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Human Functions in Safety - Developing a framework of goals, human functions and safety relevant activities for railway socio-technical systems

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Abstract

This paper presents a framework to express the role of people in establishing and maintaining system safety. The Human Functions in Safety (HFiS) framework has been developed for the railway context, describing safety-related activity within functions, and how this is shaped by overall organisational goals and contextual factors. Analysing human functions in this way moves from the reactive, accident-analytical approach that is commonly used in rail, by instead emphasising the human activity that maintains safety. The development and first application of HFiS involved three iterative stages of 1) mapping requirements to the safety literature to determine the concepts of the framework; 2) collating and synthesising data from the rail domain to determine the content of the framework; 3) review within the research team and with subject matter experts. The output from applying HFiS to railways is a detailed description of 66 human functions carried out by wide-ranging frontline staff, and the associated activities to maintain safety. This covered different types of goals (systemic, functional and individual) that shape work and specified the contextual factors that influence safety. Interrelations between human functions across the rail system are also identified. As well as supporting the understanding of rail safety, HFiS demonstrates how safety concepts can be combined and potentially applied to other large socio-technical systems. Specific guidance is presented on generic applications of HFiS concepts, including a set of generic functions with the potential to inform application of HFiS in other domains.

Keywords

Complex socio-technical systems; rail safety; people in work systems; analysis of goals and human functions; safety; context.

Highlights

- Defines a set of concepts that describe how people in frontline roles contribute to the safe and effective operation of the railways
- Provides a common structure that can be adapted and applied by designers / engineers / safety experts to understand the important roles of people in work systems
- Presents a detailed application of the framework for a railway setting, identifying human functions relevant to system-wide safety
- Presents the potential for application to new technical challenges in the railway industry and other domains.

1. Introduction

Traditionally, much emphasis has been placed on the sources of failures within systems, especially on humans and 'human error'. More recently, the focus has turned to what can be learnt about how people succeed every day (e.g. Hollnagel, 2014a; Rankin et al., 2014; Thoroman et al., 2019). This focus acknowledges that incidents and accidents are not exotic events, but manifestations of routine activity that may be disrupted by marginal variation in operational factors (Hollnagel, 2005, 2009; Hollnagel, 2014a). Critically, achieving safety is not just through safe working within a function, but often by functions working together, sometimes through informal and non-documented adaptations, to support each other in safe working (e.g. through 'heedful interrelations' on the flight deck [Weick and Roberts, 1993]; active overhearing in control room [Heath and Luff, 1994]; providing additional ad-hoc clinical support during times of high demand [Martindale et al., 2019]). One example of this situation is the construction, maintenance and operation of the railways. The railway has been described as a complex sociotechnical system (Wilson, 2014); that is, a system requiring a high degree of integration between human and technical functions to achieve system goals (Rankin et al., 2014). In the railways, these goals are to run the service safely (without harm to staff, passengers, public or assets) and punctually (in accordance with the timetable) (Millen et al., 2011). In their day-to-day work, train drivers, signallers, rolling stock maintenance workers, track engineering workers, planners and support staff all contribute safe railway operations. This may be with the aid of technical support (e.g. signalling interlocking) but is also often dependent on the human as a barrier function (Golightly et al., 2013a) or 'last line of defence' (RAIB, 2020). It is an environment where interactions between roles are necessary to give the system the adaptive capacity it requires to meet its goals (Belmonte et al., 2011). It is also a domain where technological and process change is often implemented within silos, and without an understanding of the wider reverberations and impact to safety across the system (Wilson et al., 2007; Crawford and Kift, 2018). Finally, in contrast to domains such as aviation (e.g. Thoroman et al., 2019) or healthcare (e.g. Sujan et al., 2019), it is a domain that has historically relied on reactive accident investigation within functions, rather that pro-active analysis of how safety is achieved across the system (RAIB, 2020).

It is therefore helpful to consider explicitly how people actively contribute to safety in terms of their roles and activities. To do so, a method is needed to understand the interlinked role of people in ensuring safety, across the size and scale of this type of system (i.e. the whole railway system). Specifically, the European Union Agency for Railways (ERA) commissioned the [hidden for peer review] to support the integration of human factors into European railway operations. This was to include the development of a structured framework emphasising what people in frontline roles need to do and the main risks associated with relevant work activities. It was intended that the framework should demonstrate how people interact with technical sub-systems to achieve system goals, recognising that variability and flexibility in how people fulfil their roles can finish the design of the system (Rasmussen et al, 1994), such that safety is maintained most of the time (Hollnagel et al, 2006).

While techniques such as Cognitive Work Analyses (Rasmussen et al, 1994; Vicente, 1999) may look at the functional structure of a system, or Hierarchical Task Analyses (Salmon et al., 2010) may outline the steps required for safe task completion, there was no pre-existing large scale analyses of human functions in railways, nor a suitable methodology or framework to apply. This highlighted a more general gap around tools to support comprehensive analyses of people and their contribution to safety, particularly where a wide number of system functions may be interlinked.

This paper describes the development of the Human Functions in Safety (HFiS) framework – a framework to capture and represent what people in front-line roles do to ensure safety in a socio-technical system, with frontline railways as the application domain. The paper offers the following contributions (1) presents, as the Human Functions in Safety (HFiS) Framework, an appropriate set of concepts and their relations to describe how people contribute to the safe and effective operation of systems (2) uses HFiS to provide a functional description of the railways that foregrounds the proactive human contribution to safety and related factors (e.g. context) (3) uses experience from the application of HFiS in railways to provide guidance for wider application of the framework in other domains.

The paper is structured as follows. Section 2 describes the background of the work, identifying the concepts for HFiS that are relevant to a socio-technical system such as the railway. Section 3 outlines the methodology to define the framework, capture and analyse data to populate the framework, and to review the framework both internally and with subject matter experts. Section 4 summarises the completed example of the populated framework. Section 5 presents reflections on the outputs, including how they could be used in other domains. Section 6 presents conclusions.

2. Background

2.1 The railway context

Safety is paramount in the operation of the railways. This encompasses safety to staff, passengers, public who move around the railway (e.g. at level crossings, or who trespass onto the railways), and to the physical assets of the railways (infrastructure and rolling stock). While the overall safety record of the railway is strong (EU, 2020), some aspects of safety performance have plateaued - in Great Britain, there has been a stable number of around 23,000 harmful incidents per annum (ORR, 2019) over the last 10 years. . Variable and stagnating safety performance is also evident across EU member states (EU, 2020). Functions, such as engineering, continue to have a high accident rate for trackworkers (RAIB, 2008a,b; RAIB, 2019). As well as focusing on safety within countries, common approaches are necessary across countries in pursuit of the Single European Railway (Directive 2012 2012/34/EU). Safety also impacts operational performance, reliability and customer confidence (Ross et al., 2020). This is at a time when the railway needs to assert itself as a viable, zero-carbon travel option as part of national and global climate commitments (DfT, 2020; ERRAC, 2017; UNFCC, 2015).

System complexity is defined by Flach (2012) as a state where there is high 'dimensionality' (several interacting, sometimes competing, goals that need to be balanced on a dynamic basis) and high 'interdependence' (many functions that are not only linked, but interact in a non-linear manner). The railway system is an example of such a complex system. Its operation involves people in collaboration with others, in close coupling with technical components of a system that is distributed in time and space, spanning regional, national and cultural boundaries, and constantly evolving (Wilson, 2014; Wilson et al, 2007). There are multiple goals that can compete with one another, with the need for trade-offs (e.g. of safety, reliability, efficiency, use of capacity, security, environmental sustainability and cost, [Wilson et al., 2009; Seigel and Schraagen, 2019]) in a range of operational modes (e.g. normal, degraded, emergency) (Belmonte et al., 2011; Dekker et al., 2018).

However, it is often the case that safety is examined in the railways through retrospective accident analyses, though this is rarely across multiple incidents (RAIB, 2020) and often draws on incident reporting of limited quality (Madigan et al., 2016). Furthermore, the rapid introduction of new technology such as in the driving cab and in the control room presents new risks for safe operation (Crawford and Kift, 2018; RAIB, 2019). Therefore, safety needs to continue to be prominent in design and operations. While aspects of the railways such as train driving (e.g. Baysari et al., 2008; Dunn and Williamson, 2012; Rose and Bearman, 2012; Naweed, 2014) have received significant attention in publications, others have received much less examination.

One example where there is significant safety risk and a need for more consideration of safety in design and operations is the planning and completion of rail engineering (i.e. the building and maintenance of the infrastructure assets). It is an aspect of the overall rail system where maintenance failures can lead to accidents (e.g. derailments at Bretigny-sur-Orge [Schlessinger, 2016], Grayrigg [Underwood and Waterson, 2014] and Potters Bar [HSE, 2003]). Also, the execution of the work itself introduces risk to trackworkers (Golightly et al., 2013a) such as from trains running in service around the area of maintenance (RAIB, 2008a,b; RAIB, 2019). Research in this area (Wilson et al, 2009; Ryan et al, 2012) has made explicit the functions and risks within rail engineering work systems. The execution of functions requires multi-agency and cooperative work, and new processes for the protection of work and workers on track need to accommodate the interactions between different roles (planning, supervisory - technical and safety related, operational, logistic, regulator and unions).

What becomes apparent in this analysis is not only the complexity of the core activity of engineering but also how many other aspects of the railway system are intertwined with this endeavour. These include safe driving of engineering trains or plant moving in an out of the site, the control of other train movements and protection of the area by a signaller / controller, and overhead or trackside power isolation (Farrington-Darby et al, 2005; Golightly et al, 2013a; Houghton et al, 2016; Pickup et al, 2005, 2010; Schock et al, 2010; Wilson et al, 2009, 2014). The organisation of this work is typically driven by months of planning, yet subject to changes that occur during the work itself or may need to be implemented at very short notice (e.g. for emergency infrastructure repair work) (Ferreira, 2011). Many of the barrier functions within rail engineering are either partially (e.g. signallers setting protection) or wholly (e.g. the role of trackworkers as lookouts) provided by people (Golightly et al., 2013a). This kind of work, in maintenance and engineering, but also in other underrepresented areas (e.g. station dispatch; rolling stock marshalling and shunting) requires a systemic view both of the work involved, and the human role in maintaining the safety of that work.

2.2. Concepts relevant to understanding safe work

A range of system concepts and terminology are evident in the approaches that have been used to describe and represent work (i.e. what people do) including goals, functions, task, activity, risk and safety. Scrutiny of the literature (e.g. Daniellou, 2005; ERA, 2009; Fleishman and Quaintance, 1984; Hollnagel, 2013; Locke and Latham, 2002; Naikar et al, 2006; Rasmussen, 1983; Salmon et al, 2010; Schock, 2010; Vicente, 1999; Watts and Monk, 1998) reveals that there are varying degrees of rigour in how these concepts are defined and used. In some cases, detailed accounts are available, attempting to cover the origin, definitions, different perspectives and theoretical basis for the use of concepts. Often, however, terms are not defined and take on meanings that are more typical of common usage. There was therefore a need to clarify and agree relevant definitions of specific concepts for inclusion in HFiS to express the human role in safety. While detailed definitions are given in section 3.1.2 below, the key principles and motivations behind these definitions are presented here.

The concepts of 'function' and 'task' are common in describing work. 'Function' is central to the current study and has been described as the means that are necessary (or set of activities) to achieve a goal or to produce a certain outcome (Hollnagel, 2016). 'Tasks' have been defined in terms of operations that occur around the same period of time, to meet a goal or purpose (e.g. see Miller, 1967). 'Functions' and 'tasks' are typically expressed in methods such as the Abstraction Hierarchy of a Cognitive Work Analysis or Hierarchical Task Analysis (Salmon et al., 2010).

In safety-related work, people may perform tasks not only directly related to their key safety role but also to fulfil secondary, sometimes undocumented, roles that support safe working for the system as a whole. This is part of the notion of 'Activity' of people in work. Daniellou (2005) explains how activity relates to how work is done, rather than what needs to be done. In contrast to what is foreseen at the design stage (Fadier et al, 2003; Feltovich et al, 2004), activity takes account of real operations, where people respond to a variety of situations, constraints, and unexpected events. Activity can include much more than what is considered typically in performing the task (e.g. see the example within Daniellou (2005) where the activity of a hospital assistant / porter is more than the functional component of moving people around a hospital and includes interacting with a patient to place them at ease). It is clear that people will have different representations, histories, intentions, influences and individual goals in any given set of circumstances, and therefore any description or representation of what people do (e.g. through articulation of functions, tasks or activities) must also capture the 'Context ' (e.g. the environment, including physical, social, cognitive aspects) in which they work.

In addition to understanding what people need to do (human functions, tasks), what they do in practice (activity), and what shapes the work (context), it is also important to understand what can go wrong. There are many different applications of safety analysis (Kjellen and Sklet, 2005), for example to determine if the level of risk is acceptable, or to find a weakness in the system (Harms-Ringdahl, 2003). A variety of terms (e.g. "safety relevant", "safety critical", "activities affecting safety") are typically used to refer to activities, which if completed incorrectly or ineffectively, would have safety implications (e.g. Energy Institute, 2011; ERA 2009; HSE, 1999; Patacchini, 2007; South Australia Act 2012). These terms are not synonymous. The strict definition of safety critical should refer only to activities that, if completed incorrectly, would have severe consequences. This could include handover or checking activities if there are no subsequent activities in which an error could be recovered (ERA, 2009; FAA System Safety Handbook, 2000; Harms-Ringdahl, 2009). In practice, it can be important to look beyond what is safety critical to consider a wider set of activities that could increase the probability of an incident or lead to harm (Reiman and Oedewald, 2009; ROGs, 2006; British Standard Road Vehicles, 2012). Thus the term "safety relevant" is adopted in the rest of this paper.

A systematic approach was therefore needed to incorporate relevant concepts in a method that could be used to identify, analyse, interpret and represent what people do in a complex sociotechnical system – specifically, frontline railway operations across Europe, in this way satisfying the requirements of the ERA (see Section 3.1.1). The aim was to develop a framework that would express the appropriate concepts (function, activity and contextual factors), the relationships between these concepts, and potential impacts on safety.

3. Development and application of the HFiS framework for the railway

The approach taken was broken down into three key stages
1) *Define the HFiS framework* – this involved agreeing the requirements of the lead organisation (ERA) and identifying the appropriate concepts and structure to meet these requirements
2) *Populate the framework* – this involved identifying appropriate data sources and applying a systematic approach to analysing those sources, before going through a phase of synthesis and integration to arrive at an initial description of human safety-relevant functions in the rail system
(3) *Verify the framework* – this involved both internal review by a project team and external review with subject matter experts, to arrive at a stable, agreed description of human safety-relevant functions in the rail system.
While the approach was broadly linear, the three stages and sub-stages were iterative and overlapping. For example, working within the detail of functions at stage 2 influenced the nature of the categories required to describe the context of work, initially defined at stage 1. This is represented in Figure 1.

3.1 Define the framework

3.1.1 Consult with stakeholders and determine requirements for the framework

Stakeholders from the ERA were involved at the earliest stages in agreeing the aims and scope of the work. Specifically, the research team worked in close association with a Human Factors expert and two operational experts from the ERA in developing and agreeing the organisational requirements for the framework and ensuring that the outputs from the research were relevant to the European railways. These requirements are summarised in Figure 2.

While consideration was given to pre-existing work analysis frameworks, in particular Hierarchical Task Analysis (Stammers and Shepherd, 2005; Shepherd, 2015) and Cognitive Work Analysis (Sanderson, 1999; Vicente, 1999), none were available that fully met the requirements outlined. For example, Hierarchical Task Analysis would support the description of tasks but not aspects such as the influence of competing goals (Steenhuisen et al., 2009) that would shape work. This is also a normative method (how work should be achieved) rather than formative (offering the parameters and constraints in which work could be achieved). On the other hand, use of Cognitive Work Analysis would distribute the human contribution to work and the associated contextual factors over multiple stages of analysis (work domain analysis, control task analysis, strategies analysis, social organisation and co-operation analysis, and worker competencies analysis), in a manner that was felt to be insufficient to identify the human contribution to work that was needed in this study. The decision was therefore to develop the new HFiS framework.

Figure 1 Stages of Framework development process

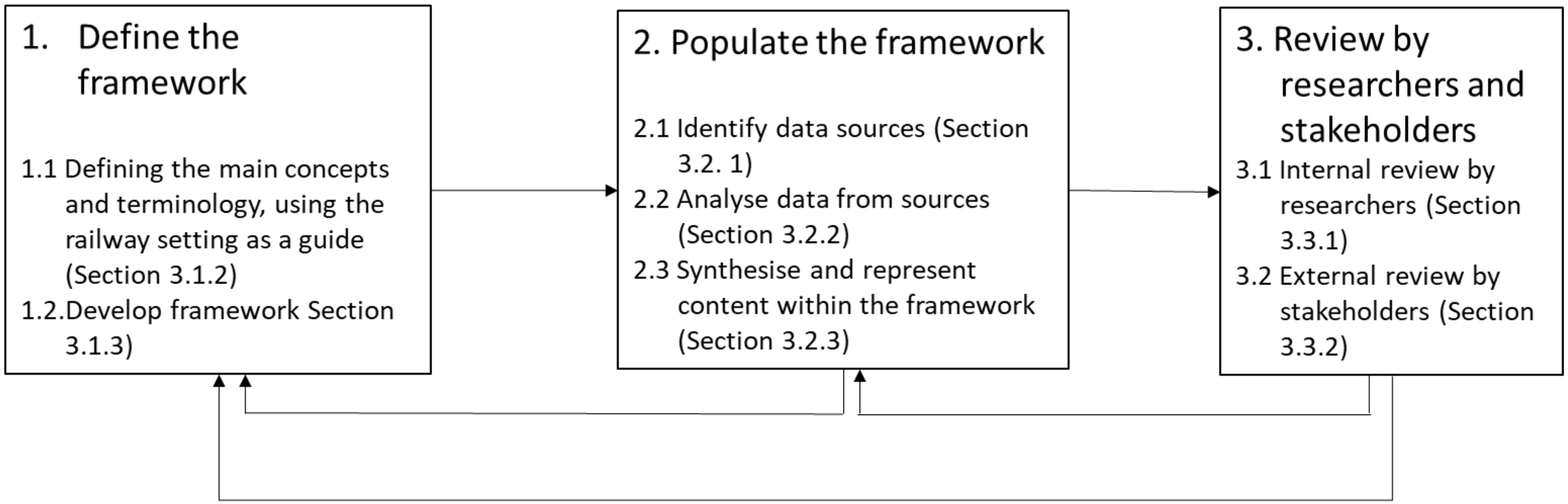


Figure 2 Requirements for the HFiS framework and outputs from use of the framework

Breadth of coverage

- Human functions should represent as many front-line job roles as possible (e.g. as known in the context of European railway systems) engaged in safety relevant activity;
- Search terms for document review should be broad enough to identify wide-ranging content (on goals, functions, tasks and safety relevant activities e.g. within railway operations).

Depth of description and analysis

- The human function should be described at a sufficient level to enable description of specific contexts (e.g. specific instances across European railways) without compromising their generic character, thus allowing widespread application across countries;
- Some human functions may be derived on the basis of more data available than others, so the level of analysis for different human functions may differ.

Identification of sources and cross-referencing

- A clear record of the data source, linked to the data collected, should be retained;
- Gaps in data which are relevant to a particular human function should be highlighted.

3.1.2 Define main concepts and terminology, using the railway setting as a guide

Based on the agreed requirements, working definitions of a preliminary list of concepts (goals, context, functions and safety relevant activities) were derived from literature (see section 2.2). The main concepts and terminology for the proposed framework were reviewed between two of the researchers and three members of the ERA project team at an early stage of the project. However, the process of refining these definitions was iterative, continuing whilst extracting, interpreting and synthesising the data from the railway domain. The final concepts and their definitions are presented in Table 1.

In order to fully capture the motivations behind human functions it was necessary to specify goals at three levels of description. The first level describes the purpose or goals of the system and is similar to the goals and values expressed in the abstraction hierarchy of Cognitive Work Analysis. The second level of goal describes the goal of the human function, in pursuance of the overall performance of the system. The third describes the organisational or personal goals that can influence the performance of the human function.

It was important to consider the context in which the activities take place in the system. Details of the 'Generic Context' describe the situation, conditions and constraints under which the human function is likely to occur. 'Safety Relevant Activities' that are associated with each function were identified and then analysed. Critically, these Safety Relevant Activities covered not only those activities that directly implement safety, but also those where people could support recovery or mitigation in response to failure, either in their own function, or as a consequence of failure in a connected function in another part of the system (e.g. trackworker lookouts alerting an engineering team in the event of an unprotected train movement). In this way, the framework captured the crucial role of human functions and human activity in 'finishing the design of the system' and maintaining safe performance.

Table 1 Definitions of relevant concepts for the project

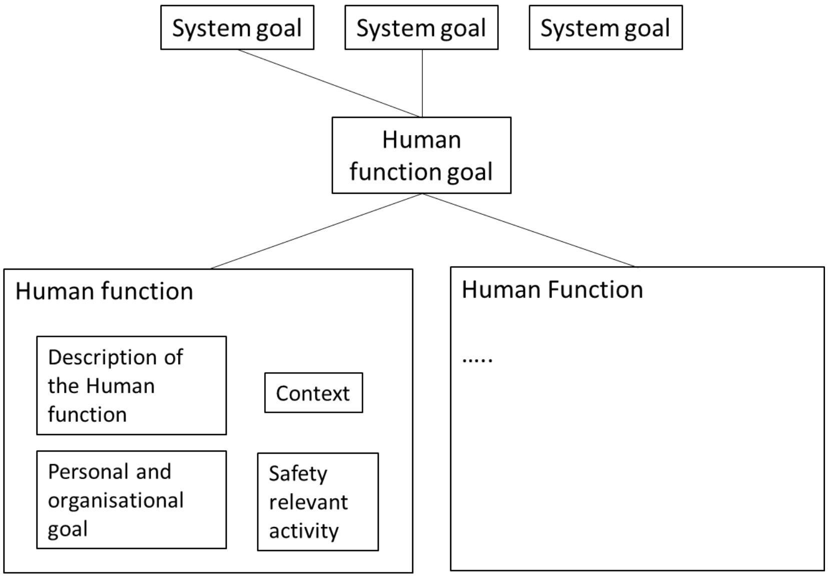
Concepts	Working Definitions
System purpose/goal	The aim of the socio-technical system. There are potentially a number of complementary or competing system goals. System goals can help in providing the criteria for success or failure of the system (e.g. Maintain safety).
Human Function goal	The aim and focus for human efforts to achieve a human function in pursuance of the system goal (e.g. To maintain, repair and extend the infrastructure).
Human Function	A set of activities or operations that must be achieved for the human function goal to be met (e.g. Establish safe working environment). This description will include a verb e.g. to communicate information. In this project, the focus is on human functions – functions that are achieved by humans; one human function may map onto several human function goals.
Personal and organisational goals	The personal or organisational goals that can influence the performance of the human function (e.g. Identify site related hazards and set up safe systems of work)
Generic Context	Narrative description of the circumstances in which the function is executed including the situation, conditions, constraints (such as time pressure, emergency, routine). This should help in setting important boundaries for the function (what is and what is not likely to be included) and to make the description of the function meaningful to the reader (e.g. the consideration of context can draw attention to how arrangements can be influenced by different sets of rules and working procedures).
Safety-Relevant Activities	Activities are the actions of a human in the system which aim to achieve the necessary human functions in the context. Safety relevant activities are those which if performed incorrectly or not performed could result in injury or damage. Safety relevant activities include those that are critical for safety (various definitions for safety critical activities are available), such as where there may be no subsequent activities that can enable recovery or mitigation from the risk of injury / damage (e.g. Communications, identification of hazards).

3.1.3 Develop framework

Having identified and defined core concepts, the next sub-stage involved formalising the relationships between concepts as a framework suitable for representing the rail system. This is visually represented in Figure 3 (with the implemented example from railways shown later in Figure 5). Human functions were the main unit of analysis and it was important to determine how these were influenced by the main system goals. However, because of the large number of human functions that work in combination, and because these groups of functions may be in pursuit of more than one system goal there was need for an intermediary concept in the framework, in this case the human function goal. Each human function was assigned to a specific human function goal, which specified the purpose of a set of functions (e.g. to maintain and repair the railway). Each human function goal was then linked to one or more overall system goals. The architecture of framework indicates that many human functions can be necessary to satisfy a human function goal. Human function goals are linked with many system goals, capturing the competing goals that influence work in the railways (Hollnagel, 2009; Wilson, 2014).

The remaining concepts were used to elaborate important features of the human function. This included the description of the personal and organisational goals that could shape the work when performing an activity (especially safety relevant activities) and the generic context for the execution of the work.

Figure 3 – Relationships between concepts in the framework



3.2 Populate the framework

3.2.1 Identify data sources

A list of the main job roles, common to international railway systems, was constructed to prompt the search for information on what people do on the railway. These search terms are presented in Table 2a.

It was important for implementation of the framework in a rail setting that the content from available sources was capable of informing what people do in railway operations across many countries (e.g. those covered by the ERA). The main sources for the data searches are listed in Table 2b. This included material from across 15 European countries.

Four criteria were used to judge the relevance and quality of the resources from the search, shown in Table 2c. Each source was assessed, noting which of the four criteria were satisfied. This approach draws on priorities of the European Railway Research Advisory Council (ERRAC, 2011) and earlier work by Eerd et al (2010) and Hignett et al (2003), who judged the quality of information in other research contexts. Sources were given a quality rating by recording each of the criteria that were satisfied by the resource (i.e. the strongest sources could satisfy all criteria). The intention was to search for sources that were sufficient to identify, describe and analyse each human function with a satisfactory degree of confidence.

Table 2a Job roles and associated terms to inform the initial search for resources and data on human functions

Category	Job roles and associated terms
Train	Drivers, preparers, controllers, crew, manager, conductor, steward, ERTMS (European Rail traffic management System)
Power supply	ECOs (Electrical control operators), electrification, pantograph
Signalling and operations	Dispatcher, despatch, authorise train movement, LOM (Local Operating Manager), MOM (Mobile Operations Manager), supervisor, ERTMS, train controller
Control	Train route planner, traffic manager, infrastructure fault control, train operator
Station	Platform manager, station dispatcher
Maintenance/infrastructure engineering	Track workers, COSS (Controller of site safety), PICOP (Person in charge of the possession), ES (Engineering Supervisor), Lookout, Handsignaller, Supervisors, Signalling and Telecommunications technicians
Rolling stock maintenance	Train maintenance, rolling stock, vehicle, axles, inspection, service
Shunters	Depot, yard, shunting
Level crossing	Crossing keeper, Level crossing operator

Table 2b Sources of data for the review

Source type	Details
Academic databases	Engineering Village, Ergonomics Abstracts, Science Direct, Web of Science, Scopus, conference proceedings – in particular the International Rail Human Factors Conference (e.g. Wilson et al, 2006))
Industry databases and websites	Including search of websites of Rail Research UK (www.rruka.org.uk/), Rail Safety and Standards Board (www.rssb.co.uk), Office of Road and Rail (orr.gov.uk), and the SPARK industry database (www.sparkrail.org)).
European websites and other information sharing platforms and sources	European Rail Research Network of Excellence (www.eurnex.org/), International Union of Railways (www.uic.org/), Transport Research Innovation Portal (www.transport-research.info/)
Other reports	Reports, theses and reference lists from rail related studies at the University of Nottingham.

Table 2c Criteria for judging the quality of sources

Label	Criteria
a.	The source informs on one or more role relating to functions or safety
b.	The document has been peer reviewed or produced by a recognised organisation
c.	The content of the sources is nationally/internationally recognised or applied by industry
d.	There is a clear methodology for the data collection in the sources

A process was applied for identifying safety relevant activities for each human function through the use of two diagnostic questions: "Are there activities, which if performed incorrectly or not performed, could result in injury or damage?" and "Are there activities linked to this function which are associated with the following checklist items?". The checklist items, summarised in Figure 4, related to a wide range of work activities that have been listed in selected sources (e.g. legislation from Australia - South Australia Act, 2012; ERA, 2009; ROGs, 2006; and Patacchini, 2007). Positive answers to either of these questions were used to prompt the recording of brief details of the relevant activity associated with the function.

Figure 4 Checklist items used in the determination of safety relevant activities

- Driving or despatching rolling stock, any other activity which is capable of controlling or affecting the movement of rolling stock.
- Signalling (and signalling operations).
- Receiving or relaying communications.
- Coupling or uncoupling rolling stock.
- Maintaining, repairing, modifying, monitoring, inspecting or testing, also including checking, designing, upgrading, installing (rolling stock and infrastructure).
- Installation of components.
- Work on or about rail infrastructure relating to the design, construction, repair, installation and maintenance of (telecommunications systems, electricity supply).
- Work involving certification as to the safety (rail infrastructure, rolling stock).
- Work involving decommissioning (rail infrastructure, rolling stock).
- Work involving the development, management or monitoring of safe working systems for railways.
- Work involving the management or monitoring of passenger safety on, in or at any railway.
- Any other work that is prescribed by the national regulations to be rail safety work.
- Checking that a vehicle is working properly and, where carrying goods, is correctly loaded before being used.
- Controlling, affecting or managing, the movement of persons on a train, on a platform, across a level crossing, or, the boarding of, or alighting from, a train, of persons.
- Working in a maintenance capacity or as a supervisor of, or look-out for, persons working in such capacity.
- Ensuring the safety of people working on or near the track.
- Relevant training or supervision.
- Abnormal / emergency events.

3.2.2 Analyse data from sources

Summary details were recorded from approximately 207 source documents. Forty three of the documents were judged to be of the highest quality (satisfying all four quality criteria – 4*) and a further 115 of the documents satisfied three of the criteria (i.e. approximately 76% were 3* or 4* rated for this review).

There were differences in the availability of evidence on different roles, with some sources enabling easy identification of human functions or the contexts in which they occur. Seventy nine of these sources related to rail engineering work, 59 covered train signalling control, 39 with content on network and electrical control, 25 on driving, station work and shunting, and 20 on train preparation and maintenance. Sufficient descriptive details were often not published, so identifying gaps in the information was important. Expert judgements were used to interpret the data from the document review, using the in-depth knowledge of the researchers over a range of prior studies. This was then used to compile the findings in a spreadsheet corresponding to a potential human function and relevant attributes (Personal and organisational goals, Generic Context, Safety-Relevant Activities). A stopping rule was applied to end the search for more data when a function could be described clearly, with either consistent interpretation across several sources for a given function, or where no further sources could be found.

3.2.3 Synthesise and represent content within the framework

The results of data analyses were discussed at a two-day workshop where the research team met to share and coordinate their outputs. The team of researchers had general expertise in rail human factors and rail safety, with different members having specific expertise in each of the main business functions in the industry (e.g. driving, signalling, railway control, maintenance). An extensive concept sorting and classification exercise was carried out at the workshop to rationalise the findings from each of the researchers, identifying common terminology and overlaps in the rail specific content that was linked to the concepts from the framework (e.g. goals and functions). Content from each of the researchers was reviewed, clustered and labelled, resolving any differences in the level of description and understanding between researchers. Potential relationships and hierarchies between the content for goals and human functions were explored. Outputs from analyses were assimilated into a single spreadsheet after the workshop. This was reviewed and revised by a single researcher to produce a standardised description of the content. To support the detailed descriptive content in the spreadsheet, a diagrammatical representation was produced for the main concepts in the framework, summarising the rail related content that has been identified for these concepts (an extract from this is shown later in Figure 5).

3.3 Review by researchers and stakeholders

3.3.1 Review by researchers

The terminology and interrelationships among concepts in the framework were first reviewed internally within the research team. Based on the alignment across all human functions, individual reviewers revised descriptions of specific human functions, ensuring equivalent levels of granularity and use of terms. This included cross-checking the work of others, resolving any queries around the expression of the content aligned with each of the concepts.

3.3.2 Review by stakeholders

Once a stable draft version of the framework, and railway content, was available, this was passed for external review by members of the ERA Human Factors Network. This comprised national representatives from UK, Italy and Germany, and representatives from two rail bodies - the International Union of Wagon Keepers (UIP) and the European Rail Infrastructure managers (EIM).

This review considered the utility of the HFiS framework, checked understanding by industry staff of the concepts in the architecture of the framework, and established whether the descriptive content in the example was applicable in a range of countries and railway contexts. This exercise was managed by the ERA Human Factors specialist who collated recommendations for revision. This included changes to the wording of several functions, splitting of some functions into separate functions, identification of several new functions and safety relevant activities, and additional description of the generic context in relation to several functions. These recommendations were integrated into a final version of the framework and associated content.

4. Overview of railway application of the HFiS Framework

This study has produced a framework of goals and human functions in the railway system. Based on the analysis of all frontline railway roles (Table 2a) and after review by the researchers and stakeholders, 66 human functions have been identified, as listed in Table 3.

The human functions have been clustered and linked to eight human function goals – provide power, manage incidents, maintain infrastructure, train operation, control movements, prepare train, passenger movements and maintain rolling stock. After internal and external review these eight goals were understood to sufficiently encompass the purposes of functions for all railway front-line staff.

The human function goals have multiple links with seven higher level system goals, as shown in Figure 5 – maintain safety, provide efficient train service, provide assets (infrastructure, rolling stock etc.), optimise passenger and journey experience, minimise environmental impact, maintain integrity of load, generate revenue / minimise losses. The relationship illustrated in Figure 5 shows how a number of human functions contribute towards the human functions goals and henceforth to the overall system goals. Similarly, multiple system goals shape the human function goals and, thus, the execution of human functions, potentially in a competing manner (Wilson, 2014).

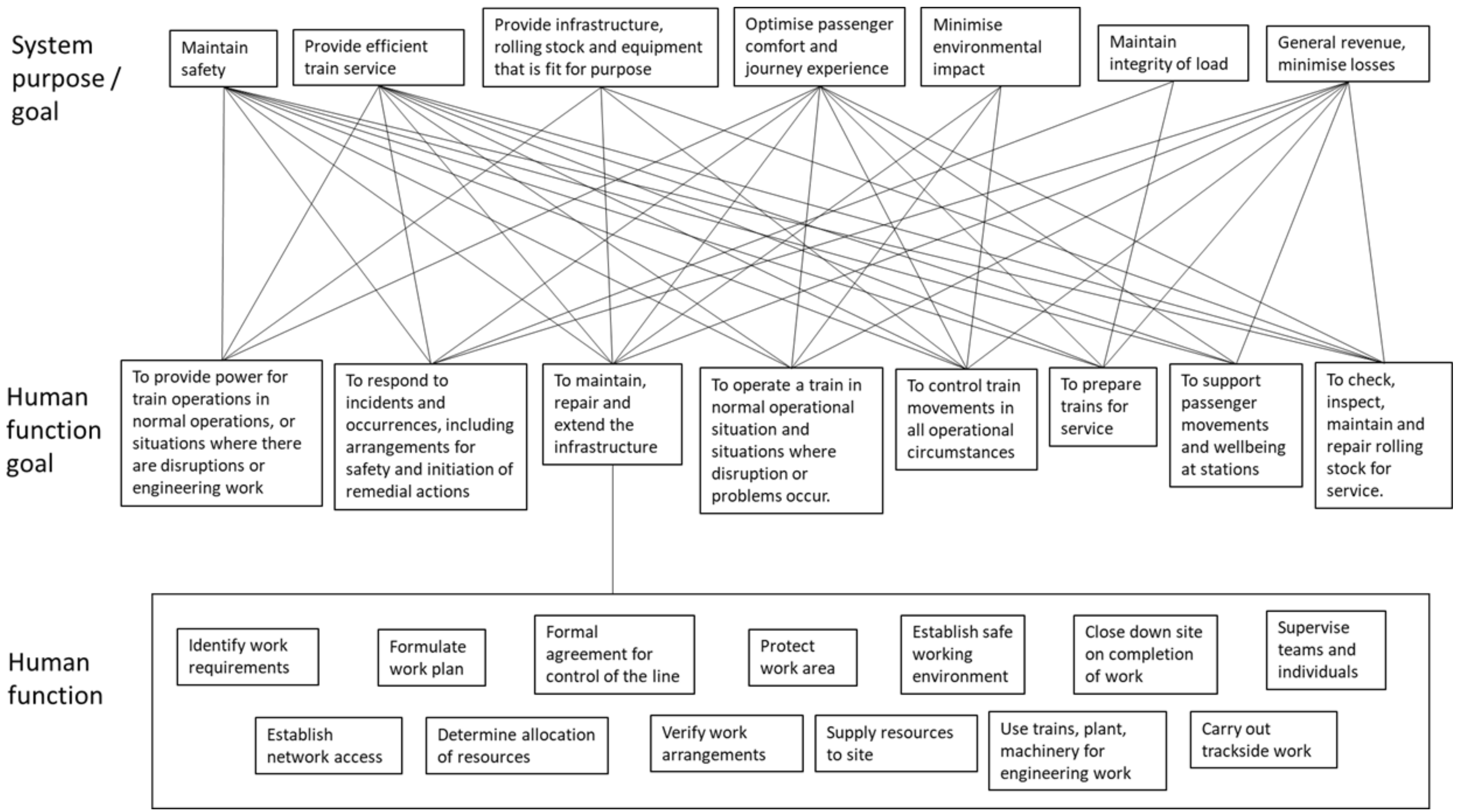
Detailed descriptive content has been provided for each concept of the framework. An extract of this detail from the populated railway example is presented in Table 4 (i.e. for the human function 'formal agreement for control of the line', part of the human function goal of 'Maintain Infrastructure'). The final spreadsheet for the railway human functions contained 73 lines of descriptive data, each similar to the extract in Table 4. This covered the 66 human functions, plus additional lines of analyses to account for a limited number of circumstances where a human function mapped to more than one of the eight human function goals.

Table 3 Final list of human functions for frontline staff, showing links with human function goals

	Human Function goals							
Functions	Power	Incidents	Maintain infra.	Train operation	Control movemen	Prepare train	passenger movemen	Maintain rolling
1. Take up power control duties	x							
2. Monitor power	x							
3. Provision of traction supply	x							
4. Detect irregularity	x	x						
5. Agreement of isolation	x							
6. Formal agreement for control of the line	x	x	X					
7. Apply isolation	x							
8. Return of power / remove isolation	x							
9. Ensure status of infrastructure	x	x						
10. Anticipate delay		x						
11. Protect incident / event area		x						
12. Coordinating failure and incident response		x						
13. Re-planning train service		x						
14. Gather and communicate incident information		x						
15. Rectify the incident		x						
16. Protect evidence		x						
17. Identify engineering work requirements			X					
18. Establish network access			X					
19. Formulate work plans			X					
20. Allocate resources			X					x
21. Verify work arrangements		x	X					
22. Protect work area			X					
23. Supply of resources to site work			X					
24. Establish safe working environment			X					
25. Use trains, plant and machinery for engineering work			X					
26. Close down site on completion of work			X					
27. Supervise teams and individuals			X		x			
28. Carry out trackside work			X					
29. Ensure authority			X					
30. Maintain appropriate speed				x				
31. Ensure train integrity and load integrity on journey				x				
32. Stop train				x				
33. Manage train control systems				x				
34. Observe and report on infrastructure				x				
35. Operate level crossing				x				
36. Despatch train					x			
37. Provide information and support to passengers				x				
38. Warn other rail users				x				
39. Handover of responsibility					x			x
40. Monitor rail network					x			
41. Authorise train movements					x			
42. Route / re-route passenger or freight service					x			
43. Record train movements					x			
44. Anticipate delays or poor traffic flow					x			
45. Deal with irregular train movements					x			
46. Provide train identification					x			
47. Manage implementation of emergency / temporary speed restrictions					x			
48. Gather and communicate information					x			
49. Control level crossing					x			
50. Stable vehicles				x				
51. Assemble / disassemble vehicle formation						x		
52. Prepare vehicles						x		

	Human Function goals							
Functions	Power	Incidents	Maintain infra.	Train operation	Control movemen	Prepare train	passenger movemen	Maintain rolling
53. Take up driving duties						x		
54. Load freight						x		
55. Assist passengers							x	
56. Prepare stations for use by passengers							x	
57. Prepare rolling stock for inspection								x
58. Inspect rolling stock								x
59. Install components onto vehicles normally in service								x
60. Maintain components on vehicles normally in service								x
61. Service rolling stock								x
62. Control crowds							x	
63. Conduct immediate mitigation, containment		x						
64. Take up control of train movement duties					x			
65. Identify rolling stock maintenance requirements								x
66. Ensure passenger and personnel safety		x						

Figure 5 Relationships between the system goals and human function goal, also showing the human functions contributing to one of the human function goals



For each human function, the personal and organisational goals give a deeper understanding of the range of perspectives and motivations that are important in achieving the human functions (e.g. there are various actors with temporary or more permanent constraints on their work). The generic context has been collected from various sources and describes specific aspects of the railway and the likely situation in which the human function will be executed. This helps to elaborate the types of constraints for the human functions and sets parameters for what scenarios should and should not be included when considering this function.

The analysis of safety relevant activities, as shown in the final column in Table 4, focuses on the performance of those activities in the most likely scenarios. This is subdivided into the potential for error, recovery, consequences and likely mitigations within the system, in relation to the performance of each function. Across the whole analysis, more than 400 safety relevant activities associated with the functions have been identified. On average, more than four safety relevant activities per human function have been identified by the diagnostic questions.

Table 4 Extract from detailed descriptive analysis for the human functional goal of maintaining, repairing and extending the infrastructure

G3. To maintain, repair and extend the infrastructure				
Human Function	**Personal and organisational goals**	**Generic Context in which the human function is carried out**	**Safety relevant activities (identified using diagnostic questions).**	**Analysis of safety relevant activities**
6. Formal agreement for control of the line	To transfer the control of the line (i) from the control of the signaller to the engineering staff for the purpose of engineering work; (ii) from the engineering staff back to the signaller at the completion of the work, to return the railway to operational use.	This is carried out in the knowledge that all mandated safety activities have taken place. These transfers are completed through a system of formal communication and instruction (from one lead party in the communication to another). Outcomes of the agreement are recorded, such as the geographical track locations and time period in which the transfer of control will be authorised. The activities are generally prescribed within strict rules and procedures and there are a series of steps in communication and recording of completed actions to monitor and ensure compliance with the procedures.	Agreement with another person(s) to authorise transfer of control of the line *Receiving or relaying communications*	**Potential for Error** There can be differences in understanding about the time at which part of the infrastructure is transferred to the control of someone else, or the precise details of which parts of the infrastructure are under the control of someone else (e.g. which lines, which parts of lines) **Potential for recovery** The formal agreement should be not be reached until each party has reached a common understanding, though it can be difficult in some circumstances to know that another person has a different understanding of the situation. **Consequence of error** Work could progress with the assumption that sufficient protection has been provided, but there may be increased risk to staff or the train service. Errors in establishing formal agreement can also delay the start of the work. **Mitigation** Strict rules and procedures for communication and recording of the outcome of agreement.

5. Discussion

5.1 The HFiS framework

The central motivation of this study was to identify and promote the role of people in establishing and maintaining safety in a complex sociotechnical system - the railways. This study provided the opportunity to establish a common framework of goals, human functions and safety relevant activities that are important to the European Railway.

Unlike other studies that seek to understand system resources, constraints or work activities, this framework offers a generic representation of what people do in railway operations, common to all European countries. This might be seen by some as a weakness in seeming to ignore the question of appropriate allocation of function between people and technology, particularly in the light of approaching changes (such as the European Railway Traffic Management System, ERTMS in railways). However, the intention has been to place greater emphasis on making explicit the roles and contributions of people, producing a framework that can be used in exploring notions such as "work as done" (Hollnagel, 2014b).

Commentary is given in Table 5 on how the framework concepts have been useful in the analysis of what people do on the European railway. The concepts in this descriptive framework are different to those that have been applied in formative analyses such as Cognitive Work Analysis (e.g. Naikar and Sanderson, 2001; Jansson et al, 2006; Jenkins et al, 2008; Rasmussen, 1985; Vicente, 1999). Abstraction Hierarchy typically extends down into capturing details of the artefacts and equipment that influence parts of the system. This study needed more at the higher levels of abstraction, especially how different types of goals (system goals *and* human function goals) influence the description and performance of the function. The analysis has demonstrated that functions have many purposes and multiple goals that are relevant (Flach, 2012). This helps to make explicit the nature of competing demands placed on frontline staff and the potential for trade-offs between the different goals (Wilson, 2014). It is often in the pursuit of these trade-offs that minor variability leads to system failure and incident (Hollnagel, 2009). The set of system goals is also more comprehensive and wide-ranging than the twin 'safety' and 'performance' goals that are usually encountered in the literature (Millen et al., 2011), encompassing factors such as comfort and revenue.

The outputs from use of the framework are built largely around a relatively short list of 66 human functions, given the coverage of all frontline roles. The list of human functions provides a manageable guide (in terms of scale) that can be used by others as the starting point for analysis of the rail system in different regions. Future work could map the identified functions to the roles that carry them out in different countries, supporting learning across countries and helping to resolve barriers to interoperability, in support of the Single European Railway (Directive 2012 2012/34/EU) and to minimise variability in railway safety performance of EU member states (EU, 2020).

Table 5 Analysis of the content on each of the concepts of the HFIS framework

Concept	Commentary
System purpose/ goal	The analysis Identified seven overarching system goals, relating to safety, train service efficiency, provision of infrastructure and rolling stock, passenger comfort and experience, environmental impact, integrity of trains / loads carried and economic factors. Safety, efficiency, comfort and economic goals link with all or almost all of the human function goals
Human Function goal	There are eight human function goals that describe the aim and focus of human efforts in the system. Each of these can be shown to be influenced by between four and six of the system goals (e.g. maintaining the infrastructure is linked to safety, efficient train service, providing infrastructure fit for purpose, comfort and passenger experience, minimising environmental impactions and generating revenue and minimising loss). The human function goals are also important in identifying groupings of functions (e.g. 13 human functions that contribute to maintaining, repairing and extending the infrastructure).
Human Functions	All human functions are linked to a goal of the function. This does not differentiate between functions that are common and those that are less common. For example, analyses of driving often considers movement authority (F29 – Ensure authority) or speed (F30 – Maintain appropriate speed), but the current analysis has highlighted the importance of use of the horn (F38 – Warn other rail users) or stabling the train (F50 – Stable vehicles). These less prominent human functions can be critical (e.g. see Lac-Megantic runaway train accident, 2013). By viewing these as functions these can be de-coupled from the role or context. While signallers primarily give movement authority (F41 – Authorise train movements) this can be given by other staff (e.g. hand signalling at trackside).
Personal and organisational goals	Definite classes of goals have been identified and functions are associated with these. Some of these are directly related to safety, such as the provision of isolation (F7 – Apply isolation) or protection for trackworkers (F22 –Protect work area). Functions are performed for various purposes (e.g. for movement of trains, or people working or using the railway), but must be performed safely (e.g. F42 – Route / re-route passenger or freight service, F43 – record train movements, F56 – Prepare stations for use by passengers). Some involve almost no overt safety critical element (e.g. F44 – Anticipate delays or poor traffic flow) but poor performance can create conditions, such as time pressure, that can lead to error and safety risk.
Generic context	Understanding of context is vital because many of the functions can be applied in radically different ways, depending on the context. For example, planning engineering work and access (F17 – Identify Engineering Work Requirements,18 – Establish Network Access, F19 - Formulate work plans) can take place months or years in advance, but can also be required at very short notice in the case of emergency repair work. Likewise, there are many different reasons why a driver might want to alert people on the track (F38 – Warn other track users), from planned sequences of sounding the horn when approaching a tunnel or crossing, through to warnings on approach to trackworkers. Therefore, many of these functions can only be interpreted in the light of the specific context of application.
Safety relevant activities	These are overwhelmingly cognitive or social in nature - monitoring, planning, communicating etc.. Some involve implementation (e.g. F45 – Deal with irregular train movements), in which case it is about following rules as described and using appropriate equipment.
Potential error / recovery / Consequence / mitigation	In most cases it is possible to suggest some specific types of error (e.g. 'incorrect switching plan' for F3- Provide traction supply), but in others it is only possible to suggest general classes of error (e.g. 'various communication errors' for F39 - Handover of responsibility). Recovery is often difficult, and can only be identified once a failure has occurred (e.g. F43 – Record train movements), or by cross-checking by other members of staff (e.g. F55 – Assist passengers). Consequences of error can include harm (to staff or passengers / public (e.g. F5 – Agree isolation, F24 – Establish safe

	working environment), but may also be the establishment of unsafe conditions that can lead indirectly to harm, or (e.g. F18 – Establish work plans) operational problems that contribute to complexity and risk (e.g. F44 -– Anticipate delays or poor traffic flow). Mitigations primarily involve people through training, knowledge, expertise and communication skills / strategies or documentation (e.g. F60 – Maintain components on vehicles normally in service).

Making context a construct of the HFiS framework has been vital. Functions can be achieved in radically different ways and the description of the generic context for performance of a function (and one that is recognisable to experts across Europe) sets the boundaries for what is being considered and is important in conducting other parts of the analysis (e.g. identification of the individual goals and the safety relevant activities). The description of the context therefore explains the situations that are typically faced by the operator (e.g. the constraints, processes, routines, pressures, motivators or other factors in the environment that influence the execution of the function). This includes functional and other influences (see the earlier commentary on Daniellou, 2005, plus similar examples in Martindale et al, 2019).

The study has collated knowledge and given specific attribution to what is known about the potential for error, opportunities for recovery (e.g. through cross-checking and communication), consequences of error and existing mitigation strategies, producing commentary on strengths and weaknesses in current knowledge in these areas. Progress has been made in understanding the most likely safety related scenarios in the specified circumstances and the potential outcomes (e.g. barriers, recovery, how consequences are kept at a low level and damage is reduced when accidents occur). One clear conclusion from the analyses is that safety relevant activities have largely been found to be cognitive or social in nature with a high number of activities that require monitoring (e.g. F2 – Monitor power, F4 – Detect irregularity, F9 – Ensure status of infrastructure) or communication (e.g. F66 – ensure passenger and personnel safety, F15 – rectify incident, F18 – Establish network access). Also, a number of functions have been noted (e.g. F16 –protect evidence, F40 – monitor rail network, F43 – record train movements) where human action offers the last line of defence. By making these functions explicit, future developments can at the very least seek to maintain the integrity of the human contribution to safety, and ideally move towards technical solutions to support or replace associated activities. Basacik and Gibson (2015) give an example of identifying and applying a technical solution to support human activity in a safety function – driver operation of train doors (F37 - Provide passenger information and support).

Outputs from the analysis largely reflect the railway of today and the near future. Technology, roles and organisational configurations may see changes over time, even quite rapidly – this is currently the case with rapid changes in how staff communicate with passengers. The fundamental high-level goals and functions (controlling trains, regulating train movements, maintaining assets) supported by humans in the rail system of different countries will ostensibly remain the same (Golightly et al, 2013b; Schipper et al., 2018). Many of the human functions are robust and likely to be enduring at this functional level of analysis, providing a degree of future proofing of the analysis and resulting output.

Changes are likely in the ways people execute these human functions with the introduction of new technologies, operational practices and cultural influences. For example, the activities in completing the human function may contribute more to monitoring or supervisory roles. These can be accompanied by changes in the context and revision of one or more of the goals (e.g. human function or organisational), with impacts on the safety relevant activities associated with the changed human function. This is already evident in roles like signalling (Sharples et al, 2011) and is likely to become more apparent, for example in the introduction of Automated Train Operation. Analysis using the framework offers the potential to examine the extent and the implications of change, providing an ongoing reference model of the current state of implementation.

The construction of HFiS and application of this to the railway example has benefited from the inputs of a team of researchers who have experience across the railway domain, derived from extensive field based observations and consultation with frontline staff in previous research work. Consequently, HFiS can help to articulate knowledge of work processes that has been built up over extended periods of time; knowledge that can be accessible to organisations, though not always formally documented. There are no existing publications or frameworks that attempt to describe the human contribution to the operation of the railway in this way or level of detail, so there is novelty in the output. This work also expands on more traditional task analyses of aspects of the rail system (e.g. on train driving, Rose and Bearman, 2012) by both representing aspects of these roles that are less commonly articulated (e.g. stable the train) and by covering roles that have historically received less attention (e.g. marshalling). Moreover, comparisons and interpretations of these less common aspects of the rail system are facilitated by being placed within a common framework, alongside areas such as driving and signalling.

5.2 Future application

5.3.1 Applying HFiS within Rail

As set out in the requirements, one important application of HFiS in railways is to understand process and technology change. An example of this is the adaptation of processes to reflect on the use of mounted autonomous vehicles or unmanned aerial vehicles (UAVs) to support inspection and maintenance (Durazo-Cardenas et al., 2014; Bertrand et al., 2017).

Taking this example, an inspection or welding robot at trackside might be considered firstly in relation to the execution of the work and how humans will collaborate with the robots to perform the work (F28 – Carry out trackside work). However, a robot can also be regarded as a piece of plant that needs to be brought to the site (F25 – Use trains, plant, and machinery for engineering work), removed at the end of the work (F26 – Close down site on completion of work), and planned as a resource (F19 – Formulate work plans; F20 – Allocate resources). If the robot is able to move up and down track it would need to remain within an area of protection (F22 – Protect work area) and potentially within an area of isolation (F5 - Agreement of isolation), drawing upon communication (F21 – Verify work arrangements) and checking functions (F40 –Monitor rail network). This type of autonomous vehicle may even be able to find its way safely between traffic outside of protected areas of the track (F41 – Authorise train movements). Further extension of this example could consider the robot as part of a team (F27 – Supervise teams and individuals) that needs to be informed of plans and arrangements for collaborative working. Adaptation to each of these functions will have considerations for the context, the kinds of error that can occur, the potential for recovery from error and the types of mitigation that needs to be developed in relation to the use of trackside robotics.

5.3.2 Applying the HFiS framework in a new domain

This framework was developed initially for the needs of rail-based organisations, but there is potential value in applying this framework to other domains that involve a complex interplay of technology, procedure and roles. This can be in terms of re-use of both the concepts of HFiS, and of generic contents that are representative of other domains. These could include high risk oil / gas / utility industries (Pasman, 2015), where human functions encompass both traditional safety-critical activities and secondary activities to maintain flexibility and resilience for safe operations. Similarly, the framework could be applied with maritime operations (Shröder-Hinrichs et al., 2013), where there are interfaces between ship operations, control operations and dockside operations. An alternative area of application is secondary (hospital) healthcare where staff take on multiple roles and activities in order to balance capacity, patient health and workload (Back et al., 2017; Martindale et al., 2019).

Table 6 shows the concepts of HFiS (Column 1), generic categories (Column 2) and examples within each of these categories (Column 3) that have been revealed in the analyses of the rail content. These generic categories can be used to prompt analysis of other work domains, guided by the phrases from the examples in the final column. This generic content is not likely to be exhaustive when applied to other domains, but is a useful starting point for others in initiating the analysis of the roles of people in work systems and can be developed with future applications of HFiS.

Table 6 Generic content from the framework

	Generic content	
Concepts from the framework	**Category**	**Examples**
System purpose/goal	• Multiple system goals	Safety; efficiency of service; provision and maintenance of infrastructure and equipment; user experience; environmental impact; economic factors; other domain specific system goals.
Human Function goal	• Supporting staff and other system users	To operate, control, support
	• Provision of resources, equipment and infrastructure for normal operations	To provide (e.g. power); maintain; repair; inspect
	• Dealing with adverse events and occurrences	To respond to
Human Functions	• Initiating and ending work / tasks / operations	Take up; close down; handover; stop; establish; prepare
	• Communications and coordination	Agree; coordinate; communicate; authorise; allocate; assist
	• Monitoring and detecting normal	Monitor; anticipate; verify; supervise; ensure; maintain (i.e. continue with); gather; record; identify; inspect; deal with

	Generic content	
Concepts from the framework	Category	Examples
	and abnormal circumstances	
	• Functional / operational	Provide; protect; establish; supply; use; carry out; conduct; manage; operate; control; assemble; install; service
Personal and organisational goals	• To take appropriate responsibility in a team	Give support / information to others (safety and service related information); ensure continuity; transfer control; confirm authority; give authority
	• To be prepared for relevant work activity	Understand current status (service, infrastructure, equipment); seek additional information; share understanding; plan; resource appropriately; prepare sites and equipment for use; establish (i.e. to set up), provide supervision
	• To support the provision of a safe environment	Safety (in the face of hazards or time constraints); provide protection for others; check for safety of others; warn people of hazards; contribute to providing a safe environment for services; check for rectification of problems; quality of service
	• To support a system that functions well	Proactive decision-making; prioritise; execute task appropriately; timeliness; maintain service during abnormality
	• To play a role in resolving problems	Support identification of defects; respond appropriate to identification of defects; anticipate future status; respond quickly to abnormalities; re-plan after disruption; restore normal service; rectify; preserve evidence; identify influencing factors
Generic context	• Working in new / unfamiliar / changing circumstances	Need to develop situation awareness; need to maintain awareness; need to prioritise when irregularities occur
	• Working in collaboration with others	Communication and development of shared understanding between people in different roles when problems arise; interactions with users or members of the public, including people alone, in groups or crowds, with different backgrounds, capabilities and experiences.
	• Working effectively in hazardous / high risk situations	Consideration for safety and timeliness of responses (without increasing risk due to time pressure); people may need to be in places of risk after an event; consideration of safety when returning to normal operations, using effective decision-making and building on experience; need for repairs of infrastructure and equipment after incidents; preservation of evidence for investigation and organisational learning
	• Maintaining infrastructure / equipment / vehicles	Procedures for planned and unplanned maintenance (routine and emergency), with need for change and flexibility; consideration of access arrangements (people and equipment); dismantling and scheduling of resources (including coping with shift changes); removal of waste and decommissioning after engineering work; people may be in multiple locations and need for development of shared understanding; physical and procedural safety barriers are common; formation of appropriate teams and provide suitable supervision; management of impacts of time pressure; recording of relevant examination / checks / testing and actions to rectify problems; scheduling of regular servicing, fuelling and cleaning.
	• Operation and use of technology equipment, vehicles	Influenced by various factors (e.g. rules, processes, technical aspects, availability of operators, normal or abnormal circumstances); assembly and disassembly or preparation of equipment by specialists or operators
	• Working in control centres or similar locations	Some people may work remotely from activities that they authorise; support or control, influencing the type of information and interfaces needed; regular and irregular circumstances; need to filter information from various sources; collaboration with others; supervisory support; type / numbers of alarms; degrees of automatic and manual control, influencing workloads and decision-making.

	Generic content	
Concepts from the framework	**Category**	**Examples**
Safety relevant activities	• Communication and coordination / authorisation	Receive or relay communication with others (staff, public, emergency services); review and approve request for action; request secondary checks; share information; record details of checks; agree with others (e.g. time and locations for access)
	• Monitoring	Review / diagnose alarms; monitor information; technology and environment; be aware of system status; supervise work; identify conflicts; identify hazards; identify defects
	• Operations	Switch off / isolate (power); follow instructions / standards; training; stop a process; secure equipment; restrict speeds; agree time and location arrangements; repair; adhere to scheduled maintenance / inspection requirements; set up safe work system; equipment checks; control movements of vehicles; ensure people are in a place of safety; reinstate the infrastructure / reassemble equipment after repair; use appropriate personal protective equipment
	• Emergency responses	Put out fires; evacuate; re-organise schedules and resources; calculate impacts of delays; estimate recovery time; collect evidence of incidents; respond to safety announcements
Potential error / recovery / Consequence / mitigation	• Error	Inaccurate / incomplete understanding of a situation; inadequate monitoring; incorrect or misunderstanding of plans; errors due to workload or time pressure; communications error leading to incorrect understanding; miss or misdiagnose alarm / warning; apply inappropriate procedure; error in sequencing; insufficient knowledge or experience; incorrect decision-making; unprotected location; failure to identify need for maintenance; delays in access for maintenance; poor planning; errors in operation of equipment / plant; violations; errors in authorisation; errors in system check / examinations; errors in recording system status
	• Recovery	Cross-checking / secondary checking of information; alarm systems; review of plans; read-back and checking during communications; support / coordination with other staff; availability of alternatives (e.g. access routes); short term re-planning; appropriate response to warnings; fail-safes in design; skill of operator; vigilance of operators; operating with caution in high risk situations
	• Consequence	Service disruption / delay; injury, fatality; miss change of system status; late detection of warnings leading to accidents; decisions based on inaccurate information; missed opportunities for organisational learning
	• Mitigation	Safe system of work; communication protocols; HMI design; ensure sufficient resources; improve design of alarms; staff training; experience and timely access to reliable information; improved procedures, protocols and agreed strategies; better communications protocols, improved warning system design; improved team working; supervision and support; improved inspection procedures; improved relationships with other organisations and stakeholders and local knowledge; contingency planning and consultation on plans; motivation and support of staff; suitable indications from support technology / warning devices; remote condition monitoring; organisational culture; appropriate equipment and environmental checks; appropriate design of working environment (equipment, environment, processes, including interlocking and fail-safes); security processes; improved design of recording forms

In order to apply the framework in a new domain, the following points would need to be considered, based on the experience of using it in rail:

- A comprehensive methodology for development and application of the framework is outlined in the current publication. Consultation and requirements definition are important starting points for new applications of the HFiS framework. The assumption is that new users may be able to use the generic prompts in Table 6 to begin to collate relevant content on the system under investigation, using these in a manner that is similar to those in Hazop studies (Kletz, 1997), to encourage reflection on the relevance to a particular situation being studied. Users should be aware that the architecture of the framework has been inspired by rail operations and may have associated bias. If these concepts are found to be applicable across a wider range of sociotechnical systems, it might be possible to shortcut some of the research activities. Stage 1 might be capable of shortcutting for a new domain, allowing earlier focus on populating (Stage 2) and verifying the content associated with the framework concepts (Stage 3). The robustness of the structure and concepts of HFiS will become clearer with repeat implementation.

- It is likely that analyses can be carried out by an individual with suitable knowledge of the system or a multi-functional team sharing different perspectives. This could be those with relevant safety or human factors experts, as in this railway example, but could also be implemented by people in an operational or management capacity who have extensive experience of their domain. In this case, the role of the safety / human factors specialist could be more as a facilitator of the method to populate the framework.
- Relevant content for population of the framework is likely to be available from existing data sources (e.g. task analyses, incident reports and data, procedures and literature) and through outputs from work based observations or consultations with staff. One avenue that has not been explored in the current analysis is the review of accident reports, incident reports and other qualitative or quantitative databases that may help to describe a system such as rail. This would provide another source of information around how functions contribute to safety and failure, though many of these reports and data sources may be limited in quality, and / or may focus on local causes rather than larger systemic factors.
- There are many ways in which outputs from the analysis can be displayed, shared within an organisation or industry and used in future investigation of the system. As an example, the diagram in Figure 5, and Tables 3 and 4 could be used as templates for initial representations of the relevant system properties.
- As a guide, all three stages of the process took around 100 person days in total. On one hand, without the availability of resources describing the system, and the project team's experience of the domain, this may have taken longer. On the other, around a third of this time was spent identifying and agreeing the concepts and architecture of the framework (Stage 1 – Define the framework) which may not be required for application in a new domain.

5.4 Limitations

A number of limitations of the approach are noted. First, while the domain described (and sociotechnical systems in general) are dynamic, the representation, as it stands is static. That is, it is not possible, as yet to see how interactions between functions are triggered and how this might be shaped by different scenarios (e.g. the difference between planned engineering work, and unplanned emergency repairs). However, this is a common problem for representing systems (Baber, 2015). It is critical within future work to identify the dynamic characteristics of these systems, understand the feedback mechanisms, delays and non-linear relationships. The information within HFiS, along with an articulation of the dynamic hypotheses, will inform an appropriate dynamic modelling approach (e.g., agent based modelling, Holman et al., 2020; system dynamics modelling, de Mattos et al., 2019).

A second limitation of the complexity of the model in terms of the number of functions. The framework comprises 66 different human functions, with associated information and overarching goals. Given the complexity and scope of rail operations, this seems a parsimonious description. Nonetheless, the detail within each function may be difficult to convey to a third-party without guidance. It is hoped that the table of generic terms, as well as guiding wider application, also can act as a glossary. It would be beneficial to test the scope of the framework against a relatively self-contained rail system, such as a metro or urban rail system.

A third limitation for potential application into other domains is the availability of data sources. In the current case, there were reasonably well documented and structured sources of information regarding the functions and their performance. This was enhanced by a number of research studies, and the research team's own experience, of the work as it is actually conducted in the field. Other sources of data may be used in conjunction, or as a substitute, for role-based descriptions and research outputs. Accident analyses and incident reporting could be useful, and a potential next step would be to check the model against such data. However, this pursuit would need to be cognisant of reverting to reactive incident reporting. More systemic cross sector analyses (e.g. RAIB, 2020) may be more appropriate than focusing on individual accident reports.
Finally, the framework is descriptive and qualitative, rather than quantitative. However, the value of the proposed framework could be greatly enhanced if it were to be complemented with data from relevant quantitative databases in efforts to quantify the risk of failure and demonstrate the active contribution of people to safety (Hollnagel, 2005).

6. Conclusions

This study has taken a human centred approach to identify and define the concepts that influence what people do to deliver safety within large sociotechnical systems, such as the railways. A framework has been produced that provides a means for articulating a common understanding of different types of goals, human functions, safety relevant activities and other system components that are important for describing work within a socio-technical system. This has been used to understand safety relevant activity in the railways. The outputs from the framework are comprehensive, both in breadth (covering a wide range of functions, for normal and disrupted situations) and in depth (high-level system goals, the contexts in which functions take place and specific errors, recovery, consequence and mitigations). These outputs give clarity on roles of frontline railway staff and how they interact with technical sub-systems, to achieve goals of railway organisations. The example of the populated framework provides descriptive content that can be used by engineers, safety / human factors practitioners and railway organisations to support integration of human factors in railway processes and to analyse human performance issues. Guidance is also provided on how the architecture of the framework could be used within other safety-related domains. Generic content from the railway example has been extracted and provided as a basis for initiating analyses in other domains.

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