Interviews with rail industry leaders about systems thinking in the management of organisational change and risk management

Michelle Nolan-McSweeney [a,b,*], Brendan Ryan [b], Sue Cobb [b]

[a] *Network Rail (retired), Milton Keynes, UK*
[b] *Human Factors Research Group, University of Nottingham, UK*

ARTICLE INFO

ABSTRACT

The rail industry in Great Britain has faced unprecedented demand for its services in the past decade, whilst addressing technological transformation, and with multiple objectives in relation to safety and performance. Systems theories seems to offer solutions for these challenges, but there has been little research on how rail organisations can establish processes and build resilience during periods of significant change that are complementary with this type of theoretical approach. This paper investigated senior business leaders' perspectives of how systems thinking is, or could be, applied in organisational design, system change and risk management. Twenty-five interviews were carried out with senior executives and managers in the railway industry. These interviews were designed to explore the perceptions of these people in policy setting and senior management roles and what they see as barriers to change within a dynamic, fast moving, industry. This included exploring both the 'work as imagined' in the corporate strategy and company procedures, as well as their understanding of 'work as done'. Two national change programmes that affect the frontline rail engineering workforce have been used as contexts to frame consultations within this study. The results identify some important points to consider for the design of change in a complex industry, and how a socio-technical system framework or model might be applied in practice.

1. Introduction

Within the fields of safety, human factors and ergonomics (HFE) there are various theories and concepts that support the design, planning and management of work, human performance and safety in complex systems such as rail (Wilson et al., 2007). The emphasis in research and practice has changed over the years, influenced by the nature and changing demands of work contexts and systems. Waterson et al. (2015) present a timeline of the main traditions, key studies and methods in system safety, spanning from the domino accident models pre-World War II, through early work in sociotechnical systems in the 1950s and 1960s, systems safety in the 1980, Rasmussen's risk management model in the late 1990s, to resilience engineering in 2013 and beyond. Beyond safety and HFE, there are other areas within the management sciences that also deal with similar concerns, where the emphasis is on other factors such as staff behaviours, motivations, decision-making, and autonomy (Shorrock and Williams, 2016).

Applying systems thinking (Rasmussen, 1997) is now the dominant approach to work organisation and safety and risk management in the HFE discipline (Wilson, 2014) and it is recognised in the safety literature that a holistic view from technological and social science disciplines is needed (Aven, 2018). Systems thinking draws from Sociotechnical Systems Theory (STS) (Trist, 1959, 1981) and the recognition of the interdependencies between technical and social aspects of the system (Klein, 2014), how outcomes emerge from the complexity of the given situation, and importance of autonomy, adaptability, and meaningful work (Walker et al., 2010). Systems thinking is also influenced by system theories (Skyttner, 2001) and appreciation of the attributes of systems, such as Wilson's (2014) six HFE system notions – need for a systems focus, concern for context, acknowledgement of interactions and complexity, holistic approaches, recognition of emergence and embedding of professional effort in organisations. Work is often described as occurring in a complex system, where complexity can be defined by its multiplicity, dynamism, and uncertainty (Walker et al, 2010). This systemic view influences how the causation of accidents or management of risk are conceptualised. The earlier approaches to safety commonly focused on linear chains of causation and focus on single causes in stable situations, where safety was viewed as an absence of

---

accidents (Hollnagel et al., 2013). Whilst there has been a focus on reducing uncertainty and risks from deviation, Rasmussen and Svedung (2000) highlight the limitations of traditional methods with the dynamic nature of many current systems, such as in transportation. Different options for control of risk have been proposed (Moorkamp et al., 2014), such as enabling opportunities for adaptation, variability in performance and self-organisation, which are common within social aspects of systems.

Moorkamp et al. (2014) elaborates on Blom's earlier (in Dutch language) classification of system types and preferred control strategies, describing the creation and maintenance of stability in closed systems, the openness to absolute variation (which may be unworkable in practice) in open systems, and the selective variation in self-referential systems.

Rasmussen's (1997) account of the dynamic, complex and adaptive nature of systems and representation of their hierarchical nature has been influential in highlighting the interactions that shape behaviour and communication across multiple system levels of government, regulators, the organisation, management, staff, and work (processes), inspiring development of various methods to support work design, proactive risk management and incident analysis (e.g. Abstraction Hierarchy, Accimaps, Actor Maps, Rasmussen and Svedung, 2000; STAMP, Leveson, 2004, 2011). The creativity and adaptive contribution of people is described by Rasmussen and Svedung (2000) as a safety resource, rather than just an error source, though it is recognised that there is typically greater focus on technical aspects of systems than social aspects (Ryan et al., 2021). The flexibility, adaptation and variability that is characterised by Rasmussen is described in the ethnographic study by Le Coze and Dupré (2022) and is evident in Resilience Engineering (Hollnagel et al., 2006), which highlights the ability of the STS to adjust prior to, during, or following changes or perturbations to sustain required operations under expected and unexpected conditions. Tradeoffs (Hollnagel, 2012; Wilson et al., 2009; Grote, 2015) are often part of the management of uncertainties in high-risk systems and application of a complex regulatory framework. How these can be achieved and the ability to effectively trade off issues of safety, costs and productivity are questions posed previously (Wilson et al., 2009), but have yet to be comprehensively answered. Hollnagel et al. (2006) also emphasises the potential gap between the 'work as imagined' in the corporate strategy and company procedures that senior staff may be more familiar with, and the 'work as done' by the frontline staff, to ensure the resilience of the system and encourages a focus on what is needed for everyday performance to go right (Hollnagel, 2012). As a consequence, safety is about the ability to succeed under varying conditions (Hollnagel, 2012; Hollnagel et al., 2013).

Railways operate within a complex landscape which includes national and international organisations and devolved government bodies, regulators, train and freight operators, suppliers, trade unions, trade associations, and safety and passenger bodies. Successful operations require continuous improvement in safety and performance (Network Rail, 2020), and depend on managing social and technical interactions effectively, both internally, and across the wider rail industry. Whilst railways are generally reported to be safer than other forms of public transport (ORR, 2020), there is still room for improvement, particularly within workforce safety. In Great Britain, Network Rail's safety leadership has strengthened and broadened through new regional structures in a process of decentralisation of decision-making, and there are closer alliances with train and freight operators to address safety and performance, and to balance what are seen as sometimes conflicting goals. Rail staff at all system levels must constantly make critical business decisions. These require an understanding and continuous dialogue about how the system works (e.g. prioritising train paths, such as a faster running passenger train ahead of a slower running freight), and the consequences of any trade-offs. Given performance targets, and penalties for delays, incidents and accidents, the industry focus is much more on ensuring things go right, rather than purely a reactive approach to things going wrong.

There are compelling arguments about how systems thinking, proactive risk management and resilience engineering help organisations in understanding the interactions across the levels of the system (government bodies, regulators, the organisation, management, staff and the work processes) that shape behaviour and safety outcomes (Rasmussen, 1997) and the trade-offs and adjustments that are needed to manage uncertainties (Hollnagel, 2012; Wilson et al., 2009; Grote, 2015). Currently, there is little research available on how an organisation that faces an array of challenges in a complex and changing rail industry uses the underlying principles from system and safety theory to complement the development and application of processes. It is not known whether these system-based ideas are appealing to staff in industry, and how easy they are to apply effectively within industry contexts.

Several studies in the literature have started to explore these types of issues with senior business leaders. Reiman and Oedewald (2007) used interviews to investigate the cultural conceptions of key decision makers and their accounts of perceived barriers to change in their work, in the nuclear sector. Their 19 interviews (6 technicians, 6 foremen, 2 planners, 2 experts, and 3 line managers) took place in one nuclear power plant, identifying a tendency to react to errors and accidents, rather than a proactive focus on safety attitudes and values and understanding organisational core tasks.

Later work (Reiman, 2010) also shows that research on the maintenance function of an organisation has focused mainly on human errors and individual-level issues, though social and organisational factors do receive attention on occasion because of high profile incidents.

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

Both the Reiman and Oedewald (2007) work, and the Makins and Kirwan (2016) study, reveal current gaps in understanding and research of how senior business leaders make critical decisions concerning safety. Makins and Kirwan (2016) explored a breadth of perspectives from different organisations, but typically relying on contributions from one representative from an organisation. Reiman's and Oedewald's (2007) work was primarily aimed at identifying the strengths and weaknesses of the culture in a single case organisation in relation to the demands of maintenance task. Their focus was on 'safety' being socially constructed, interpreted, and embedded, and how the 'safety culture' of the organisation becomes evident in change situations including how change is perceived and personnel respond to it. Whilst the two studies referred to above draw on opinions from different levels of the organisational structures, they do not focus on wider systems thinking concepts and the effects of systems change on the broader issue of organisational effectiveness.

The focus of this article, therefore, expands the consultation with Senior Business Leaders and Managers in a new sector, the rail industry, including a range of perspectives from different senior roles and functions within the main organisations in the industry. The interviews were carried out with people in the higher levels of the system hierarchy as they are currently best placed to understand the implications of a system change involving decentralisation and greater control at regional levels, as well as their ability to influence change in the wider GB socio-technical system.

The consultation was designed to explore how a complex sector, such as rail, can design work systems and processes that continue to support human performance during periods of significant change and are resilient to unanticipated events. This aim of this study was to undertake interviews with senior business leaders in the rail industry to explore their perspectives of how systems thinking is, or could be, applied in

organisational design, system change and risk management. The inter-view questions were constructed to collect information on the under-standing and application of common concepts from system and safety theory and related analysis models. This included potential gaps be-tween the 'work as imagined' in the corporate strategy and their un-derstanding of the company procedures and the 'work as done' in everyday performance, the potential for the emergence of new roles, communication channels, relationships and collaborations, power structures, barriers to change, sources of decision making, competence and capacity of managers. It was assumed that interviewees in these business roles may not be familiar with some of the academic concepts and terminology (for example, of a socio-technical system). Therefore, questions were phrased using general terminology that would be familiar in the industry (e.g. culture, organisation design, standards, rules, trade-offs etc.). As the intention was to determine which concepts people in industry were familiar and which they found useful, it was important not to prompt explicitly in eliciting information from the business leaders.

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

2. Method

The development and application of an interview study of senior leaders from a variety of roles, functions and organisations is described in Section 2.1 to 2.4.

2.1. Participants

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

2.2. Approach to the interviews

There were two stages to the interview process. Twenty Executive and Senior Managers were interviewed in the first stage. Five additional Executives and Senior Managers took part in interviews in the second stage, after an opportunity arose to include these five additional par-ticipants when their diaries permitted. This allowed for a focused dis-cussion on some of the findings that emerged from analysis of the first stage of interviews.

Approval for the study was provided by the University's Faculty of Engineering Research Ethics Committee. The interviewees were con-tacted directly via email, receiving details of what they were expected to do as part of the study. Participants were asked to give informed consent for participation. Each interview took between 60 and 90 min and was carried out face-to-face. The responses were recorded in hand-written notes, as well as the use of a digital voice recorder.

2.3. Interview content

The interview questions were inspired by content from previous interview studies and related safety literature, especially Rasmussen's (1997) STS social and organisational levels:

- An overview of the interviewee's current job role and extent of their decision-making authority within the system (similar in approach to Makins and Kirwan's (2016) study of airline executives).
- Examples of organisational goals / objectives and priorities, and views on accountability and responsibility, and any system bound-aries (whether performance, economic or workload related).
- Examples of their understanding of key interfaces, complexity, workflows, capability and risk management, and the need for any trade-offs (akin to Reiman's and Oedewald's (2007) assessment of complex socio-technical systems within the nuclear sector).
- Views and perceptions of how change is managed within a complex sector such as rail and effects on the employees, structure, funding, change (e.g. organisational change, culture change, programme change) and relevant learning from this (reflecting on earlier studies by Clarke (1999), and Farrington-Darby et al. (2005)).
- Examples of demonstrable leadership, thoughts about relationships between safety and performance, and what resilience might mean in the context of managing and mitigating safety and production risks (Wilson et al., 2009).
- Views on organisational learning and the extent to which lessons learnt from incidents and accidents were shared, and effectively actioned in a complex GB rail system (e.g. organisational failures at NASA identified after the Challenger and Columbia accidents, some 17 years apart (Hall, 2003; Leveson, 2008)).
- Examples of what 'corporate memory' means to interviewees, and especially ownership of this (building on the work of Birkland (1997) on disasters as focusing events, where attention is given to their causes but does not always lead to changes in policy, thus there are repeat accidents as time elapses and historical events are forgotten).

The questions were generally open in nature for the initial 20 in-terviews (5 Executives, 15 Senior Managers) to elicit the participants' feelings and views, and explore how organisational processes work in particular contexts, environments, and settings, and at higher and lower organisational levels. A variety of circumstances were introduced in each interview to explore how a range of processes may be applied and communicated within a hierarchy (e.g. higher management, or staff at a lower level), and in different situations (e.g. 'normal' operations, versus 'degraded' mode following a major accident). The understanding of systems thinking was explored, as applied within the matrix structure, particularly around considering the system as a 'whole' and the re-lationships and interfaces within that. The second stage of interviews was more narrowly focused on issues that were raised from the first phase interviewees (without divulging the source of the topic).

2.4. Method of analysis of the interviews

The interview voice recordings were transcribed into an interview record form, enabling theme-based content analysis (Mayring, 2000) and comparative analysis across the interviews. Rasmussen and Sve-dung's (2000) dynamic approach to risk management places an emphasis on: how decisions are made based on the information available to the decision-makers; the capabilities of the organisation and in-dividuals; the flow of work and how people use technology and apply processes; and how the goals and functions of the organisation are achieved in real life situations.

The five themes from Rasmussen and Svedung (2000) - Objectives, Status Information, Capability, Awareness and Priorities (see Table 1 below), were used as a template for structuring the initial classification of information from the in-depth interviews with senior leaders and

Table 1
Themes related to the information available to decision makers and their capability of safety control:

Objectives: are objectives and values with respect to operational as well as safety issues properly communicated within the system?

Status information: are the individual decision makers (staff, management, regulators etc.) properly informed about the system status in terms comparable to the objectives? Are the boundaries of acceptable performance around the target state 'visible' to them?

Capability: are these decision makers competent with respect to the functional properties of the organisation, of the technical core and the basic safety design philosophy? Do they know the parameters sensitive to control of performance in a changing environment?

Awareness: are decision makers prompted to consider risk in the dynamic flow of work? Are they - continuously during normal work - made aware of the safety implications of their every-day work business decisions?

Priorities: are decision makers committed to safety? Is management, for instance, prepared to allocate adequate resources to maintenance of defences? Does regulatory effort serve to control management priorities?

adapted from Rasmussen and Svedung (2000).

managers (i.e. those operating at the company management level in Rasmussen and Svedung's actor maps). Further inductive coding was undertaken to identify sub-themes within each of the five main themes (e.g. 'clarity of objectives / vision' was assigned as a sub-theme in the main theme of Objectives). This approach led to the organisation of information, supporting the extraction of often repeated themes, and helping to identify relevant supporting or contradictory evidence or comments. Responses from Executives and Senior Managers were compared to identify commonality or differences between the groups.

3. Findings from the interviews

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

Sections 3.1 to 3.5 report the findings within each of Rasmussen and Svedung's five main themes and the additional sub-themes that have been identified during the analysis of the interview content. These themes and sub-themes are illustrated in Fig. 1.

There were more than 30 h of interviews that were transcribed, including 323 coded key words / phrases. Table 2 shows the relative frequencies in each main theme.

The counts of content in themes enabled comparison across Executive and Senior Manager responses. Whilst there is no distinction in the

Table 2
Counts content in each main theme from Rasmussen and Svedung (2000).

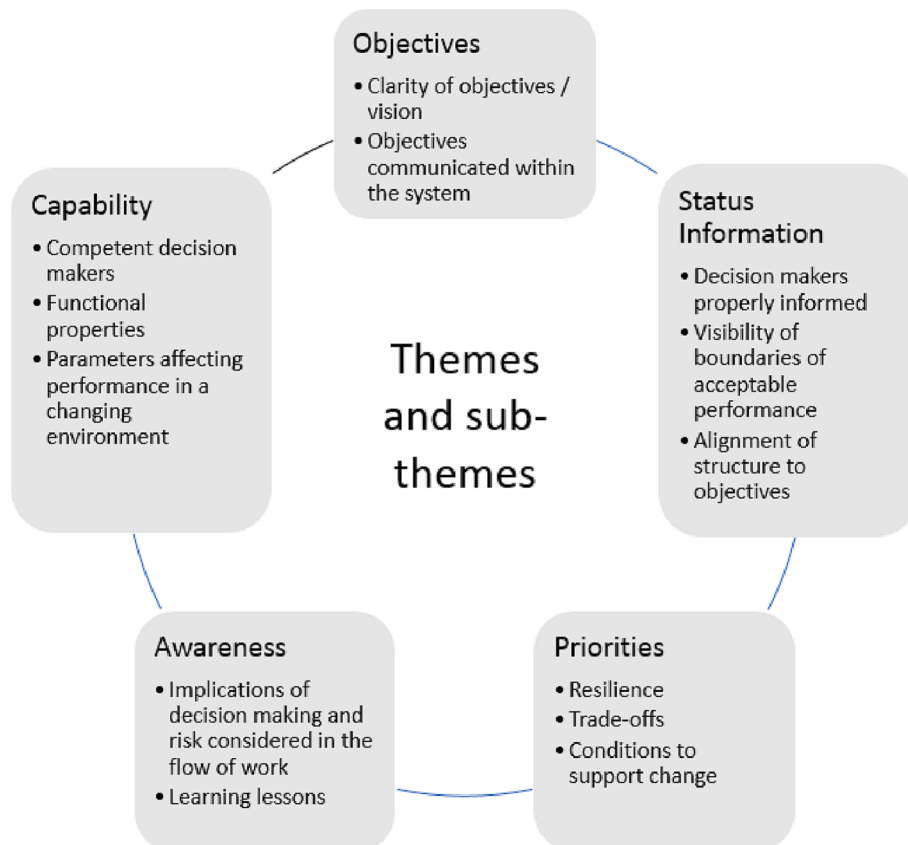| Main theme	No. of key words / phrases
Objectives	61
Status information	42
Capability	155
Awareness	36
Priorities	29
Total	323

Fig. 1. Themes and sub-themes.

priority of the themes in the way Rasmussen and Svedung (2000) portray them, in practice – from the GB rail interviews – it would seem that the theme of 'capability' has more relevance in the minds of business leaders because of the need for competent decision making in a complex (safety critical) industry, where change is almost constant.

3.1. Objectives

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

Discussion with the interviewees revolved around the organisational context and how the safety vision, objectives and goals are communicated and delivered. The change to decentralise parts of Network Rail into 5 Regions, with 14 Routes as part of a matrix structure, with national functions in support, (e.g. Route Services, the Technical Authority etc.) were mentioned, as well as the understanding of the collective accountabilities for safety and operational performance, delivery, and continuous improvement of current performance. Wider industry issues were also considered, particularly around the significance of the changes being brought about and the pace of change being sought within the rail sector, and how operational as well as safety matters could be effectively communicated within the wider system. Sub-themes were identified in the analysis of the interviews around the clarity of the objectives and vision, how and to who these are communicated, and the operation of the system as a whole, including economic considerations.

3.1.1. Clarity of objectives / vision

On the overall theme of objectives, 40% of the responses from Executives and Senior Managers referred to the need for a greater clarity of objectives and/or vision. Three key challenges were also reported in relation to this theme, as shown in Fig. 2.

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

A quote from a Senior Manager puts this into context:

"We need to develop mutual trust and understanding between the different levels of the organisation and industry. We all believe in safety first, but some might say that does not always manifest itself in our actions, and especially how we communicate expectations of those we want to deliver our goals."
[Senior Manager 4]

The second challenge identified was around ambiguous authority, and what came out from the interviews was that 'ownership' is lacking

whilst ambiguous authority prevails.

A significant proportion (over seventy percent) of both Executives and Senior Managers said they thought there was still a conflict between safety and people's actual autonomy within the system, and to address the gap would require clear decisions on ownership of particular activities or tasks by the business function. There seems to be a widely held view that Network Rail's organisation needed to mature such that the decentralised Regions were able to realise the autonomy sought.

A Senior Manager said:

"We need to better engage with our people….so there is 'ownership' of objectives and delivery of goals around safety, performance etc. We cannot continue with ill-defined accountabilities and responsibilities, and the ambiguity this brings, and people can hide behind."
[Senior Manager 9]

The third challenge was around silo-focused employees. Both groups of participants expressed concerns that whilst Network Rail was reorganising itself with decentralised Regions, in practice people were still working very much in their old ways. As a result, organisational silos continued, regardless of the aspirations for the business to operate within a matrix structure (see Fig. 2). Some of this was attributed to not preparing people adequately for the changes, whilst several thought it was down to a lack of commitment in middle-management, in both horizontal and vertical dimensions of the matrix to make the relationships work effectively, and *"old ways of working were not going to go away overnight"* (Senior Manager 3).

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

"We still expect decisions to be made within a hierarchical structure, yet we have devolved accountabilities locally, but unwittingly cause confusion and blur lines of responsibility when we are not clear on expectations and the role of individuals within the system."
[Senior Manager 5]

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

"The industry cannot stand still; it is becoming more complex. Network Rail must evolve, and at pace, which I think it is starting to do, but there are individual cultures, and local cultures, even within specific teams that make change so damned difficult at times."
[Executive 6]

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

3.1.2. Objectives communicated within the system

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

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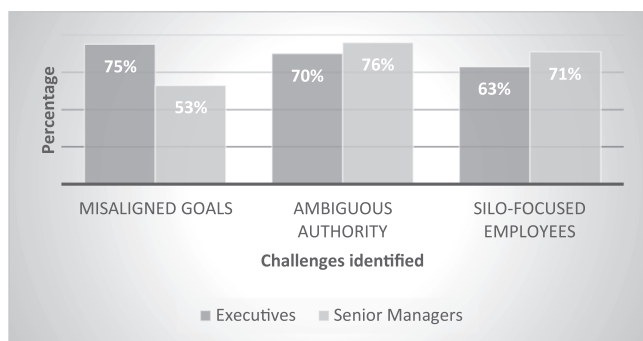
As one Senior Manager warned:

Fig. 2. Comparison of the challenges that were identified from interviews of eight Rail Executives and seventeen Senior Managers.
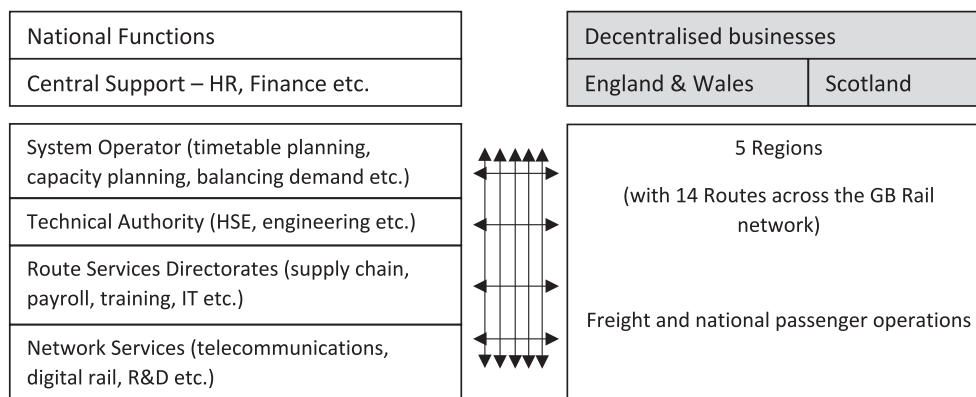
National Functions			Decentralised businesses	
Central Support – HR, Finance etc.			England & Wales	Scotland

System Operator (timetable planning, capacity planning, balancing demand etc.)		5 Regions (with 14 Routes across the GB Rail network)
Technical Authority (HSE, engineering etc.)		
Route Services Directorates (supply chain, payroll, training, IT etc.)		
Network Services (telecommunications, digital rail, R&D etc.)		Freight and national passenger operations

Fig. 3. Network Rail Matrix Structure: adapted from Network Rail (2020).

"….the system is complex technically, is diverse geographically, and there are multiple stakeholders to consider."
[Senior Manager 2]

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

"There's a genuine willingness to learn and improve, but it just takes time, and the road will be a bit bumpy along the way. We need to encourage sharing of best practice in the devolved model, and communicate, communicate, communicate!"
[Executive 8]

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

"Change in the organisation is often feared and therefore resisted. Making changes in Network Rail is extremely hard; there is a deeply embedded conservatism that we have to overcome if we are to be more dynamic in delivering on our objectives and vision for the future."
[Executive 5]

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

3.2. Status information

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

Discussion with the interviewees revolved around the organisational context and the range of decision-makers at different levels within the

industry, e.g. frontline staff, management, regulators, and particularly the impact of decisions within a complex structure influenced by politics, funding, and unforeseen issues such as the Covid pandemic that required decisions at pace, and across the entire sector during the period 2020/21.

3.2.1. Decision makers being properly informed

On the overall theme of status information, 40% of interviewees said safety and [operational] performance must go hand in hand if the system was to remain safe and effective. This, they said, required decision makers to understand the part they played in the system. Organisational objectives around safety and performance were reported as being impacted by multiple factors, often caused by mismatches in systems thinking, planning, data, or risk approach. For example, a third of the Rail Executive and Senior Manager interviews identified a number of contemporary challenges of the matrix organisational form that need to be addressed if objectives and plans are to be achieved.

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

One of those interviewed said:

"It is important to appreciate the position individuals find themselves, mainly around risk perception, and the abilities of staff to effectively challenge decisions when they themselves are also having to make real-time, operational, decisions often unsighted by what is happening elsewhere."
[Executive 6]

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

"We need to be able to spot any 'warning signs' as decisions are made and changed. If not, we struggle to recover from this downstream, and we go on to hold an 'inquisition' as to why things were allowed to get out of control."
[Executive 1]

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

visibility between objectives and the way the organisation was presently structured to deliver these. This 'tension' was reported as a concern to some interviewees, and one suggested that:

"….[poor] decisions which are later questioned can get down-played because decision-making isn't always transparent to others within the system, and especially around how the decision-making itself was informed for example through knowledge, experience, data analytics, or the use of artificial intelligence."
[Executive 8]

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

3.2.2. Visibility of boundaries of acceptable (safety and operational) performance

Of the 25 interviews carried out, it was clear that many participants felt very strongly that safer and better operational performance could be achieved through better decision-making and planning, and the indicators of safety and operational performance were probably not visible to their respective organisations, across all levels, despite monitoring and reporting of trends across a number of data sets.

There were clear concerns that whilst there was plenty of information, this was not necessarily readily accessible or visible to those that could make best use of it. Another point, made by several, was that the reactive nature to indicators of unacceptable performance led to a 'firefighting' approach, and a tendency to find counter measures as quickly as possible to avoid a deteriorating trend, without necessarily adopting the right solution due to the haste. The move to a more considered and proactive approach was certainly the preferred choice for many interviewees, but how to achieve this was seen as complex, and one senior manager said it felt like they were 'asking to boil the ocean' whenever the subject arose with their teams because of how the data seems so elusive to them.

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

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

3.2.3. Alignment of structures to objectives

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

When asked, many interviewees were able to describe their respective safety management systems, and supporting structures, but could not do so in the context of the wider integration required across the levels of the wider rail system. Their knowledge appeared to be limited to their immediate sphere of control or work area. There were, however, two Executive level interviewees with experience in other transport-related sectors. They had strong views on how they saw the value of operating in a clearly defined system, particularly if it is a complex one with multiple layers and functions.

They talked about:

"…having common goals and objectives across organisations."
[Executive 3]
"….and interactions and dependencies needing to be made clear across all levels [and functions] of the system."
[Executive 6]

Several questions were posed regarding what might happen, for example, in the event of a major incident or accident, and decisions required in relation to line closures, media handling and the like. Individuals reported that they would operate within the boundaries of their knowledge and experience, but they were aware that this may not extend to a full appreciation of what others did or might decide to do.

Very few of the interview participants could meaningfully describe, for example, all the rail safety organisations and their roles and responsibilities, and even fewer understood the part industry organisations (such as the Rail Delivery Group – who have responsibility for bringing together the companies that run Britain's railway, to deliver a better railway) directly play in decision making.

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

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

The interviews expose the differences between Rasmussen's (1997) hierarchical model of safety control and the actual practice of GB Rail organisations; reflected in the Rail Executives' and Senior Managers' recognition that a systems approach is not always easy. Most of the interviewees could describe how decisions made at higher levels within the complex rail structure should flow down through their organisations as the information flows upwards (e.g. management need to be informed about safety and performance against objectives). However, they admitted that this is not always how things work in practice due to a range of factors including commercial imperatives and political drivers.

3.3. Capability

The overall theme of capability was the most common category to emerge from the interviews, and has a broader organisational perspective used in the context of organisation design, systems or processes, and competence of people and behaviours. Questions on the topic of capability informed the creation of the sub-themes: competent decision-

makers, functional properties, and parameters affecting safety and operational performance in a changing environment.

3.3.1. Competent decision makers

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

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

"Behaviour change and the way people think and make decisions is critical to success; this is a cultural challenge as some dislike the ambiguity of risk-based decision making and want everything controlled by standards, whereas we should be aiming for control through capability…..Too much emphasis is on everyone wanting things to be 'black and white' and standardised in a way that precludes individuals from thinking for themselves within the boundaries of their capability. It's about time we trusted people to do the right thing at the right time, in the knowledge they are trained and competent for the role assigned."
[Senior Manager 1]

"The matrix decision-based approach is still lacking in Network Rail, so individuals tend to make decisions within a hierarchy. Accountability and responsibility are blurred because of the chains of command and who has the final 'say'."
[Senior Manager 6]

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

3.3.2. Functional properties (organisation design and technical core)

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

"….we expect too much of some of our people. Looking at 'change' in isolation makes [the programmes] appear achievable; put them all together and it exposes the enormity of the task. The same resources, usually the frontline, are impacted over and over again."
[Senior Manager 9]

Rasmussen and Svedung (2000) previously noted that decisions makers need to be competent in regard to the operational, technical and

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

3.3.3. Parameters affecting safety and operational performance in a changing environment

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

"Responsibilities always evolve; they are never completely static, and I think this is true whether in normal operations or periods of perturbation. My big worry is how we have failed to develop people with the necessary skills to deal with the railway as a system, and this needs addressing."
[Executive 3]

"We don't generally have a positive behavioural impact on our people; they often feel 'done to' and we need to develop a workforce with a degree of autonomy, improving their decision-making skills, and making better use of their technical abilities. We need our people to know what is expected of them, like making risk-based decisions in a forever changing system, and without fear of blame."
[Senior Manager 6]

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

3.4. Awareness

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

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

3.4.1. Implications of decision-making and risk considered in the flow of work

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

Almost all the interviewees expressed concerns about the potential for a disconnect between goals, objectives, roles and responsibilities, and authority. Many believe this situation may continue for a while in a complex sector, operating under emergency measures during the Covid

pandemic, and facing more uncertainty following the publication of the Williams-Shapps 'Plan for Rail' (DfT, 2021), which is seeking to create a new structure for rail (addressing issues of consolidation, efficiencies, and greater customer engagement).

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

"……we need to operate effectively in a 'live' railway, accepting some people may make mistakes. We need to allow for a 'fail fast, learn faster' mindset. By stifling decision-making, we stifle creativity, and we don't take advantage of the opportunities to learn."
[Executive 4]

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

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

[Senior Manager 15]

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

"We have recently created an opportunity for people to challenge our standards, but very few of these challenges come from the frontline which makes me suspicious in as much that we know we have people taking decisions out there but probably not following procedures. Making 'live' decisions without recourse to requesting changes to a Standard is a whole lot easier! Therefore, the risk of non-compliance is sure to exist, but I am not convinced we want to hear that, or indeed know what best to tackle first given the likely scale."
[Executive 4]

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

3.4.2. Learning lessons

Many of the interviewees reported a desire of Network Rail to continuously improve, and an almost relentless pursuit of information and real-time data to inform decision-making for every-day activities (for example, on-train recording / monitoring of the ride-quality over the track, and crossings). However, a number felt that the introduction of technologies was occurring at such a pace that this makes exceedingly difficult for the frontline worker to keep abreast of their part in decision-making – either directly or indirectly – because of diagnostic tools, and system apps seemingly doing some of this risk analysis 'work' for them.

As Leveson (2011) has previously identified, and a number of those interviewed stated, learning from past events (i.e. knowing what happened, why, and what to do), and sharing this, must be a prerequisite

for the organisation if it is to become more resilient.

"Organisational learning must be a source of the knowledge from where our improvement programmes and activities should be driven. This way we have good, closed-loop learning processes."
[Senior Manager 9]
"We need to start combining our various data sources – investigations, report recommendations, inspections, audits, assessments – and supplement them with more systemic approaches that allow us to avoid surprises. We've introduced bowties in support of risk management as an example, but they are really complicated for the frontline, and I am not sure we go back and properly revisit them in light of incidents. Why not?"
[Senior Manager 15]

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

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

3.5. Priorities

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

3.5.1. Resilience

Resilience engineering relies on a holistic view of systems. This perspective, known as systems thinking, has been influenced by the likes of Hollnagel, Woods and Leveson (2006), and Jens Rasmussen (1997), in recent decades.

When the Rail Executives and Senior Managers were asked about their understanding of the term 'resilience' and what this means for safety performance, and operational reliability, they often went on to describe resilience through the people aspects of the system (e.g. resourcing, competence, knowledge) or the assets or technologies within the system (e.g. component reliability, IT resilience). Rarely did they mention the system as a whole. Many of the interviewees proffered their views on managing complexity in a rail system, and that this is, or will be, a required core skill, including an awareness of the impact an individual's decisions have on others. Some said that decision-making can be a reaction to the pressure, and it may not be the right decision, but reputation management can become pervasive.

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

The required qualities of a resilient system (adaptability, high levels of redundancy, quality information) were discussed with interviewees, and the Executives and Senior Managers acknowledged their importance to deliver successful operations in a dynamic system. All eight of the Executives interviewed said they would welcome the ability to adapt

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

3.5.2. Trade-offs

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

One Senior Manager said that risk management in the rail system requires them to understand how pressures in the overall system – meaning government, the Regulator, management, and the frontline – affect decision-making. This means decisions affect several other layers, and many interviewees reported that someone usually must make some kind of trade-off, usually at quite a junior level within the hierarchy. An example cited was a timetable change and the differing priorities of the Government, the Regulator, the infrastructure owner, train operator and local management – all of whom have different organisational contexts or conditions influencing them, and it might be the local planning team that ultimately makes the trade-off.

That said, there was also a suggestion by several interviewees that they wondered if trade-offs between safety and performance will be possible in future. Their concern centred around increasing system complexity, and how those in the system would be able to intelligently manage the various interactions – design approvals, communications, real-time data reporting, information systems, media management – such that they could be anticipated, managed, and guarded against. One Senior Manager said:

> "….the interfaces are already a problem and I can only see the situation worsening in some cases if we don't sort out the industry structure."
> [Executive 3]

Getting the right balance between sufficient resources for planning a task and the resources to undertake the task, may require a trade-off. It is recognised that poor planning could lead to poor execution, but if resources are scarce, it is necessary to consider where efforts are prioritised. The interviewees had mixed views on whether some things – like resource allocation – are truly 'tradeable' and if some individuals would know where to best place their efforts. Hollnagel (2009) discusses the Efficiency and Thoroughness Trade-off (ETTO) and it may be necessary for rail organisations, in future, to develop these skills, allowing for a blend of efficiency and thoroughness, e.g. providing adequate time and resources to undertake a track inspection, whilst ensuring the checking process is in itself thorough (i.e. not cutting corners or running the risk of later delays caused by missed defects). Understanding conflicting issues of safety, performance and service with other organisational goals is difficult (Wilson et al., 2009). What is espoused as corporate safety priorities (e.g. fatigue management to help staff and managers reduce excess working hours) does not necessarily reflect how trade-off decisions are made, especially where thoroughness is often sacrificed for efficiency (usually because of poor time management, or process bureaucracy).

3.5.3. Conditions to support change

During the interviews some of the participants said that to be able to deliver results, and create the right conditions to support change, there needed to be targets in place that everyone bought into, and adequate resources available to maintain effective operations. However, several managers also said that this was not straightforward within a complex,

highly regulated, landscape and within an ever-changing environment and the 'resilience' of the people and system should not be taken for granted.

An Executive was clear when they said:

> "*We employ thousands of people, and they play an active part in the way we operate and deliver a transport service, and yet it is us in management that often design poor organisation structures, create complicated and bureaucratic processes to follow, and ask our staff to manage conflicting goals almost on a daily basis. How we expect them to be resilient – and so many are – is a credit to them because of a shared sense of purpose to deliver for passengers, and a commitment to dealing with whatever increased demand is placed upon them. Are we resilient, yes, but we must avoid sharp-end workarounds and adaption at any cost…..that's how mistakes and accidents happen.*"
> [Executive 1]

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

3.6. Synthesising the findings from the thematic analysis

Table 3 draws together the findings from the thematic analysis of interview data, highlighting the content that indicates awareness of systems thinking by the interviewees and also where their responses indicated limitations in implementation of systems thinking in this industrial context.

4. Discussion

Much of the literature on how people work in complex organisations (Grote, 2020), socio-technical systems (Trist, 1959), High Reliability Organisations (Weick, 1987, Weick et al., 1999) and loosely and tightly coupled work systems (Bernard et al., 2020), systems-thinking (Leveson, 2011), and resilience engineering (Hollnagel et al., 2006) helps to highlight the importance of integrating safety and human factors into a socio-technical system framework or model and conceptualise the way in which such approaches can be developed. However, there is commonly a lack of details on how to turn the theory into practice, or how the concepts within the theory are experienced or applied in practice. The aim of this current study was, therefore, to investigate senior business leaders' perspectives of how systems thinking is, or could be, applied in organisational design, system change and risk management in the complexity of the rail sector. This type of senior level population can be hard to access in research studies in safety, so the current set of in-depth interviews has been valuable in producing examples of how these industry leaders express their ideas about safety in the work system, offering viewpoints from different senior roles and functions within the main organisations in the industry. Using the five themes based on Rasmussen's and Svedung's (2000) risk management framework helped with structuring the analysis of the interview responses. Within these themes, 13 sub-themes were identified, characterising the information that should be available to decision makers and thereby their capability of safety control, along with the challenges of, and barriers to, organisational change. These findings are based on the perceptions of the people best placed to initiate and implement change, having the experience and authority on the subject matter at hand. This demonstrates the understanding of a real-world STS currently in operation in GB railways, potentially with wider value to safety science, and for other sectors, where the themes and sub-themes may be translatable for system design, analysis, and operation within typical hierarchical safety control structures.

Analysis of the findings in Table 3 shows how these industry leaders

Table 3

Synthesis of content indicating awareness of systems thinking and limitations in the implementation of systems thinking.

Theme and sub-theme	Content indicating awareness of system thinking	Content indicating limitations in implementation of system thinking
Objectives	*Content in this theme includes explanation of how change to decentralisation in the industry is impacting on the organisational structure, accountabilities of staff and performance*	
Clarity of objectives / vision	• Recognition of constant change in industry, increase in complexity and need to evolve at pace.	• Need for greater clarity of objectives, resolving misaligned goals, ambiguous authority and silo focussed employees. • Actions of managers need to be consistent with statements around the importance of safety. • Recognition of gaps between an intention for autonomy and actual autonomy given to people. Aware of some progress, but weaknesses in commitment of managers and impact of sub-cultures, with continuation of old ways of decision-making and working in spite of intended changes with decentralisation.
Objectives communicated within the system	• Recognition of importance of communication within the system. The complexity of the change is recognised.	• Positive impressions of the organisational changes in progress, though messaging about these needs improvement, especially to be more supportive to staff.
Status information	*Content in this theme focused on whether decisions makers are informed sufficiently about the system and visibility of what is acceptable performance*	
Decision makers properly informed	• Recognition of inter-dependence of safety and performance, which is dependent on people knowing their role in the system.	• Importance of developing the competence of people and enabling access to the necessary information to make the right decisions. • Decision-making and the information used in decision-making needs to be transparent. Need people to be agile and able to spot and react to warning signs about loss of control.
Visibility of boundaries of acceptable (safety and operational) performance		• Existing monitoring and reporting do not give sufficient visibility of safety and operational performance to the people that need this for better decision-making and planning. • More proactive approaches are needed, with a more positive focus on measures of safety and

Table 3 (*continued*)

Theme and sub-theme	Content indicating awareness of system thinking	Content indicating limitations in implementation of system thinking
Alignment of structure to objectives		organisational performance. • The organisational structure, roles and responsibility, levels of authority, and wider industry relationships need to be properly developed, understood and communicated. • The importance of upward and downward information flows were recognised, but these are impeded in practice by commercial and political factors. • There were differing viewpoints on the appropriate level of autonomy, span of control and decision latitude for staff.
Capability	*Content analysis indicated recognition of the importance of capability of staff*	
Competent decision makers		• People have to make decisions in sub-optimal situations (e.g. under time pressure when problems arise or to work around problems of poor design of process or equipment). • There is a lack of clarity in accountabilities and reluctance to move away from hierarchical decision-making and reliance on standards.
Functional properties		• Expectations are too high on people in the industry, who will need to be able to adapt quickly to be able to deliver industry objectives around the scale of change. • Recognition that restructuring is needed, clarifying responsibilities to ensure decision-making is coordinated across the industry.
Parameters affecting (safety and operational) performance in a changing environment	• Importance of developing people to be able to respond with autonomy to a dynamic situation and deal with the railway as a system, which is constantly changing.	
Awareness	*This related to awareness of risk in normal work processes and during operational perturbations*	
Implications of decision-making, and risk considered in the flow of work	• Explanation of how the railway still needs to function in the meantime and the industry needs to adapt to situations that are faced, support people in their decisions and encourage learning	• Awareness of disconnections between goals/objectives, roles/responsibilities, and authority, and this is unlikely to change during a time of major reorganisation of the rail industry.

Table 3 (*continued*)

Theme and sub-theme	Content indicating awareness of system thinking	Content indicating limitations in implementation of system thinking
	from the decisions that are made and deviations from standards.	
Learning lessons		• There is a desire for continuous improvement, but people have difficulty keeping up with the scale of available data and introduction of new technology and use this effectively in decision-making. Recognition of the need to improve how information from various data sources is combined and shared.
Priorities	*These highlight the collective views of where commitments to safety are needed.*	
Resilience	• Qualities such as adaptability, redundancy and quality information were recognised as being important.	• This was often explained at an individual level, rather than a characteristic of the system. Adapting and changing procedures and processes needs to be possible at pace and coordinated so that changes are made at the same time in the system.
Trade-offs	• There is consideration of the implications of decisions at different system levels e.g. government, regulator, management, front line.	• The need for trade-offs is recognised, though the increasing complexity of the industry makes this difficult for decisionmakers.
Conditions to support change		• Provision of agreeable targets and sufficient resource and been suggested to support implementation of change, though change is made more difficult by the complexity, level of regulation and ever-changing operational environment. • It is recognised that too much emphasis can be placed on people to make the change, in difficult circumstances.

are aware of the interdependence of safety and performance (see the related systematic review by Hashemian and Triantis, 2023, on the relationship between production pressure and safety) and the impact of change and the need to adapt and evolve whilst continuing to function within the complexity (Weick, et al. 1999) of the operational railway. The importance of communication is recognised, as well as the implications of decisions on different system actors. The need for clarity in roles is appreciated, and the importance of developing the capability of staff to be able to respond to system perturbations has also been explained.

Whilst the interviews have helped to illustrate the good awareness of systems thinking of the senior leaders in this industry, they have also exposed perceptions of limitations in the application of systems thinking and highlighted areas for development within the industry. For example, there are several reports of inconsistency between goals/intentions and

action, such as around the importance of safety or level of autonomy in decision making. There are weaknesses in ensuring competence in staff and supporting the kind of agility that is needed in decision-making and responses to operational situations. It is also explained how the industry needs to be more proactive in its response to risk, with transparency in decision making. Improvements in the design of organisational structures are needed, with clearer specification of roles and the decision authority within these, with appropriate expectations of people in these complex and changing settings. Improvements are also needed in the synthesis of information from various sources and sharing of data from monitoring activities. The industry may need to be open to considering new organisational forms and principles, enabling structuring and timely re-structuring according to on-going operational needs, to enable staff to perform effectively in this type of changing and unpredictable, high hazard environment (Bigley and Roberts, 2001).

There have been benefits of undertaking qualitative research with a select group of interviewees. Opportunities to gain access to such a group of influential people in the rail industry are rare and these in-depth interviews have helped to generate an understanding of the multiple goals and objectives of a range of organisations, presenting a picture of the complexity of the rail industry. Whilst these are limited to the perspective of the higher levels in the system hierarchy, these are drawn from various business functions and responsibilities in this sector and have sufficient breadth to enable different perspectives from people at this level of the system. There were no efforts to include contact with frontline workers in this study to directly examine interactions across system levels, communication flows or where there may be process, people, or technology issues during change implementation, though these could be applied usefully in future as an extension of this research.

The findings from the analysis identify several important points to consider for organisational design and management of change in a complex industry, and how a socio-technical system framework or model might be applied in practice: firstly on the need for recognition that a systems approach is needed to support change; secondly on practical insights on understanding and managing trade-offs; and finally on dealing with uncertainty and the implications of flexibility vs fixed approaches to control.

4.1. Recognition that a systems approach is needed to support change

The interview analysis has produced descriptive details to elaborate on a number of the enablers and barriers to change that have also been considered by earlier researchers (see Eason et al., 1996; Eason, 2014; Mumford, 2000), including integrative approaches for effective implementation of new technology into work organisations, such that both technical and social aspects of systems (Klein, 2014, Aven, 2018) are considered, and with effective key stakeholder participation. However, the interviews with rail leaders suggests that such an integrative approach is difficult in practice because of the hierarchical nature of the organisation(s) involved and the tendency to focus on technical 'silos' rather than across disciplines, functions, and layers. Even when change is initiated, the Executives and Senior Managers recognise that it does not always happen in the way envisaged at the outset. Thus, participation or stakeholder buy-in can be piecemeal at best, or even non-existent in some cases.

In socio-technical systems the work or technical aspects of systems, such as work processes, task definitions, equipment, and information flow, are usually defined or evolve in an organisation. The social aspects of systems, such as the people or culture are integral to the working environment and the technical and the social aspects of the system are interdependent (Klein, 2014). Each aspect should be designed along with the other (Walker, 2015), but the interviews illustrate how good examples of such a joined-up approach were not readily identifiable. Instead, these two aspects of the system appear to have been designed or evolved independently; technical procedures are developed separately to the organisation design and management. This, in part, is because

human actions, decisions and technological factors are not well understood in the wider, whole system, context. Furthermore, interconnections between organisations in the rail industry are often limited, sometimes because of the way organisational sensitivities or work silos govern what is shared, but also as a result of different political drivers and funding pressures. To work well in practice a multi-factorial, holistic, systems approach is required whereby the politics might be put aside, taking opportunities to design and evolve systems that reflect the needs of the business(es), end-users and managers, and where the means of undertaking tasks that are flexibly specified wherever possible.

It is common to see recommendations of the need to take a systems approach, but what this means in practice is not often explained. Clegg's (2000) nineteen principles of socio-technical design might serve as a useful blueprint for this, considering all facets relating to the socio- and technical- aspects including design choices, simplicity over complexity (without oversimplifying, Weick, et al., 1999), and core processes being integrated. However, there appear to be clear gaps in what the theorists suggest as an approach and the practical execution of this. For example, the industry leaders found it difficult to imagine being able to design changes from a 'blank piece of paper' or using professional judgement to decide what constitutes a core process, largely because of their inability to simply stop a process and design a new one whilst having to keep the railway running. They also identified that having the resources and support required across multiple layers and disciplines to deliver change at scale was essential, but rarely achieved due to affordability and an issue of competence.

The rail system is increasingly complex, and the interviews show that whilst there is a highly connected system of people, resources, processes, and organisations involved, there remains an issue of capability around competence, capacity, and readiness to manage change at scale or risk across the entire system. Hence, there is the tendency to focus on discrete interventions which are then narrowly monitored. The idea of a systems approach is not new to the railways; timetabling and system operations are good examples of how systems, design and risk are considered, but the broader understanding of the social factors (including human interactions, and wellbeing) and the part they play in overall system performance are usually lacking, primarily because of the tendency to focus on technical solutions rather than the people aspects of change (Ryan et al., 2021).

4.2. Understanding and managing trade-offs within a complex regulatory framework

The interview analysis helped to highlight some key facets of systems thinking in a dynamic system and resilience engineering, and how these concepts are applied in practice. For example, some interviewees suggested that the focus tends to be on the very traditional risk-based approach in managing change and thereby the controls, policies and procedures needed for compliance, though the difficulties of predicting and controlling risk in complex systems has been recognised and broader qualitative approaches to risk assessment may need to be developed (Aven, 2017, 2018).

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

Within a socio-technical system, and thereby the system of systems within that, there are many challenges including sub-systems, each with their own purpose to fulfil (Maier, 1998). Some interviewees questioned whether there can be such a thing as a legitimate 'trade-off' in a safety critical industry when different pressures come to bear on parts of the

sector, i.e. the sub-systems. The interviewees offered their perspectives on management information and reporting, which suggest that different sources of risk in rail need to be more visible, considering trade-offs between socio-, technical and economic performance when making decisions, and the effects on reputation and service. As others have previously found, it is difficult for individuals to make decisions when they do not necessarily understand the wider context (Rasmussen, 1997) or how a decision might translate across boundaries (Leveson, 2012) or the impact on the overall system (Salmon et al., 2012).

Rasmussen (1997) said that safety management of organisations with dynamic operations should be based on *"an identification of the boundary of safe performance by analysis of the work system, and the criteria that drive the continuous adaptive modification of behaviour"*. In the case of the rail system these boundaries are constantly under pressure (Hashemian and Triantis, 2023) to deliver a safe but performing railway, often arising in the midst of operational perturbations. That said, there was good practice identified from the interviews where industry leaders showed a real awareness of what we know as the principles of resilience engineering, despite constraints imposed by divergent goals or perceived mixed messages with respect to safety, profitability and/or performance. For example, the industry has made great efforts around capacity planning and scheduling to forecast timetable risks before conflicts occur, and it has been important for different functions to know each other's ways of working but also their capabilities and limitations.

4.3. Dealing with uncertainty and implications of flexibility vs fixed approaches to control

Interviewing rail industry leaders and decision makers about organisational change, has provided an understanding of the workplace organisation and potential behaviours that facilitate or impede change implementation in the GB rail industry. The research has revealed how Network Rail has consciously embarked on a programme of greater decentralisation, supported by many interviewees, with a view to enabling flexibility by empowering frontline workers in decision-making. However, this study has also shown that this is not necessarily happening in practice and some very Senior Managers say they still prefer centralised control, which they believe provides stability and control over defined processes. The interview analysis has exposed the tension in the advocated direction (e.g. centralisation and standardisation, with greater control preferred by some interviewees, or decentralisation and distribution of decision-making to well-informed people who are closer to the frontline, as preferences for other interviewees). Whilst concerns about increases in uncertainty with devolved decision-making have been raised, it has been explained previously how an increase in uncertainty may promote safety, by encouraging worker participation and providing opportunities for learning (Griffin and Grote, 2020). Considering the balance of opinions, the interviews suggested that railway rules and procedures are more 'fixed' than 'flexible' whilst decentralisation is progressively rolled out. Therefore, involving end-users in future change design and seeking their views on where tasks should be flexibly specified might be a way to gauge where any 'uncertainty' may already exist within the system and where this may be explored or exploited (Griffin and Grote, 2020).

5. Conclusions

This study has collected the perspectives of senior leaders from a variety of organisations and functions in the rail industry to consider how common concepts and ideas in system thinking and related theories and methods are, or could be, applied in practice in a high risk, complex, industry.

Perceptions of organisational design, management and change are described. Categories from Rasmussen and Svedung's (2000) dynamic approach to risk management in the context of complexity have been used and extended to structure the outputs, gathering insights into

information that is needed for decision-making, and the decision-maker's subsequent capability of control, and the implications that follow. The results from the analyses underline wide ranging systemic issues, from the perspective of the rail industry leaders. Whilst their awareness of system concepts is good and shows an openness to systems thinking and ideas for resolving these concerns, the analysis also highlights a number of weaknesses in implementation from a systems perspective. These seem to be largely problems of putting the theory or good intentions into practice, such as supporting people to be able to work with appropriate agility in this type of challenging environment. These problems are commonly exacerbated by the complexity and changing nature of the industry and operational context, and the difficulties in enabling transparency in areas such as role definition, decision authority and in the kind of real time data that can help with understanding the current status of the system. The interviews have been effective in collecting tangible examples of systemic challenges, and there are valuable practical and operational insights offered by this group of experienced rail industry leaders. The industry now needs support from the research community in overcoming these barriers to implementation of system approaches.

CRediT authorship contribution statement

Michelle Nolan-McSweeney: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Brendan Ryan:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Conceptualization. **Sue Cobb:** Writing – review & editing, Supervision, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

References

Aven, T., 2017. How some types of risk assessments can support resilience analysis and management. Reliab. Eng. Syst. Saf. 167, 536–543.

Aven, T., 2018. A risk interpretation of sociotechnical safety perspectives. Reliab. Eng. Syst. Saf. 175, 13–18.

Bernard, C.I., Morineau, T., Thierry, S., 2020. The degrees of freedom problem: How to guide trajectories with the dynamic safety model to assist activity in loosely coupled work systems. Saf. Sci. 129 (2020), 194712.

Bigley, G.A., Roberts, K.H., 2001. The incident command system: high-reliability organizing for complex and volatile task environments. Acad. Manag. J. 44 (6), 1281–1299.

Clarke, S., 1999. Perceptions of organisational safety: implications for the development of safety culture. J. Organ. Behav. 20 (2), 185–198.

Clegg, C.W., 2000. Socio-technical principles for system design. Appl. Ergon. 31, 463–477.

Dekker, S., 2003. Failure to adapt or adaptations that fail: Contrasting models on procedures and safety. Appl. Ergon. 34 (3), 233–238.

Dekker, S., 2011. Drift into Failure. From Hunting Broken Components to Understanding Complex Systems. Ashgate, Farnham.

Department for Transport (DfT), 2022. Rail Factsheet 2021 (26 January 2022).

Eason, K.D., 2014. Afterword: the past, present and future of sociotechnical systems theory. Appl. Ergon. 45 (2), 213–220.

Eason, K.D., Harker, S.D., Olphert, C.S., 1996. Representing sociotechnical systems options in the development of new forms of work organization. Eur. J. Work Org. Psychol. 5 (3), 399e420.

Farrington-Darby, T., Pickup, L., Wilson, J.R., 2005. Safety culture in railway maintenance. Saf. Sci. 43 (2005), 39–60.

Griffin, M.A., Grote, G., 2020. When is more uncertainty better? A model of uncertainty regulation and effectiveness. Acad. Manag. Rev. 45 (4), 745–765.

Grote, G., 2015. Promoting safety by increasing uncertainty – Implications for risk management. Saf. Sci. 71, 71–79.

Grote, G., 2020. Safety and autonomy: a contradiction forever. Saf. Sci. 127 (2020), 104709.

Hall, J.L., 2003. Columbia and challenger: organisational failure at NASA. Space Policy 19 (2003), 239–247.

Hashemian, S.M., Triantis, K., 2023. Production pressure and its relationship to safety: a systematic review and future directions. Saf. Sci. 159, 106045.

Hollnagel, E., 2009. The ETTO Principle: Efficiency-Thoroughness Trade-Off. Ashgate Publishing Ltd., England.

Hollnagel, E., 2012. FRAM: The Functional Resonance Analysis Method: Modelling Complex Socio-technical Systems. Ashgate Publishing Ltd., England.

Hollnagel, E., Woods, D.D., Leveson, N., 2006. Resilience Engineering. Concepts and Precepts. Ashgate Publishing Ltd., England.

Hollnagel, E., Leonhardt, J., Shorrock, S., Licu, T., 2013. From Safety-I to Safety-II. A White Paper. EUROCONTROL Network Manager, Brussels.

Hollnagel, E. (Ed.), 2008. Safety Management – looking back or looking forward. In: Hollnagel, E., Nemeth, C.P., Dekker, S. (Eds.), Resilience Engineering. Concepts and Precepts. Aldershot, Ashgate.

Klein, L., 2014. What do we actually mean by 'sociotechnical'? On values, boundaries and the problems of language. Appl. Ergonom. 45, 137–142.

Le Coze, J.-C., Dupré, M., 2022. Safety as a network, digital and global reality. Saf. Sci. 156, 105896.

Leveson, N.G., 2004. A new accident model for engineering safer systems. Saf. Sci. 42 (4), 237–270.

Leveson, N.G., 2008. Technical and managerial factors in the NASA Challenger and Columbia losses: Looking forward to the future. In: Kleinman, D.L. (Ed.), Controversies in science and technology (Vol.2). Mary Ann Liebert Publishing, New Rochelle, NY.

Leveson, N., 2011. Applying systems thinking to analyse and learn from events. Saf. Sci. 49 (2011), 55–64.

Leveson, N., 2012. Engineering a Safer World: Systems Thinking Applied to Safety. MIT Press, Cambridge, Mass.; London.

Maier, M.W., 1998. Architecting principles for systems-of-systems. Syst. Eng. 1, 267–284.

Makins, N., Kirwan, B., 2016. White paper: keeping the aviation industry safe: safety intelligence and safety wisdom. Future sky safety. . Eur. Res. Establish. Aeronaut.

Mayring, P., 2000. Qualitative Content Analysis. Art 20 Forum: Qual. Soc. Res. 1. http ://www.qualitative-research.net/index.php/fqs/article/view/1089/2385.

Moorkamp, M., Kramer, E.-H., van Gulijk, C., Ale, B., 2014. Safety management theory and the expeditionary organization: a critical theoretical reflection. Saf. Sci. 69, 71–81.

Mumford, E., 2000. A socio-technical approach to systems design. Require. Eng. 5, 125e133.

Network Rail, 2020. Network Statement 2020.

Office of Rail and Road, 2020. Annual Report of Health and Safety Performance on Britain's Railways 2019/20.

Rasmussen, J., 1997. Risk management in a dynamic society: a modelling problem. Saf. Sci. 27, 183–213.

Rasmussen, J., Svedung, I., 2000. Proactive Risk Management in a Dynamic Society. Risk & Environmental Department, Swedish Rescue Services Agency, Karlstad.

Reiman, T., Oedewald, P., 2007. Assessment of complex sociotechnical systems – theoretical issues concerning the use of organisational culture and organisational core task concepts. Saf. Sci. 45 (2007), 745–768.

Reiman, T., Rollenhagen, C., Pieetikainen, E., Heikkila, J., 2015. Principles of adaptive management in complex safety-critical organisations. Saf. Sci. 71 (2015), 80–92.

Reiman, T., 2010. Understanding maintenance work in safety-critical organisations - managing the performance variability. Theoretical Issues in Ergonomics Science. 12: 4, 339-366.

Ryan, B., Golightly, D., Pickup, L., Reinartz, S., Atkinson, S., Dadashi, N., 2021. Human functions in safety - developing a framework of goals, human functions and safety relevant activities for railway socio-technical systems. Saf. Sci. 140, 105279.

Salmon, P.M., McClure, R., Stanton, N.A., 2012. Road transport in drift? Applying contemporary systems thinking to toad safety. Saf. Sci. 50, 1829–1838.

Shorrock, S., Williams, C., 2016. Human Factors and Ergonomics in Practice: Improving System Performance and Human Well-Being in the Real World. Routledge.

Skyttner, L., 2001. General Systems Theory: Ideas & Applications. World Scientific.

Snook, S.A., 2000. Friendly Fire: The Accidental Shootdown of US Black Hawks Over Northern Iraq. Princeton University Press, Woodstock, UK.

Trist, E., 1959. Socio-Technical Systems. The Tavistock Insitute of Human Relations:, London, UK. Report 572.

Trist, E., 1981. The evolution of socio-technical system: A conceptual framework and an action research program. Occas. Pap. 2 (June).

Walker, G.H., Stanton, N.A., Salmon, P.M., Jenkins, D.P., Rafferty, L., 2010. Translating concepts of complexity to the field of ergonomics. Ergonomics 53 (10), 1175–1186.

Walker, G., 2015. Come back sociotechnical systems theory, all is forgiven. Civil Eng. Environ. Syst. 32(1–2), 170–179.

Waterson, P., Robertson, M.M., Cooke, N.J., Militello,, L., Roth, R., Stanton, N.A., 2015. Defining the methodological challenges and opportunities for an effective science of sociotechnical systems and safety, Ergonomics 58(4), 565–599.

Weick, K.E., 1987. Organizational culture as a source of high reliability. California Management review, Volume XXIX 2, 112–127.

Weick, K.E., Sutcliffe, K.M., Obstfeld, D., 1999. Organizing for High Reliability: Processes of Collective Mindfulness. In: Sutton, R.S., Staw, B.M. (Eds.), Research in Organizational Behavior, vol. 1. Jai Press, Stanford, pp. 81–123.

Wilson, J.R., 2014. Fundamentals of systems ergonomics/human factors. Appl. Ergon. 45 (1), 5–13.

Wilson, J.R., Farrington-Darby, T., Cox, G., Bye, R., Hockey, G.R.J., 2007. The railway as a socio-technical system: human factors at the heart of successful rail engineering. Proc. Inst. Mech. Eng., Part F: J. Rail Rapid Transit 221 (1), 101–115.

Wilson, J.R., Ryan, B., Schock, A., Ferreira, P., Smith, S., Pitsopoulos, J., 2009. Understanding safety and production risks in rail engineering planning and protection. Ergonomics 52 (7), 774–790.

Woods, D.D., 2006. Essential characteristics of resilience. In: Hollnagel, E., Woods, D.D., Leveson, N. (Eds.), Resilience Engineering: Concepts and Precepts. Ashgate, Farnham.

Woods, D.D., Dekker, S., Cook, R., Johannesenm, I., Sarter, N., 2010. Behind Human Error, second ed. Ashgate, Farnham.

Further reading

Birkland, T.A., 1997. After Disaster: Agenda setting, public policy, and focusing events. Georgetown University Press, Washington, DC.

Glassman, R.B., 1973. Persistence and loose coupling in living systems. Behav. Sci. 18 (2), 83–98.

Holland, J.H., 2002. Complex adaptive systems and spontaneous emergence. In: Curzio, A.Q., Fortis, M. (Eds.), Complexity and Industrial Clusters. Physica-Verlag, Heidelberg, Germany, pp. 24–34.

Johansson, B., Lindgren, M., 2008. A quick and dirty evaluation of resilience enhancing properties in safety critical systems. In: Hollnagel, E., Pieri, F., Rigaud, E. (Eds.), Third Symposium on Resilience Engineering, 28–30 Oct 2008, École des mines de Paris.

Le Coze, J.C., 2013. What have we learned about learning from accidents? OPst-disasters reflections. Safety Science 51 (2013), 441–453.

Leveson, N., 2017. Rasmussen's legacy: a paradigm change in engineering for safety. Appl. Ergon. 59 (2017), 581–591.

Nolan-McSweeney, M., Ryan, B., Cobb, S., 2018. Getting the right culture to make safety systems work in a complex rail industry. In: Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018). Volume VI: Transport Ergonomics and Human Factors (TEHF), Aerospace Human Factors and Ergonomics, pp. 489–503.

Nolan-McSweeney, M., Ryan, B., Cobb, S., 2019. Engineering the Right Change Culture in a Complex (GB) Rail Industry. Advances in Human Factors of Transportation. In: Proceedings of the AHFE 2019 International Conference on Human Factors in Transportation, July 24–28, 2019, Washington D.C., USA, pp. 250–260.

Network Rail, 2019. Delivery Plan: Control Period 6. High level summary.

Perrow, C., 1984. Normal Accidents. Living with High-Risk Technologies. Basic Books, New York.

Rasmussen, J., 1982. Human errors: a taxonomy for describing human malfunction in industrial installations. J. Occup. Accid. 4, 311–335. Elsevier Scientific Publishers.

Rasmussen, J., 1986. Information Processing and Human-Machine Interaction: An Approach to Cognitive Engineering. North Holland.

Reason, J., 1997. Managing the Risks of Organisational Accidents. Ashgate, Farnham.

Roberts, K.H., 1990. Some characteristics of one type of high reliability organisation. Organ. Sci. 1, 160–176.

Ryan, G.W., Bernard, H.R., 2000. Data management and analysis methods. In: Denzin, N., Lincoln, Y. (Eds.), Handbook of Qualitative Research, 2nd ed. Sage, Thousand Oaks, CA, pp. 769–802.

Stacey, R.D., 1996. Complexity and Creativity in Organisations. Berret-Koehler Publishers, San Francisco.

Taylor, F.W., 1911. The Principles of Scientific Management. Harper & Brothers Publishers, New York, NY.

Weick, K.E., 1976. Educational organisations as loosely couple systems. Adm. Science. Q. 21, 1–19.