of information to create (working) mental models of the situation to guide decision-making and problem-solving. These mental models, the plans and the response are flexible and adapt to the development of the situation.
Control Team	**Supporting the team and other stakeholders: *teamwork***	Each IC plays a role within the team. Teamwork also extends to other interfacing teams within the network. Cognitions are distributed to enhance the efficiency of the planning and implementation of the response.
Network	**Spreading the information: *creating collective awareness***	Incidents are managed by a network of individuals and teams. Information flow is bidirectional: Incident Controllers gather and disseminate real-time information crucial for their own and other teams' dynamic adaptations, as well as for network collaboration.

These findings revealed different sources of stability and flexibility. The work of signallers appeared as the main source of stability, which in turn is supported by automation, prescriptive rules, and local practices. Decision-making autonomy and access to resources revealed important sources of flexibility, highlighting the importance of empowerment to effective flexible behaviours.

In accordance with previous findings in this thesis, the present findings also demonstrate that stability and flexibility may coexist – and even show co-dependency – within the same mechanism or process, as is the case of flexible rules and learned routines. Altogether, sources and mechanisms for stability, flexibility and those in which both coexist, make it possible for the IC to adapt and effectively and safely manage eventualities (Table 8-12).

Table 8-12 Summary of stability and flexibility sources, mechanisms and integration

Goal	Source	Mechanism
Stability	Signallers	Automation Prescriptive Rules Local Norms
	Other safety-critical actors (BTP, Police, Ambulance and Fire services)	
Flexibility	Empowerment	Decision-Making Authority Resources Information Flexible Rules
	Teamwork	Resources Knowledge Manpower
Stability & Flexibility	Flexible Rules	Stable goals & flexible actions
	Routines	Stable mental models Flexible behaviours
	Learned reasoning	'Common Sense'

8.9 Discussion

This case study examined the real-life activities of rail infrastructure incident controllers (ICs), using real-case examples to illustrate dynamic adaptations. ICs' ability to adapt and maintain operations under unexpected conditions exemplifies resilience in practice (Pariès et al., 2013). The findings highlighted the importance of balancing stability and flexibility to support resilience (Grote, 2015, 2011; McDonald, 2006). Exploring the dynamics of incident management in the ROC provides a clear example of concurrently managing safety under two contrasting approaches: the classic risk mitigation approach aimed at reducing uncertainty in the signalling room, and the resilient approach aimed at managing uncertainty in the control room.

In the signalling room, uncertainty is reduced (and stability achieved) through central control, adherence to strict standards and high automation, measures typically used to manage safety under the classic risk mitigation approach. In the control room, uncertainty is managed in two ways. Firstly, by transforming uncertainty into certainty. The incident management process begins with high uncertainty about the incident's conditions. ICs work to form an accurate mental model of the event, its context, and the available resources. They gather information to transition from the 'unknown' to the ‘known’, creating as much certainty as possible about the situation. Secondly, they consider the possible or most likely outcomes of different aspects of the situation (e.g., passengers are most likely to self-evacuate) and take actions that are most likely to achieve the desired outcomes.

These two approaches to managing uncertainty represent different understandings of uncertainty that often coexist in Complex Socio-Technical Systems (CSS). The first approach reflects epistemological uncertainty, where uncertainty arises from incomplete knowledge or information. The second approach reflects ontological uncertainty, where uncertainty is inherent to complex systems. In such systems, outcomes are uncertain due to intricate, non-linear interactions among the system’s components, making it impossible to predict system behaviour with certainty (see Chapter 3, Section 3.2). Consequently, while information is necessary to transform uncertainty into certainty regarding the current state of the incident, contingency plans and an experienced, skilled control team are essential for managing the potential outcomes of the incident.

Flexible rules and routines to balance stability and flexibility in work behaviours have been well described in safety and organisational research (e.g., Grote, 2016b; Pentland & Feldman, 2005; Weichbrodt & Grote, 2010; Weick & Sutcliffe, 2011). These findings also revealed the importance of informally learned reasoning as a source of stability and flexibility in the incident management process. Participants referred to ‘common sense’ as a higher-level principle guiding decision-making. Weick (1995) uses the concept of ‘sensemaking’ to explain how professionals develop a shared, ‘common’ sense of how to understand, interpret and respond to new situations.

In Weick's (1995) theory, shared understandings are built through three components: a frame, a cue, and their connection (Czarniawska, 1997). Sensemaking involves interpreting new, uncertain, or ambiguous information (the cue) by relating it to a stable, familiar context (the frame), thereby creating understanding through their connection. Therefore, by connecting a cue to an existing frame, individuals can make sense of a situation within the context of what they already know. These shared frames include rules and procedures, professional jargon and language, stories and narratives, norms and values, mental models, and routines. Many of these elements have been described in this study as a source of stability guiding IC’s flexible behaviours.

From this study, it cannot be determined whether ICs' shared 'common' sense is confined to individual site teams, creating microcultures. However, participants' accounts suggest that while signallers' formal training and prescriptive rules might imply less variation, controllers' informal training and flexible rules could offer greater system-wide stability (i.e., ROCs). This points to a shared occupational (sub)culture rather than microcultures at each site. To answer this question further research is needed.

8.10 Chapter conclusions

Rail operation control teams play a crucial role in ensuring continuous, safe and efficient operations in the face of contingencies. This study was set to explore stability and flexibility in rail operations in practice focusing on the activity of infrastructure incident controllers (ICs). The study has identified, described and discussed a) ICs' functions and processes underlying their role in incident management; b) sources of stability and flexibility supporting the IC's activity, and c) ways in which stability and flexibility are integrated in the incident control process. From these findings, it may be concluded that:

- The role of the IC is key to solving local failures and preventing potential system-wide effects of these local failures or the actions to resolve them.
- Incident management requires dynamic problem-solving to adapt as the incident unfolds and the resources vary. Empowering ICs with the flexibility, authority and resources is core to dynamic planning and adaptation to the changing circumstances.
- Successful resolution of incidents also involves minimising uncertainties regarding how failures occurred, the local consequences, and the potential network-wide effects. Teamwork and collaboration with other teams in the network are key to reducing uncertainty and managing local failure and potential global consequences.
- Signallers play a key role in incident management by providing the stability over which adaptations can develop safely.
- The type of training, rules, technologies and context surrounding the signallers and ICs' roles are aligned with the stable and flexible nature of their roles.

- Despite the flexible rules and informal training attached to the IC's activity, ICs seem to develop stable, collective behavioural routines and reasoning patterns. These are also a source of stability to their flexible activities.

8.11 Limitations and questions raised

This case study provided a unique opportunity to explore adaptations in rail infrastructure incident control, offering insights not only into the activities of Incident Controllers (ICs) but also into how their actions are supported by signallers. Due to time and site-access constraints, only 11 site visits were possible, which can be considered a limitation. However, to the best of the researcher's knowledge, this is the first case study examining ICs' adaptations in practice, framed by the concepts of stability and flexibility. Therefore, this case study served as an initial exploration. Additionally, the controllers' acceptance of the researcher, along with their openness and enthusiasm for the research project, facilitated the collection of rich data, counterbalancing the limited time available for data collection.

This initial exploration could set the basis for a longer case study. A longer case study taking an ethnographic approach could explore in-depth shared frames of reference as a source of stability. Furthermore, a multisite or cross-sectional case study could shed light on the question raised in the discussion regarding micro-cultures versus (sub)cultures as a source of stability supporting flexibility and adaptation.

9 Discussion

9.1 Introduction

This thesis has explored operational safety in the GB railway system through two key concepts anchored in Grote's uncertainty management framework: stability and flexibility (Grote, 2016b; 2015). Stability characterises an operational model that, through hierarchical control structures and adherence to standards, aims to increase safety by controlling hazards and minimising uncertainties. This centralised control approach is dominant in safety-critical systems such as railways. Centralised control relies on predictions of how the system will work and prescribed control measures to mitigate risks (Chapter 3, Section 3.1).

However, authors such as Resilience Engineering (RE) scholars argue that modern systems are too complex and uncertainty too high to rely solely on predictions and standardised control measures (e.g., Hollnagel et al., 2006; Dekker, 2014; Woods, 2018). They advocate for creating adaptive systems that can navigate changing demands and uncertainties. To adapt, systems need to be flexible, relying on local actors who can manage safety in context. Creating systems that are both stable and flexible appears contradictory, a contradiction that must be resolved for complex systems to evolve into complex adaptive systems (Harvey, 2018; Nolan-McSweeney, 2022)

The GB railway system offers a unique opportunity to explore this contradiction. Firstly, the GB rail socio-technical system is complex (Nolan-McSweeney, 2022; Ryan et al., 2021; Wilson, 2014). Secondly, despite being operated under a classic centralised control paradigm, this system demonstrates a good adaptive capacity. For example, it adapted to the unprecedented demands and surprises posed by the COVID-19 pandemic while maintaining safety performance. Moreover, the GB rail industry is facing rising demands for efficiency and innovation, along with budget cuts and sector reforms, altogether increasing the requirements for flexibility. Thus, it is essential to explore ways to integrate the existing safety management approach with alternative methods.

With a view of informing theory and practice, the aim of this doctoral research was to explore ways to increase flexibility in work processes and behaviours without compromising the system's safety. Underpinned by Grote's uncertainty management framework (Grote, 2016b; 2015) and informed by research in organisational management (e.g., March, 1991; Farjoun, 2010; Feldman & Pentland, 2003; O'Reilly & Tushman, 2013), this research embraced the duality of stability and flexibility, using these concepts as two separate dimensions, not mutually exclusive. To accomplish the aim and objectives, a combination of methods that included interviews, observations, and document analysis were used in four qualitative studies. The methods and findings of each study in relation to the objectives are summarised in Table 9-1.

Overall, in line with the research aim, the findings seek to explain:

1. Risks associated with increasing flexibility.
2. Preconditions for efficiently embedding flexibility.
3. Mechanisms for enhancing stability and flexibility and their integration.
4. Examples of different operational needs for stability and flexibility.

The various mechanisms for enhancing and integrating stability and flexibility revealed in the research studies were discussed in their respective discussion sections and will not be discussed again here. An overview of the findings discussed in this chapter is outlined next.

Section 9.2 delves into debates on central versus local risk management (e.g., Perrow, 1999; Weick & Sutcliffe, 2015). It discusses the interplay between centralisation and decentralisation, key mechanisms for stability and flexibility respectively. Integrating both is crucial to counterbalance each other's risks and limitations.

Barriers and preconditions for flexibility are discussed in Section 9.3. Understanding the different worldviews within the system and managing good relationships and trust appear crucial to safety management (e.g., Carroll, 1998; Grote, 2024; Journé, 2018). Building on organisational, psychological, and safety literature (e.g., Kanter, 1993; Spreitzer, 1995; Reason, 1997), the section also explores empowerment and fair culture as essential preconditions for flexibility.

Section 9.4 discusses two main mechanisms to bridge stability and flexibility: collaboration and culture. Culture has long been regarded as a stabilising force for coordinating decentralised action (Weick, 1987). Here, standardisation is discussed as one possible underlying mechanism to achieve that effect. Through collaboration, a holistic view can be formed from local perspectives, enhancing coordination, reducing uncertainty, and supporting innovation. The discussions in Sections 9.2 to 9.4 are depicted in Figure 9.1.

Systems and organisations have different operational needs for stability and flexibility (LaPorte & Consolini, 1991; Weick & Roberts, 1993; Grote, 2019a). A framework for considering these needs in relation to stability and flexibility-enhancing tools is presented in Section 9.5. The final finding discussed in Section 9.7 relates to trade-off debates (e.g., Hollnagel, 2009; Dekker, 2004), offering insights into how safety and efficiency are approached across the various system levels explored in this research.

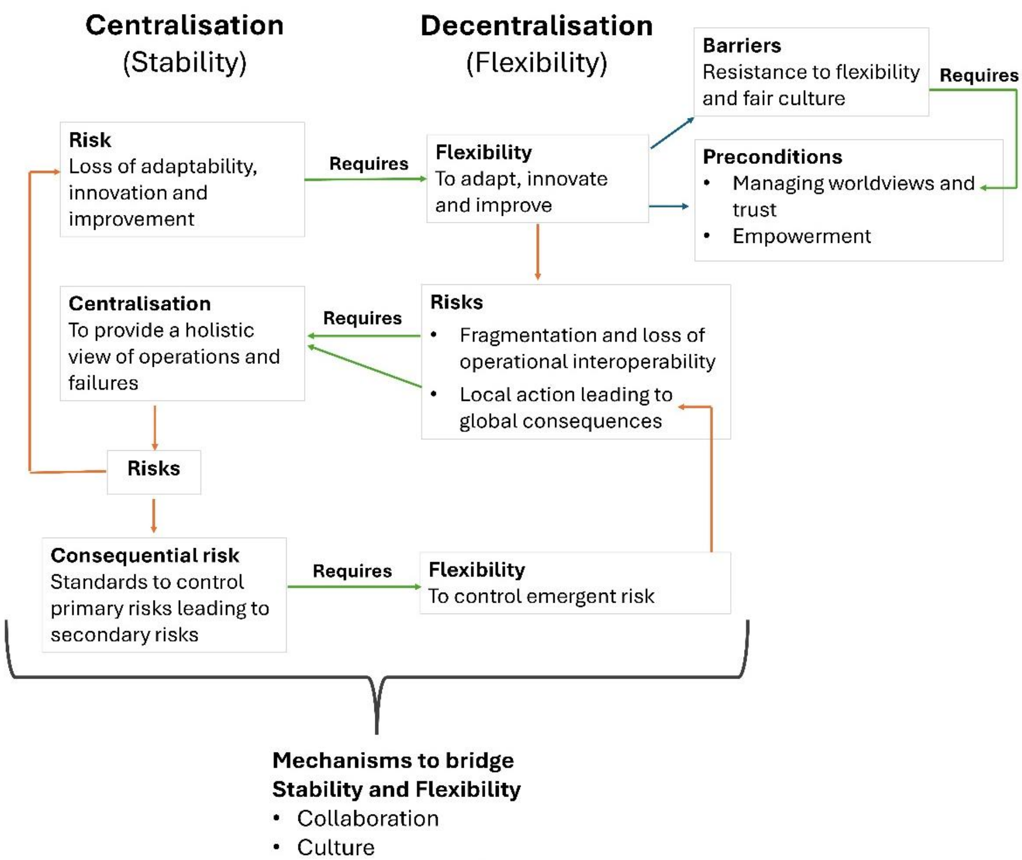

Figure 9-1 Overview of Sections 9.2 to 9.4. , showing the interplay between centralisation and decentralisation (Section 9.2), two proposed mechanisms to integrate both (Section 9.4), and barriers and preconditions to flexibility (Section 9.3).

Table 9-1 Summary of research findings in relation to the research objectives

Objective	Study 1	Study 2	Study 3	Study 4
To describe sources, preconditions and barriers for stability and flexibility	**Flexibility Source**: Five flexibility-enhancing mechanisms: funnel structure, substitution, off-the-shelf standards, level of prescription, and level of obligation		**Flexibility Source:** Collaborative groups **Flexibility Precondition**: (Fair) Culture, Empowerment, Trust, good relationships, **Flexibility Barriers**: Accountability; trust, attitudes, beliefs (worldviews)	**Flexibility Sources**: Empowerment (DM Authority, Resources, Information, Flexible Rules); Teamwork (Resources, Knowledge, Manpower) **Stability sources**: Signaller (Automation, rules); Routines.
To provide a nuanced understanding of stability- and flexibility-enhancing tools and mechanisms in relation to operational needs for stability and flexibility	By distinguishing prescription and obligation as separate features of rules or standards, the potential for tailoring rule types to diverse operational demands is significantly broadened.		COVID-19 Management example of operation under high-stability and high-flexibility demands. Train driving as example of operation under high-stability and low-flexibility demands.	Incidents management: high-stability and high-flexibility demands. Signaller's activity: high-stability and low-flexibility demands (degraded mode) and low-stability and low-flexibility (normal operation)
To investigate whether stability and flexibility integrate, and if so, describe how they do	Flexibility-enhancing mechanisms embedded in mechanisms typically used for stability.	Collaborative rulemaking	Collaborative groups, Culture Dynamic adaptations	Routines (Stable mental models & Flexible behaviours)

9.2 Centralisation and the whole

An important function of centralisation often neglected in safety research is its role in providing a holistic view of risk and operations (Macrae, 2014). The findings in Studies 3 and 4 (Chapters 7 and 8) demonstrate the importance of maintaining this holistic perspective to ensure operational interoperability and prevent knock-on effects caused by consequential risk or local incidents. Fragmentation, identified in Study 3 as a main risk of decentralisation, can endanger operational interoperability.

Consequential risk and other issues resulting in the propagation of problems from local to global may or may not be due to increased flexibility at the local level. However, they serve to illustrate that local actions may have system-wide (global) consequences, a risk of flexibility often overlooked when considering adaptation. Overall, these findings highlight the importance of integrating stability and flexibility through central and local control. Each approach has inherent risks, but these can be mitigated by the strengths offered by the other approach.

9.2.1 Decentralisation, fragmentation and operational Interoperability

Operational interoperability describes the system's capacity to sustain efficient operations across system boundaries. This capacity is particularly important in a system like railways that expand across regions (Wilson, 2014). Facilitating operational interoperability is a key function of standardisation. First, standards serve as a functional model for the entire operation (Disconzi & Saurin, 2024). Second, standardisation ensures that the same practices and procedures are followed consistently across the railway network. This stability significantly reduces complexity (as fewer component varieties are needed) and uncertainty (as the same rules apply system-wide, facilitating their application). A reduction in complexity and uncertainty promotes efficient operations by minimising the need for constant adjustments and improvisation, leading to a more systematic and efficient execution of processes. It also enhances safety by reducing the chances of errors for organisations and their staff when operating across the system's boundaries. That said, there are two issues to consider. One is that central standardisation may not help to reduce complexity if central standards are not kept to the minimum necessary. The other is that system-wide standardisation is only advantageous for processes or tasks that apply across the system boundaries, as the custom marks[75] example in Section 7.4.1.2.

Notice that a holistic view and operational management go beyond the ‘physical’ system’s boundaries. The results in Study 1 (Chapter 5) highlight the importance of considering ‘temporal’ boundaries – maintaining consistency between local, current practices and global, future objectives. The study explains that derogations and variations while providing flexibility to organisations, are centrally assessed to ensure that the proposed alternatives do not have detrimental consequences for the activities of other organisations. The assessment also considers whether these alternatives impose constraints on the future operation of the system as a whole. In other words, centralisation allows for the consideration of future compatibilities of local practices with the long-term interests of the whole system.

If a model of decentralisation leads to the fragmentation of the railway system, operational interoperability would be directly endangered. Weick and Sutcliffe (2015) argue that local actors' decision-making contributes to safe and efficient operations because decisions are made by those with a good situational picture. These findings indicate a similar premise regarding decentralised business functions. However, while fragmentation is not a problem at the frontline, it reveals a considerable problem at the system level. As Perrow claims and this research supports, equally important for efficiency and safety is maintaining the ‘big picture’ appreciated from the centre (Perrow, 1999).

9.2.2 When local meets global

Consequential risk is the term used in rail to refer to emergent risks that may arise from operational standards. This phenomenon illustrates that in complex, tightly coupled systems, local actions can have global repercussions. The role of network and signal controllers in the rail operation centre (ROC) is crucial in preventing the knock-on effects of local issues at a systemic level. This was examined through the activities of incident controllers (ICs) in Study 4 (Chapter 8). Beyond emphasising the importance of maintaining a holistic view, the study provided a practical example of

[75] Custom marks are the signs at the platforms that indicate the train driver where to stop. Each train company had their own before the RSSB standardised them.

integrating stability and flexibility to enhance system resilience (McDonald, 2006) and described the mechanisms underlying this integration.

Considering the role of ROCs in system recovery and resilience has implications regarding the limitations of approaching the concepts of centralisation and decentralisation solely in terms of where decision-making is placed (i.e., centrally or locally). While the stabilising role of signallers is underpinned by strict central standards, real-time local adaptations are made by actors (ICs) who operate removed from the context in which the disruption occurs. In incident control, nevertheless, decision-making is not solely a matter of where decisions are made but also when. Stability involves a priori decision-making (through pre-established standards), while adaptation involves decision-making a posteriori (in real-time and post-event). Macrae (2019) introduces a temporal dimension where decision-making may be quick or slow, depending on whether it occurs before or after the disruption. That said, Study 4 demonstrates that these quick (a posteriori) decisions are supported by contingency plans and flexible rules established centrally (a priori), indicating that quick and slow decisions also concur.

9.3 Preconditions for flexibility

9.3.1 Managing worldviews and trust.

In the context of this research, *worldviews* represent frameworks through which individuals and groups interpret and understand safety and their role in it. They encompass perceptions, beliefs, attitudes, values and assumptions about how the system works, what is risk, and what is their role and the role of others in managing risks and uncertainties (Grote, 2018b; 2020). Worldviews influence how people perceive and assess events, make decisions, and interact with others. In an industry or organisational context, these worldviews are often shared within professional groups and represent different (sub)cultures within organisations and systems (Schein, 1996).

These (sub)cultures, which Journé (2018, p. 64) defines as "*the knowledge, values, attitudes and practices created and mobilised in order to "do a good job" in a risky environment",* are located within the organisation's working groups and professional communities. According to Carroll (1998), professional groups have specific approaches to risk and safety control, arising from their own 'mental models' and 'logics,' which guide their safety behaviours. Consequently, these logics and behaviours become integral to their professional culture, resulting from successfully addressing specific problems in particular ways. This means that frontline operators' adjustments to situational demands and uncertainty may reflect not only immediate adaptations but also a deeper approach to risk and safety. This research shows the importance of understanding worldviews to increase flexibility in operations. For example, train drivers' worldviews of what is safe influence decisions about running the train, even when these views contradict engineers' professional recommendations (Chapter 7).

Understanding worldviews involves appreciating the various beliefs and attitudes that influence whom and what people in the system trust and distrust. For example, increasing flexibility meets resistance among train drivers due to their trust in prescriptive rules and their distrust of central management. They perceive flexibility as a cost-cutting measure and view the rules they follow as safety guarantors. Their trust in rules can be understood in terms of their deep sense of responsibility toward the passengers they transport and their need to reduce uncertainty by maintaining their activity as stable as possible. A similar attitude and trust in strict protocols were found among signallers, who appeared to distrust and disapprove of the often lax application of rules by track maintenance teams (Study 4, Chapter 8).

Grote (2018b; 2024) suggests that tolerance for uncertainty, and consequently flexibility and prescription, varies across professional or occupational (sub)cultures. While engineers and executives aim to reduce uncertainty, the need for frontline resilience requires managing, rather than reducing, uncertainty. However, the examples of train drivers and signallers imply that low tolerance for uncertainty is also present among frontline (sub)cultures, whose role in operational resilience involves reducing uncertainty and maintaining stability (Studies 3 and 4). This, while confirming Grote’s argument, suggests that individuals' tolerance for uncertainty is more related to their role than to whether they work at the blunt or sharp end.

Likewise, the interview study (Chapter 7) revealed that the senior managers’ views regarding reducing uncertainty at the frontline vary between individuals, with some managers advocating for a more flexible approach, while others emphasising the importance of strict prescription. Differing choices in uncertainty management among senior managers does not mean that they do not seek uncertainty reduction through planning and control measures, as

Grote (2016a) proposes. What the findings suggest is that tolerance to and choices of uncertainty management may also be moderated by trust and appreciation of other' professional groups activities.

For instance, while some senior managers showed distrust of the frontline using autonomy for their own good, others understood that frontline workarounds are a product of the pressures they put on them. Likewise, train drivers' distrust in flexibility appears to fade when their role changes and move to management. These examples highlight the importance of fostering interprofessional trust in operational management and implementing a change towards increasing flexibility in processes and behaviours.

This research supports previous safety literature highlighting the relationship between trust, distrust, and safety performance outcomes (e.g., Zacharatos et al., 2005; Conchie and Donald, 2006; Eid et al., 2012). In the UK, this relationship has been confirmed in construction (Conchie et al., 2011), the oil and gas sector (Abiodun, 2024), and railways (Jeffcott et al., 2006). Trust in management influences operators' perceptions and behaviours (Luria, 2010), while distrust hinders knowledge sharing (Edmondson, 1999; Jeffcott et al., 2006) and cooperation among teams (Cho, 2006).

According to Barbalet (2005), trust also serves as a stabilising force during uncertainty because it allows people or entities to turn to each other despite inherent unpredictabilities. Trust endows confidence that the other party will act as expected, offering confidence and fostering collaboration and decision-making amidst ambiguity. Similarly, research has shown that trust fosters teams and interorganisational collaboration (Costa et al., 2018; Fodor et al., 2018) and decreases conflict (Curseu & Schruijer, 2010). This research has found that collaboration supports holistic management in complex, decentralised systems such as railways, further highlighting the importance of nurturing trust in safety.

9.3.2 Empowerment

In safety research, flexibility is often understood in terms of autonomy or increased decision-making powers (see Section 3.4). However, the research in Studies 3 and 4 (Chapters 7 and 8) revealed that endowing autonomy is insufficient for effectively increasing flexibility if the frontline is not empowered. In other words, empowerment is a precondition for enhancing flexibility safely and efficiently.

The literature often distinguishes between two types of empowerment in organisations: structural and psychological. Structural empowerment is rooted in job design and job characteristics research. It primarily focuses on transferring authority and responsibility from upper management to employees (Campion et al., 1993; Maynard et al., 2012). Essentially, it addresses organisational conditions and arrangements that create situations, policies, and procedures for distributing power, decision-making, and formal control over resources (Kanter, 1993).

Psychological empowerment centres on individuals feeling they have control over their work (e.g., Spreitzer, 1995; Thomas & Velthouse, 1990). Maynard et al. (2012) note that it is associated with Bandura’s (1977) self-efficacy construct, focusing more on employees' perceptions of empowerment rather than the actual transfer of authority and responsibility.

Kanter (1993) argues that structural empowerment and resources are crucial for increasing employees’ autonomy. This was discussed in Chapter 8, which findings showed that empowerment is essential for enacting the required flexibility to manage incidents. In the study, empowerment was referred to as granting the authority and resources necessary to make decisions. Resources included access to necessary information (sourced from people and technologies), flexible rules, competence and the team itself. The team offered a valuable resource in the form of diverse skills, knowledge, and manpower.

Resistance to accepting greater control was identified as a barrier to increasing autonomy in Study 3 (Chapter 7). This resistance, found to be rooted in fear of being blamed for operational decisions, may indicate a lack of psychological empowerment; employees may not feel empowered if they fear repercussions for their decisions. The issue of fearing repercussions is well-known in safety research (e.g., Reason, 1997; Dekker, 2012), and, in accordance with the literature, the study found that fostering a fair culture is crucial. However, resistance to autonomy may also stem from a lack of structural empowerment and resources.

The findings of Study 3 suggest that flexibility in infrastructure maintenance teams was often exercised to compensate for a lack of resources. Research has found that, although not sufficient on its own, structural empowerment is a necessary precursor to psychological empowerment (Mathieu et al., 2006).

If frontline staff do not have the authority and resources to feel psychologically empowered, resistance to autonomy is not surprising. Nevertheless, this does not explain the unions' resistance to Network Rail's introduction of a fair culture approach, as found in the study. Based on findings from this research, a possible explanation for the unions' resistance to a fair culture may be distrust in top management or scepticism about the reasons behind promoting flexibility in the first place.

9.4 Bridging stability and flexibility

9.4.1 Collaboration

The potential of collaboration as a mechanism to bridge stability and flexibility emerged as a key finding in three of the four studies included in this thesis (Studies 2, 3 and 4). Hart (2019) argues that 'systems thinking' can be achieved through collaboration by highlighting the impacts of changes across subsystems. Study 3 (Chapter 7) identified the value of interprofessional and interorganisational collaboration in enabling holistic management and bridging the gap between centralisation and decentralisation. These collaborative groups play a crucial role in reducing uncertainty and preventing fragmentation in decentralised systems. This occurs by facilitating communication flows, strategic actions, information sharing, and coordination at operational and organisational interfaces. Collaboration between different professionals (e.g., signallers and controllers) and different organisations (e.g., TOCs, NR and BTP) was also crucial to providing a holistic view of incidents and their management (Study 4, Chapter 8).

One of these groups, the Traffic and Operation Management Standards Committee (TOM SC), was examined in Study 2 (Chapter 6) concerning collaborative rulemaking. Involving rule users from across the system with complementary skills and diverse knowledge helps maintain stability by reducing uncertainty (Saurin et al., 2013). Likewise, monitoring and revising rules based on diverse people's knowledge and experiences support innovation and improvement (Kanter, 2008), which are outcomes sought by operational models aiming to support flexibility and adapt to increasing uncertainty. Additionally, including people from the frontline in the rule monitoring process is key for integrating safety management and risk management functions. This integration, often challenging within organisations, results in more comprehensive and effective safety management strategies (Sloan, 2007). Underpinned by processes such as consultation, negotiation, consensus, and relationship management, collaborative rulemaking further evidences the centrality of social processes for both resilience and improvement.

Hart (2019) argues that collaboration is challenging because collaborators often have differing and competing interests. He distinguishes between ordinary self-interest (acting only for oneself) and enlightened self-interest (acting for the system's benefit). Hart advocates that successful collaboration requires engaging with enlightened self-interest, focusing on improving the overall system rather than just individual gain. He emphasises that trust is crucial; all collaborators must trust that the other participants are working in the interests of the system rather than for themselves. Study 3 revealed that trust and shared sense of purpose and direction were crucial for the rail industry’s collaborative response during the COVID-19 crisis. The analysis also suggests, supporting Shulman's (2023) findings, that the effectiveness of collaborative groups is influenced by the quality of relationships among their members.

9.4.2 Culture

One of the key findings of this research pertains to the relationship between centralisation, standardisation, and culture. In accordance with previous literature, culture appeared as a mechanism with the potential to bridge stability and flexibility. For example, Mearns et al., (2009) emphasise the importance of culture in providing direction when operators face scenarios that have not been foreseen and formally determined by the safety management systems. They argue that making the safe decision in these pressured, uncertain situations will depend on safety culture. Weick (1987) claims that culture can be the unifying element bridging centralisation and decentralisation by providing central values to guide local decision-making. When decisions across the organisation are based on the same values and premises, decentralised practices can harmonise.

Weick’s (1987) argument lies at the heart of High Reliability Organizations (HROs); however, two points should be considered. Firstly, HROs exhibit strong structure, hierarchies, and clear roles and responsibilities. This structured hierarchy swiftly dissolves and reorganises to manage local emergencies. Decentralisation is feasible because it originates from a stable, centralised structure (Roberts & Rousseau, 1989; Glendon et al., 2006; Harvey et al., 2019). Secondly, decentralisation entails empowering frontline actors to make decisions and adapt flexibly to local conditions. However, once the situation is resolved, control is re-centralised.

Decentralisation in the context of Network Rail (NR) has a different connotation. It refers to the devolution of control to the various regions. The issue highlighted in Study 3 (Chapter 7) is that this type of decentralisation may lead to local units creating their own cultures by adapting organisational values to fit their local context. Therefore, while culture can serve as a unifying force, the challenge lies in maintaining a stable culture across a decentralised system, which presents somewhat of a paradox. This is where standardisation may play a role.

Study 3 findings suggest that culture may be embedded in the organisation through the rules, provided that the implicit meaning of these rules effectively conveys organisational values. If cultural values can be ingrained in operational rules, culture may be maintained throughout the system by aligning the implicit meaning of local rules with central values. In other words, maintaining the implicit meaning of rules consistent across central and local contexts may help sustain a stable, unified culture system-wide.

This relationship between rules and culture means that a cultural shift could be supported by changing the rules. This research indicates that a cultural shift towards a more tolerant view of flexibility is necessary to develop a more adaptive railway system. Earlier in this chapter, we discussed the influence of occupational (sub)cultures in trusting flexibility and the measures to enhance it to support adaptation. However, (sub)cultures are inevitable and necessary because they emerge from effectively addressing challenges inherent in professional activities (Schein, 2016).

As discussed earlier with decentralised systems, coordinating operations across such units requires a unified culture that can be embedded in rules. Although the various (sub)cultures within the railway system are not geographically decentralised units, they represent decentralised mental models and logic. Study 3 illustrates how the culture among train drivers changed over time through rule changes. Theoretically, similar approaches could be applied to other professional groups within the railway sector.

Suggesting that rules can support a cultural change does not mean that culture can be changed by solely changing the rules. Moreover, a limitation of this approach is that it would be more effective in (sub)cultures that are more prone to follow the rules in the first place. Likewise, this type of change appears to take time, therefore, it needs to be embedded within a long-term strategy, which may be challenging in the changing political and socio-economic context in which the GB railway operates. Yet, the potential of rules to unify culture is to be considered.

9.5 Managing varying operational demands for stability and flexibility

Organisations encounter varying demands for stability and flexibility to navigate internal and external uncertainties, necessitating shifts between different operational modes (LaPorte & Consolini, 1991; Weick & Roberts, 1993; Grote, 2019a). Viewing stability and flexibility as distinct concepts yields four operational modes derived from varying combinations of low and high demands for each (Grote et al., 2018). This research has identified examples of these operational modes within railway contexts, illustrated in Figure 9-2.

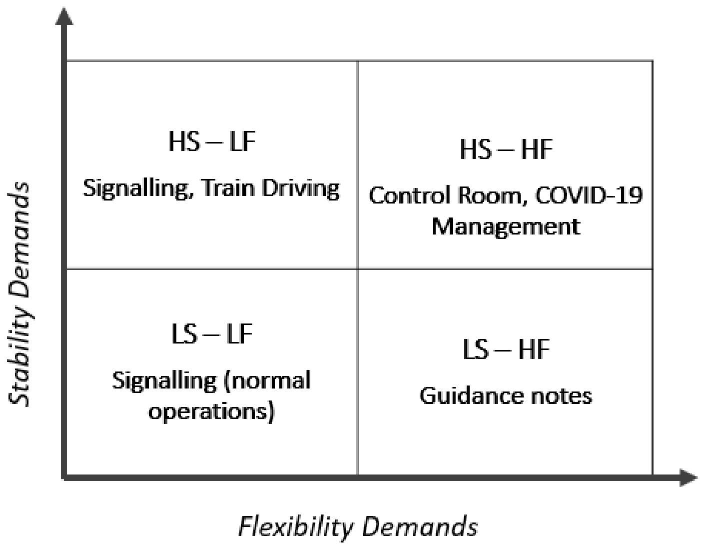

Figure 9-2 Framework populated with identified varying operational needs for stability and flexibility

It was observed in Study 4 (Chapter 8) that much of the signaller's role requires both low stability and low flexibility, primarily due to the high automation of the signalling system. After the train departs from the station area and in the absence of any incidents or the need to facilitate access for maintenance workers (tasks requiring high stability and low flexibility for coordination), the signaller's main responsibility shifts to system surveillance (low stability and low flexibility).

When an incident does occur, the signalling system is designed to fail safely, but it requires the signaller to shift again to handle the degraded scenario. Studies 3 and 4 indicated that while degraded situations are predictable in nature (though their timing is not), the operational mode demands high stability and low flexibility. This mode enhances outcome reliability in predictable situations by relying on tested control measures and enabling effective coordination between the signaller and the train driver. As emphasized in Chapter 5, rules with high levels of prescription and obligation effectively restrict flexibility and maintain the required stability.

The research revealed that while degraded situations occur in a rather predictable manner, the global repercussions of local failures within a complex and tightly coupled system are notably unpredictable. Therefore, effectively managing disruptions or contingencies demands both high flexibility and high stability. Study 4 exemplifies this operational approach, which is achieved through the joint action of signallers and incident controllers. Another instance of operations requiring both high stability and flexibility is detailed in Chapter 7, based on interviewees' experiences in rail operations management during the COVID-19 pandemic (refer to Section 7.5).

Examples of activities requiring low stability and high flexibility were not identified during the research. However, based on this and previous research (e.g., Hale & Borys, 2013b), it is reasonable to suggest as an example, normal operations when risks are contained (i.e., no interfaces requiring coordination) and the operator is experienced. These situations would require low stability; allowing high flexibility through goal rules or green standards would offer opportunities for improvement and innovation. Flexible rules combining level of prescription and level of obligation to adapt to different demands for stability and flexibility were presented and discussed in Study 1 (Chapter 5).

9.6 Is there always a trade-off in safety management?

This last section discusses stability and flexibility in terms of trade-offs. Even the aim of this thesis, 'increasing flexibility without compromising the system's safety,' implies some conflict between them. The issue of trade-offs, which involves balancing conflicting goals, is well described in safety research. For example, Hollnagel (2009) refers to the Efficiency-Thoroughness Trade-Off (ETTO) principle, and Dekker (2004) discusses a trade-off between safety and performance. Thoroughness aims to enhance safety by ensuring preconditions for success, while efficiency focuses on improving performance. According to Hollnagel (2009), trade-offs are omnipresent in decision-making across sociotechnical systems, influencing individual and collective choices, with performance pressures often driving trade-offs in favour of efficiency (Woods, 2003). Although trade-offs are well documented, they traditionally view safety and performance as independent and opposed. However, findings in this research suggest that safety and performance can also be interconnected.

Interviewees in Study 3 (Chapter 7) explained that operational rules are directed to performance and safety is embedded. This implies that safety cannot be compromised or treated separately from performance, as it is inherently ingrained within the operational standards. Furthermore, the findings indicate that safety is a prerequisite for performance, as accidents significantly hinder performance outcomes. Similarly, the repercussions of consequential risks demonstrate that any performance issues can elevate risks, thereby jeopardising safety. Therefore, safety not only precedes performance but is also interdependent with it *to some extent*. Stress is put into 'to some extent' because performance declines during degraded situations to uphold safety. Thus, it is incorrect to assume that decreased performance necessarily leads to increased risk.

While the interviewees emphasise the importance of performance and safety is portrayed as given, as a non-negotiable pre-requisite, these findings reflect the views of rule-makers. A reasonable question would be whether this view is shared at the sharp-end. These and other studies (e.g., Ferreira, 2011) suggest that safety is not as non-negotiable for rail maintenance workers. However, the case study in Chapter 8 demonstrates that, although performance is the focus, safety is embedded and non-negotiable in rail operation control and incident management (corroborating Study 3 findings).

The interrelation between safety and performance described does not imply, nevertheless, that organisations cannot neglect safety in favour of performance. The issue of organisational drift is well-known in safety science (Snook, 2002; Dekker, 2011). While adhering to regulations, performance and safety remain inseparable, overconfidence in system safety, common in ultra-safe systems, can lead to complacency (Dekker & Pitzer, 2016). Under sustained system or local pressures (e.g., budget cuts or workforce shortages), central practices may be subtly modified to accommodate demands, resulting in a gradual, mutual adaptation of rules and practices that erode safety and lead to failure.

9.7 Conclusion

This thesis has identified several stability and flexibility-enhancing tools and mechanisms. It has also analysed different requirements for stability and flexibility, which have been represented within a framework. Describing mechanisms to enhance or constrain flexibility is important, but understanding the degree of stability and flexibility that must be applied is equally crucial. This framework helpfully offers a starting point to consider the available tools in relation to differing operational needs.

Describing flexibility-enhancing tools is core to increasing flexibility. However, no matter how many tools for increasing flexibility are available to organisations and their members, they will not be effective if people or organisations resist or do not accept flexibility. The greatest barrier to flexibility is not technical or operational; it is rooted in social processes. The research has identified important preconditions for embedding flexibility in rail operations, highlighting the cruciality of social processes and people's worldviews. To increase flexibility safely and efficiently, it must first be accepted by the people working within the system. Employees will not accept flexibility if they do not trust the reasons behind making the system more flexible. Equally important is interprofessional appreciation and trust (Grote, 2019b; 2024). Additionally, fully empowering those enacting flexibility is crucial. However, people often resist empowerment due to fear of being blamed for their decisions, which is why a fair culture is essential. A challenge identified in this research is that people also resist fair culture, a challenge that must be overcome for greater flexibility to be implemented.

Finally, while stability is often approached in terms of control and aimed at constraining flexibility, this research has argued for the crucial role of centralisation in overcoming two major risks associated with flexibility. The first risk is that local actions can have global consequences. The second is system fragmentation, which detrimentally affects operational interoperability. This research has presented two ways to mitigate the risk of fragmentation and bridge centralisation with decentralisation. One approach is through collaboration; the other involves using standards in a less traditional manner to bridge stability and flexibility through culture. Here again, social processes and people's worldviews are at the core of this mechanism's efficient management.

9.8 Methodological considerations

The strengths and limitations of studies in this thesis are discussed in each study chapter (Chapters 5 to 8). This section discusses the methodological challenges and opportunities of the research as a whole.

A qualitative multi-methods approach was utilised for this research, which included documents, interviews and observations as the main methods of data collection. This approach offered the researcher the opportunity to examine operational safety management from three angles: what is documented by the industry and regulator, what is experienced by people in the industry and what is observed in real-life practice.

Choosing an open, flexible design was particularly important to make virtue out of necessity in the context of major sector reforms and amidst a pandemic. For example, the COVID-19 pandemic posed many challenges including restricted access to research facilities and limited face-to-face interactions. As a result, studies such as the case study presented in Chapter 8 (Study 4) were not considered and embedded into the research design from the start. Accessing the hectic and bureaucratic rail industry is difficult, and doing so during a period of high uncertainty was particularly challenging. The initial contacts were human factors specialists who value academic research and had prior collaborations with the university. However, the pressures and uncertainties they and their teams faced made the process slower and more difficult than usual. On the other hand, what the industry experienced offered a unique opportunity to incorporate data regarding rail operations when facing a ‘black swan’ event (Taleb, 2007).

Recruiting participants during these challenging times was also difficult. Email recruitment in a corporate setting is always hard due to the sheer volume of emails received, and this volume was even more problematic with people working from home. Among the many messages they must read and act upon, it is difficult to attract attention to unsolicited emails, especially when requests ask for an hour of their already busy schedules. This was particularly challenging when attempting to reach out to executives and top managers during a time of major reforms and industry pressures, with many people leaving the industry.

Due to recruitment difficulties, some role categories were underrepresented in the interview study, as explained in Chapter 7. However, in-depth interviews were the best method to achieve the research objectives and explore unplanned paths discovered during the interviews. For example, Study 2 emerged from following a lead during the interviews, which was also possible due to the openness and flexibility of the research design.

10 Conclusion

This thesis was motivated by previous research advocating for the need to integrate traditional approaches to operational safety in safety-critical systems with those focused on increasing systems' adaptability. The challenges currently faced by the GB railway system illustrate the relevance to real-world practice of investigating this issue. Throughout the research, the intention was to contribute to both theory and practice. Producing research that can contribute to practice is not an easy endeavour (Ryan, 2020). Steven Shorrock argues that, for safety research to be relevant and useful, it should 1) stem from real-world problems, 2) be workplace-based and involve the workforce in real situations and 3) be relevant and helpful to safety practitioners (Shorrock, 2020). These suggestions have been considered throughout to produce research findings that can be useful to those involved in the safe and efficient management of rail operations.

In exploring operational safety as it unfolds in practice, this research has highlighted issues that seem obvious to industry professionals but are often overlooked by researchers, such as the consideration of safety and performance as a unit. Additionally, this research has provided empirical evidence to support safety research and theory, particularly regarding how stability and flexibility, rather than being antithetical, often integrate and even co-depend. This thesis concludes by presenting the contributions of this research to both theory and practice and proposing future work related to these contributions.

10.1 Contributions and future work

This research has highlighted several issues often overlooked in safety research, which have implications for and contribute to both theory and practice. While the explorative nature of this thesis means these issues were not explored in depth, they provide a foundation for future, more comprehensive investigations.

1. Safety and performance are harder to neatly separate in practice than in safety research. Although the distinction is apparent in maintenance workers, supporting previous research (Ferreira, 2011), at certain levels or within specific occupational groups, safety and performance

are not clearly differentiated. This was found among the rule-makers (Chapter 7) and rule-users (Chapter 8) investigated in this study. Future research could explore this issue further to bridge possible gaps between theory and practice.

2. Centralisation in safety research advocating for adaptation often overlooks the benefits of central control. Centralisation is typically viewed as a means to constrain performance and coordinate behaviours, but it also plays a crucial role in a) providing a holistic view of operations (Chapters 7 and 9), b) managing the risks of local actions impacting the global operation (Chapters 7 and 9), and c) ensuring a fair distribution of certain resources across the system (Chapter 7). These findings contribute to both theory and practice. Conceptually, they call for more nuanced conceptualisations of centralisation and decentralisation. In practice, these findings highlight the need to retain some features of centralisation when greater decentralisation is in process. Furthermore, the findings suggest that rebalancing attention between central control and flexibility might be valuable in research and practice. By systematically considering the nature of stability and the benefits of centralisation to systemic stability, centralisation might be approached as a foundation to enhance organisational adaptability and resilience. This approach would help in effectively integrating the strengths of both centralised and decentralised structures.
3. This thesis revealed mechanisms to prevent fragmentation and bridge centralisation and decentralisation, such as collaborative groups. Future research could investigate the effective management of collaborative groups as mechanisms to enhance a holistic view, particularly if central standardisation is minimised.
4. Another mechanism to bridge centralisation and decentralisation revealed in this thesis is culture. This thesis' findings suggest a relationship between culture and rules, proposing rules as artefacts with the potential to influence the assumptions underlying culture (Chapter 7). A deep understanding of the interplay between culture and rules, namely how culture may influence, emerge from, reinforce and be reinforced by standardisation would have significant practical implications. Future work in this direction could aim to better understand this interplay, which in turn would contribute to the organisational culture literature.

5. Previous research in rules management has described the impact of different levels of prescription in allowing flexibility to the rule user (e.g., Grote & Weichbrodt, 2007; Hale & Swuste, 1998). This research adds to the safety rules management literature by distinguishing between the level of prescription and the level of obligation within the rule formulation (Chapter 5).
6. This research found further evidence of the criticality of trust to safety management, contributing to the organisational literature on trust (e.g., Jeffcott et al., 2006; Zacharatos et al., 2005; Flin & Burns, 2004). Noteworthy is the finding relating to the rail unions' resistance to fair culture. It suggests the need for more nuanced empirical work to understand how fair culture is perceived across different organisational levels and so better supported and implemented.
7. As highlighted in Chapter 5, it is important for organisations to understand the level of flexibility to be applied to rules and processes. This thesis contributes by offering a framework to comprehend and consider varying operational demands and needs for stability and flexibility.
8. Finally, one significant contribution of this thesis is the transferability of its findings, which are likely to be relevant across a range of complex sociotechnical sectors. The railways provided an exemplary environment for exploring the dynamics of stability and flexibility within operational frameworks; however, understanding how and in what manner these findings apply to other sectors requires further empirical investigation. It is evident that other sectors will encounter different experiences of stability and flexibility interactions, influenced by factors such as the nature of operations, socio-cultural dynamics, and political and economic landscapes. Yet, by demonstrating how principles of stability and flexibility can be understood and applied in the railway context, this thesis provides valuable insights into operational management beyond the specific context of rail operations.

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Appendix I Examples of interviewees' accounts used to triangulate the findings

Findings it supports	Participant	Quote
Funnel structure	103	*‘all of the standards and rules that we write they need to fall within a standard framework, a regulatory framework. You need to meet the requirements that are there, on the law. You need to see things top down. And when you are writing your part, we need to be very careful that we are not duplicating legislation or even worse, contradicting something that is already out there in the legislation’*
		‘laws are very general. There is simply general. They said that, for example, “you need to look after the welfare of your employees as far as it is reasonably practicable”, that's the law. Underneath laws you have regulations. Regulations have a little be more detail into that. Underneath regulations, for example now in the railways, we have notices and national technical specification notices. They have even more detail underneath on that how you do different elements. Then underneath that, comes some of the standards that we work on [organisation] that have more detail, and then we have the rules for frontline staff... So it depends on which level you are looking at this. You have more of the detail that you need to do something’
	105	*‘Most of our standards are aimed at the organizational level. So if you think of, let's stay with competency management, which is a good area, we have standards there that relate to certain aspects of competency management. We're not comprehensive, to be honest on that. We provide requirements on an organization for them, for example, to have a competency management system. We don't necessarily prescribe how that competency management system works, so we might give some guidance of what it looks to achieve, and, in some cases, we may have requirements on what things are to achieve, but we have very few requirements as to what they actually are and how organizations then interpret this’*

		'But all of our standards are aimed at the organizational level and they are insufficient themselves then to meet the objectives, they need to be supported with procedures or standards or equivalent within the respective companies. And if you take Network Rail, for example, we've got about 350 standards and related documents in our catalogue. Network Rail, I think has near about 10,000 standards and related documents. Some of those are only forms, but that's what they've got within their quality management system. And their standards reflect our standards. But of course then go into much more detail.'
Off-the-shelf solutions	103	*'a very important aspect for companies is to have the safety management systems and to have risk assessments. So when you do a risk assessment, you try to find out what is the potential risk or potential hazards that you may have in your own environment. Once you identify them, then you start saying, "OK, how am I going to mitigate them?" There is this a standard out there that [organisation] is doing that could help". You decide whether you want to adopt it or not. It's really up to you, because the rule is there doesn't mean that you have to follow that rule'.*
Level of prescription	105	*'As a person that writes standards regularly, you always like to leave a little bit of flexibility in the standard that you can exploit it if need be, because as I said, it can be very robust. They can say "you must do X, Y and Z". Not leave any chance, not leave any discretion, "you must" is a thing that you can put in'*
	401	*'the railway industry is part way along a much longer journey at the moment in trying to move away from prescription, and from having a set of very tightly defined, codified rules. And trying to, basically, move away from that to a more goal setting approach where we say "you have to do things safely, but it's up to you, as an organization, to decide exactly how you do things safely". And getting that... that's an easy thing to say, but it's quite a hard thing to get it right in practice in each case.'*
	507	*'outcome based standard would generally be quite a bit more prescriptive. And again, that can vary as well depending on what level you're targeting at. For example, we weren't having a Teams meeting, but we were going to meet face to face. You could say to me, "right, I would like you to meet me at Milton Keane Station at 08:00 on Thursday morning". But you don't necessarily have to tell me that I have to get the train and then walk this way to it. I could catch a bus, I could bike, I could drive, I could come up the night before, stay in a*

		hotel and then walk down in the morning. So those are all ways to deliver the outcome that's been specified.... Or you can specify how you do it. It depends on the level it's being targeted at. So you can write a standard that says, "I want you to meet me at 08:00 at Milton King Station tomorrow morning and I want you to get the 730 bus from this particular location, walk along this street, turn right into the station, and I'll be there". That's an outcome based standard as well. But obviously the more competence you have, the less prescriptive you need to be. And again, it can also vary as well depending on what type of equipment you've got because there's some types of equipment that need to be inspected and maintained in only one specific way and it can't be open to interpretation. You do it in this way and only this way.'
Level of obligation	500	*'we have three levels in our standards, so there's green, amber and red. And it's mandated or non mandated requirements. So the green are sort of what we would like you to do, but if you can think of how to do it better, you don't have to tell us you can do it better. And then the amber requirements are those that you have to do in that way, and if you don't want to do it that way, you have to apply for a variation against it and it has to be approved. And the red, you can't apply for variations, you have to do it that way no matter what'*
Level of obligation & Substitution	500	*'on the amber sections of the standards, anything that's amber that's mandated, you can apply for a variation or a derogation against it. So if your project can't comply with that or they think actually there's a better way of doing it, then they can apply for that.'*
Substitution	500	*'we have different processes in place as well, so variations are sort of an internal challenge process as well. So it's where someone says, "actually we could do it like this, it might be better", and then the standard owner will see that go, "oh, that's a good idea, yeah, I'll update the standard". We have external challenge processes, so that's on information on our website, so suppliers and contractors can put a challenge against our standard in and say, "actually you ask us to do this, but it'd be much quicker and much more efficient if we did it this way".'*

Appendix II - Potential pitfalls in thematic analysis

Braun and Clark's (2006) list of potential pitfalls to avoid when doing thematic analysis proposed.

Pitfall	Description
1	Failing to analyse the data properly. Thematic analysis should have an analytic narrative and not simply paraphrase the content of extracts. Extracts should illustrate and support a deeper analysis that goes beyond their specific content, helping to make sense of the data and convey its meaning to the reader.
2	Using the data collection questions as the 'themes'.
3	A weak or unconvincing analysis, with too much overlap between themes, or where the themes are not internally coherent and consistent. Each theme should cohere around a central idea or concept. The theme fails adequately to capture the majority of the data or fails to provide a rich description or interpretation of one or more aspects of the data.
4	A mismatch between the data and the analytic claims made about it. The analysis does not consider other obvious alternative readings of the data or fails to consider variation or contradiction in the account that is produced.
5	A mismatch between theory and analytic claims. The analysis must ensure that the interpretations of the data are consistent with the theoretical framework.