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Understanding safety and production risks in rail engineering planning and protection

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Much of the published human factors work on risk is to do with safety and within this is concerned with prediction and analysis of human error and with human reliability assessment. Less has been published on human factors contributions to understanding and managing project, business, engineering and other forms of risk and still less jointly assessing risk to do with broad issues of 'safety' and broad issues of 'production' or 'performance'. This paper contains a general commentary on human factors and assessment of risk of various kinds, in the context of the aims of ergonomics and concerns about being too risk averse. The paper then describes a specific project, in rail engineering, where the notion of a human factors case has been employed to analyse engineering functions and related human factors issues. A human factors issues register for potential system disturbances has been developed, prior to a human factors risk assessment, which jointly covers safety and production (engineering delivery) concerns. The paper concludes with a commentary on the potential relevance of a resilience engineering perspective to understanding rail engineering systems risk. Design, planning and management of complex systems will increasingly have to address the issue of making trade-offs between safety and production, and ergonomics should be central to this. The paper addresses the relevant issues and does so in an under-published domain – rail systems engineering work.

Keywords: human factors risk; risk assessment, rail; engineering risk; resilience engineering; function analysis

1. Introduction

In many of the complex systems that are the concern of researchers in ergonomics/human factors there is a need to jointly address different aspects of performance throughout the system lifecycle. To do this, trade-offs and compromises have to be made and the balance that must be achieved is often typified as that between 'performance' and 'safety'. As Morel *et al.* (2008) say: 'this trade-off is quite fundamental . . . the safest aircraft never flies, the safest anaesthesia is never given . . .' (p. 3). Although in the context of this debate performance is usually understood to be associated with the effective and efficient running of the system, strictly of course, safety is just one of the variables of performance. Therefore, this paper will summarise non-safety performance as 'production.'

Production/safety trade-offs in systems design and operation take place at a time of debate on the role of safety in society and the dangers of becoming a risk-averse culture. In light of this, does the profession of human factors have the tools and approaches to allow the joint assessment of the safety of those working within or affected by the system and also the effective and productive performance of the system? Also, are there approaches to allow one to define balanced solutions to systems design, which must meet apparently disparate and sometimes even counteracting goals?

Many introductory texts on ergonomics/human factors will explain how its aims are to jointly meet the needs of employer and employee, of producer and consumer and to support outcomes such as effectiveness, efficiency, quality, cost, health and safety, comfort, convenience and satisfaction. The holistic nature of the discipline and approach is stressed. However, it is at least arguable that, in practice, most work in human factors, perhaps understandably, tends to address just a limited subset of the aims and potential outcomes. By the same token, although ostensibly taking a systems approach, much ergonomics work still appears to concentrate on very limited sets of factors and variables – a point made by Alan Hedge in a plenary address at the New Zealand Ergonomics Society 2007 conference. There is also a related concern about the decomposition implicit in many ergonomics studies employing detailed task or human reliability analysis. (Such perceptions may be a function of publication biases – space and editorial restrictions perhaps requiring tight and limited journal papers that only represent a small part of what has been done in

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research studies, and the consultants who may have carried out real systems studies with multiple perspectives and factors tending not to publish for a variety of well-known reasons.) Therefore, the ergonomics literature contains little on approaches and tools that enable assessment of human factors issues and related risks for both safety and production, especially in large, distributed, 'messy' systems (although see Wilson *et al.* 2009, for a study of human factors risks in a government regulatory and certification regime).

The focus application domain for this paper is rail. Human factors contributions to improvements in rail systems design and operations have clearly increased in volume, quality and impact in the past few years. In the UK, for instance, the ergonomics/human factors teams at Rail Safety and Standards Board and at Network Rail have made substantial and vital contributions from their different perspectives and remits. The wider efforts in the twenty-first century, across Europe in particular but also countries such as the USA and Australia, are documented in two books from the first two international rail human factors conferences (Wilson *et al.* 2005, 2007b).

The greatest number of rail human factors research contributions have been in driving, signalling and control, with some directed at passengers and the public. Less published work is available for rail engineering including maintenance, enhancements and renewals, although see Roth *et al.* 2006, Roth and Multer 2007 and Ryan *et al.* 2007 for exceptions. In part, this may reflect the influence of the 'traditional' human factors focus on individuals at workplaces (whether from a cognitive or physical viewpoint or both), as found in signal boxes or train cabs, for instance, and as a corollary that the distributed domain of track engineering work makes it much more difficult to study and subsequently to implement improvements. There may also have been an influence of business goals and a presumption on the part of the industry and funding bodies that the ergonomics problems worth addressing first, whether from a safety, service quality or system effectiveness viewpoint, lie in understanding and designing for the movement of trains.

Human factors/ergonomics will be central to any efforts to improve rail engineering work systems. Such a contribution will range from better design of track maintenance equipment to improved planning of track possessions, from development of advanced mobile communications systems to development of systems of work that enhance safety and productivity, and much else besides. A proposed new set of arrangements to give workers faster and longer access to the track and to provide safe working conditions provides the background to this paper. As a consequence, the present authors are concerned with how human factors can offer analyses and assessments that provide a basis for joint enhancement of safety and 'production', the latter in this case meaning the efficient, effective, reliable, timely and high quality delivery of engineering work. The nature of the railway domain, as with all safety critical industries, is such that although a new development may have primarily performance efficiency or performance quality goals, the earliest reviews and assessments of the project are likely to be in terms of safety – whether or not through a formal safety case and review. This has implications for the early human factors analyses that are conducted, because this will be safety-orientated, sometimes to the exclusion of other criteria.

This paper has two broad themes. The first and more concrete theme is to describe an approach being taken to the understanding of human factors, and human factors-related risk identification, in current and future systems of rail engineering work. The wider and more generic theme is to ask questions about how ergonomics/human factors does what it says it should do – accounts for all aspects of performance in systems risk analysis. In addition, the focus domain is distributed (in time and space), collaborative work – physical, cognitive and social in nature – which is taxing and extending the human factors method set as one moves from focusing on the 'one person-one (fixed) workstation-one location' to 'n people-n (mobile and fixed) workstations-n locations (see Wilson *et al.* 2003 and also Walker *et al.* 2006 for an example in the same domain).

The paper moves from the introduction into further discussion of the safety/production trade-offs alluded to above, in the context of concerns about risk aversion in society and the consequences for effective systems. Then there is a description of the focus domain, the railway and rail engineering work and introduction to proposals for new ways of managing this work and the safe but efficient access to the track that is required. The body of the paper describes a project to analyse functions and to assess risks within rail engineering. This is within a framework of a human factors case (see EUROCONTROL 2007). Then the discussion assesses what has been done and raises the possibility that such joint assessment of safety and production risks, and decisions on the systems design trade-offs that will be necessary, may take place within an adapted framework of resilience engineering.

2. Risk and human factors

At the time that the first version of this paper was written, the first author had taken up a joint academic position in University of New South Wales as well as an original position at University of Nottingham, and in so doing had moved from an academic school (Engineering) where the concern is to make things work to an academic school (Risk and Safety Science) where the concern is to make things safer and healthier. This is a simplification for the sake of the argument, but one that has led to considerable thinking about the nature of risk, the levels that should be expected and the balance to be struck between action and protection. In the rail industry worldwide one could find bodies and institutions where the emphasis has been on engineering and operating an infrastructure that is fit for purpose, which usually means developing systems that are effective and reliable and then implementing appropriate safety controls. On the other hand, there will also be organisations whose (perhaps statutory) role has been to prioritise the safety of the rail network and of all its users (it must be said that there is increasing emphasis upon an operational railway at the same time – e.g. Rail Safety and Standards Board 2005). These need not be two antithetical philosophies but the two different (crudely stated) priorities – 'get it to work and then make it as safe as is practicable' and 'make it safe and then see how to make it work' – illustrate differences in understanding, assessing and managing risk.

A particular concern is how ergonomists make a contribution that balances concern for safety and concern for other desirable performance measures such as effectiveness, efficiency, usability, reliability, quality, etc; for shorthand these are sometimes described together as 'production' as in the safety-production debates that have taken place in manufacturing and process industries, for instance. If the discipline really has not yet come to terms with risk assessment to meet such a variety of system performance needs, part of the reason may lie in the 'safety in ergonomics or ergonomics in safety debate'; in other words, does one see ergonomics considerations as a part of achieving system safety, or does one see safety as just one of a number of criteria for human-centred systems performance? These different viewpoints have in fact become very apparent in reading reviews by colleagues of earlier drafts of this paper.

As context for this introspection about ergonomics there is the current debate about levels of acceptable risk in society, embracing fears about a compensation culture, diatribes about over-protection from the 'nanny state' and sensible discussions about acceptable levels of safety that one can afford. Whilst thinking about the interacting roles of engineering, safety systems and human factors, a serious debate is emerging on the nature of risk, on society's acceptance or fear of risk and on the implications for all industrial, commercial and social systems. Several years ago, Slovic (1993) pointed out that as society becomes healthier and safer so the public becomes more, not less, concerned about the risks that they face. More recently a report has been issued in the UK called 'Risk, responsibility and regulation: whose risk is it anyway?' by the Better Regulation Commission (2006) (in 2008 it was announced that this commission would become the Risk and Regulation Advisory Council). The report highlights many examples of how risk, perception of risk and the reaction of the authorities to the chance of risk through fear of liability and potential insurance costs have apparently affected life in the UK. These examples include those related to serious incidents, for instance, the disruption to the whole UK rail network after the Hatfield rail crash in October 2000, through very cautious speed restrictions and running rules, which possibly increased temporarily the numbers of passengers travelling by road rather than rail. This is a potential decrease in institutional risk at the expense of an increase in societal risk (Rothstein 2006); the potential shift in transport mode and possible increase in risk is also touched on, in a Dutch context, by Hale and Heijer (2006).

At about the same time a UK House of Lords Select Committee issued a report about the management of risk, intended to be a response to politicians who suggest that society may have developed an 'unbalanced attitude to risk and that this has had a detrimental effect on the way that risk is managed' (Select Committee on Economic Affairs 2006). An interesting report, which amongst other things identifies the subjective nature of much risk, suggests a need for caution in performing cost benefit analyses and criticises principles such as 'as low as reasonably practicable', the case is made that they believe it is actually the increased perception that there is a risk averse society that then drives policy. The report also implies that more precision in measurement of risk should be and is possible (although the current authors' own view is that the road to quantification of risk concerning human factors is littered with difficulties and dangers and that it is better to not have quantification than have spurious quantification for quantification's sake).

These two reports then define a battleground that, the present authors think, is vital for the profession of human factors/ergonomics. At the extremes are a gung ho, 'liberal' culture and an ossified, overprotective one, but it is in the more subtle differences in approach and emphasis and in understanding of risk nearer the middle of the spectrum of views that concern should lie. The Health and Safety Executive amongst others has attempted to dispel any misconceptions around overzealous safety-related interventions, with a part of their website devoted to exploding 'health and safety gone mad' myths. However, there appears to be little or no effort in the other direction from the human factors community to address seriously limits to the safety that public and employees can expect. Since the discipline is defined as balancing performance with welfare needs, which tries to meet the objectives of employers and employees, and of producers and consumers, it is the responsibility of those in the profession to be able to contribute to design and implementation that properly balances production and safety.

The debate was summed up very well at a meeting with senior rail industry representatives. The focus was on why engineering work often occurs during only half of the 6-h allocated slot, the balance of the time being used in moving vehicles and equipment and people up to the worksite and then off again. One attendee said

> If this were the construction industry we would be spending half a shift putting up the boards and fences and then all sit back and say "phew, that's a job well done" and forget what we actually have to do is to put up a building.

This may come about because of spending a large amount of time planning and implementing safety controls and only then wondering about how to get the job done, rather than designing systems that support people to plan and carry out engineering work and within that make sure that safe systems are in place.

It is emphasised here that the authors are not saying that safety is less important than reliable and effective performance and than production issues generally. The authors are saying, gently, that safety should be handled sensibly on a risk-aware basis and then given an appropriate priority, rather than allowing it to become the sole driving force that perhaps it sometimes is. Safety is one, though a very important one, of the criteria for performance of any system.

3. The context – rail engineering

3.1. Extent of rail engineering work

There is vast scope for improvement in rail networks – in terms of costs, time, reliability, quality and safety – if better ways to plan and deliver engineering work can be found. The continued increase in the use of rail as a means of transportation for both passengers and freight over recent years has placed heavy demands on the UK railway infrastructure. As a result, there has been an increase in the level of maintenance and enhancement work required to keep the track conditioned for high operational performance. In the UK, Network Rail are responsible for over 20,000 miles of track and in 2006 approximately 700 miles of rail were upgraded, with 500 miles of sleepers, 500 miles of ballast and 600 switches and crossings (treble the rate of the late 1990s) (Network Rail 2006). There has been much improved performance in terms of continued reduction in the numbers of broken rails and the reduction of signals passed at danger, for example, but the scale of engineering work required to achieve these results brings its own difficulties. When engineering is carried out, from the smallest maintenance job to wholesale line enhancement, trains must either be stopped from travelling on one or more lines or the track workers must 'share' the track with the trains, getting on and off as required. The implications for both effective train running and for safety are obvious.

3.2. Possessions and engineering work

Engineering work on the UK railway exists in a number of forms and ranges from relatively quick, routine maintenance procedures to fairly lengthy, complex large-scale renewals work. In addition, there is a multitude of methods employed to carry out the work – from the use of manually operated tools, to more complex methods involving use of heavy machinery, on-track plant and engineering trains for the transportation of materials (Figure 1).

Engineering possessions and protection systems are important features of railway maintenance and renewals activities, allowing workers to get access to the railway in the absence of traffic. An industry-wide rule book allows for nearly 30 different types of possessions or systems of protection for work (for example, for short periods of time or extended periods of time, on a single line or all lines in a section of track). Possessions are where engineering and maintenance workers and plant (including engineering trains) possess the track rather than it being available for the movement of passenger and freight traffic. In short-term work, protection of workers may be achieved by a controller of site safety, who will communicate directly with the signaller to obtain protection using the signalling system. Where work is likely to cause little disruption to the infrastructure (e.g. some inspection tasks), signal only protection may be sufficient. However, this is usually supported by other controls that are set out in different subsections in the rule book (such as the disconnection of the signal or use of other devices to prevent inadvertent operation of the signal whilst work is in progress). For work of longer duration, where engineering trains, plant or vehicles are to be used, and where greater disruption to the infrastructure is inevitable (e.g. re-laying track) signal protection is supplemented with on-site protection and auditory and visual warnings (possession limit boards and detonators) and specific work sites for different packages of work are usually established within the possession. Duties of key staff such as the person in charge of possession and engineering supervisor, including how they should communicate with the signaller, deliver

(a)

(b)

Figure 1. Examples of small-scale and large-scale rail engineering works.

briefings, make arrangements for on-site protection, set up work sites and authorise train movements. The protection and work systems set up will be affected by a number of factors, which include the complexity of the track layout, the nature of the work in the work site (or neighbouring work sites), the size of the work site, the type of equipment and plant being used, electrical isolation requirements and the duration of the work.

Major track re-laying works will be likely to require multiple contractors and groups of workers in different parts of a large work site, extensive provision of plant and equipment for a variety of tasks and movement of many trains for supplies of materials, equipment, tamping and removal of scrap. The work will be likely to run over a number of shifts and key staff may have to hand over control of the work site to colleagues. In contrast, a smaller maintenance job might involve a single gang of workers in a shorter work site, in which work is carried out over a part of a shift. This type of work may require the use of a limited amount of equipment and there may be no movements or limited movements of trains or road rail vehicles.

3.3. *Proposals for new arrangements for track possession*

In late 2005 and early 2006 the Chief Engineer of Network Rail formed a working group in order to examine possible ways to improve the efficiency and effectiveness of engineering work on the UK railway. This working group agreed a set of high-level goals that should guide future systems and processes of engineering. The thrust of the initiative was to investigate why so much time and other resources seemed to be 'wasted' and not used for the actual engineering work, why there appeared to be gross inefficiencies in the system and to propose access and engineering process changes that, at the least, would maintain current safety levels. In a wider view of the tensions implicit in meeting the multiple criteria for running a railway, Andrew Hale has commented that in the context of the Dutch railways:

> Planning is done assuming that all will go well within quite narrow margins of deviation. Once the system goes outside these, the controller is left to improvise with very little support, resulting in him very often using the strategy of closing down the system and stopping all the trains in the defined area and then gradually starting things up again once safety has become guaranteed . . . this also occurs with over-running maintenance.
>
> (A.R. Hale 2008, personal communication)

Amongst the working group recommendations for feasibility testing on the UK railway were treat maintenance as an extended duration train path, maximise the types of work that can take place without blocking additional lines, renewals to use fixed signalling wherever possible to signal engineering trains and ensure that key resources and especially engineering trains and on-track plant are in place to start engineering work as soon as the possession is taken.

The Network Rail Ergonomics National Specialist Team and the Centre for Rail Human Factors at the University of Nottingham provided a supportive contribution to the Chief Engineer's working group. Considerable progress had already been made on understanding human factors within rail engineering activities, with studies of safety culture and violations on the track (e.g. Farrington-Darby *et al.* 2005), the work of the engineering supervisor, communications and briefings (e.g. Ryan *et al.* 2007), inspection processes and attitudes, culture and support for track workers and for managers and supervisors (e.g. Farrington-Darby *et al.* 2008, Murphy 2008). One particular proposal that emerged from the working group was for a completely different system and set of processes and rules by which possession of the line for engineering work would be granted, engineering trains and plant moved into place and protection provided for people, equipment and infrastructure. Many of the thoughts about the ergonomics approach to understanding systems risk and to joint analysis of safety and production risk have been informed by work on this large project. Some of the contribution is described in the next section.

4. Human factors issues identification in rail engineering

4.1. *Human factors case*

The work that the human factors team has carried out to support development of new arrangements by which rail engineering work is planned, controlled, protected and delivered is summarised here. However, details of the actual changes to the process and rules are not provided and are not required for the thesis of the paper. The objectives of the human factors work supporting the rail engineering project were to: provide a human factors assurance framework for the programme; identify human factors issues, potential disturbances and potential human factors risks in the current and proposed future systems; integrate with the work being performed on the safety case for the project; generally support development into a safe and effective work process.

The human factors contribution has been structured around the human factors case, currently being developed at EUROCONTROL (EUROCONTROL 2007, Kirwan 2007) and about which the present authors were made aware by the external advisor on the project, Barry Kirwan. The human factors case helps to guide the management of human factors issues during the development of a system, or during system change, and can fit alongside other 'cases', such as the business case, engineering case, safety case and environment case. It is intended to be a comprehensive, structured and integrated approach to the description, analysis and management of all the relevant human factors issues in a project, ensuring that best use is made of human performance, increasing efficiency, capacity and safety. According to EUROCONTROL this can 'fill the void' of human factors contribution to a safety case and amongst other things can allow early identification and management of human factors issues and human factors implications. From the present authors' viewpoint, the human factors case had potential for supporting the making of rational trade-offs in assessing the new system of work, in allowing outcomes other than safety to be accounted, for which is not always the situation when human factors analysis sits within a safety case.

The human factors case as proposed by EUROCONTROL (2007) contains five specific stages:

(1) Fact finding – collection of background information on the system, environment, stakeholders and documentation, scoping the project from a human factors perspective to identify what will change, who will be affected and how they will be affected.
(2) Issues analysis – identifying and prioritising human factors issues and their potential impacts in human performance on the project.
(3) Action plan – describing actions and mitigations to address the human factors issues.
(4) Actions implementation – implementation of the action plan, with the output of the human factors case report containing findings and conclusions from actions taken.
(5) Human factors case review – an independent review of the human factors case.

The issues analysis stage is interesting in helping support joint work with engineering and operations specialists. It covers what needs to be addressed in the human factors contribution and what could go wrong, considering whichever are most relevant out of the broad and well-known (to engineers and managers) human factors issues of human machine interaction, work environment, etc. (see Table 1). It also addresses the human factors impacts, which are the less tangible (for an engineering audience) effects on human performance and on the system; such impacts include situation awareness, workload and human error.

The work has also been structured to follow the key stages outlined in the industry guidance for engineering safety management (the 'Yellow Book'; Rail Safety and Standards Board 2007); notably, function analyses, human factors issues identification, human factors risk identification and initial human factors risk assessment. Human factors risk assessment means assessment of those risks in the widest sense, which are associated with the human factors at individual, team and organisation levels; risks that emerge from the performance of people and organisations and also those risks that impact on any people in any way.

Table 1. Human factors issues and impacts on human performance (based on guidance from EUROCONTROL, 2007).

Human factors issues	Impacts on human performance
• HMI	• Acceptance
• Work environment	• Cognitive processes
• Teams & communications	• Comfort
• Procedures, roles and responsibilities	• Error
• Organisation & staffing	• Fatigue
• Training & development	• Job satisfaction
	• Motivation
	• Situation awareness
	• Skill change
	• Stress
	• Trust
	• Workload

Therefore, the outline human factors case programme has consisted of:

- function analysis, to enhance understanding of rail engineering work and provide structure for later parts of the analysis (fact finding);
- first identification of human factors issues, including analysis of communications (fact finding);
- development of a human factors issues register, including a first structured assessment of the human and organisational risks – to safety and to effective engineering performance – that the identified human factors issues might pose (issues analysis).

To achieve this, work has been carried out in a number of (sometimes iterative) stages, as summarised in Figure 2.

4.2. *Function analyses*

A first breakdown was produced of five top level functions, relevant to current and future approaches to railway engineering work, and described without reference to existing roles and procedures (since these were likely to change with any new arrangements). These functions are identification and planning of engineering work, access to the track, protection from power sources, delivery of the work and return of the line to traffic. These functions were used as a starting point for the structured breakdown and further analysis of the activities involved in engineering work. The function breakdown and analysis has been achieved through review of documentation, use of on-site observations and a series of one-to-one interviews and workshops with workers in key roles from a range of geographical locations. This included over 20 site visits

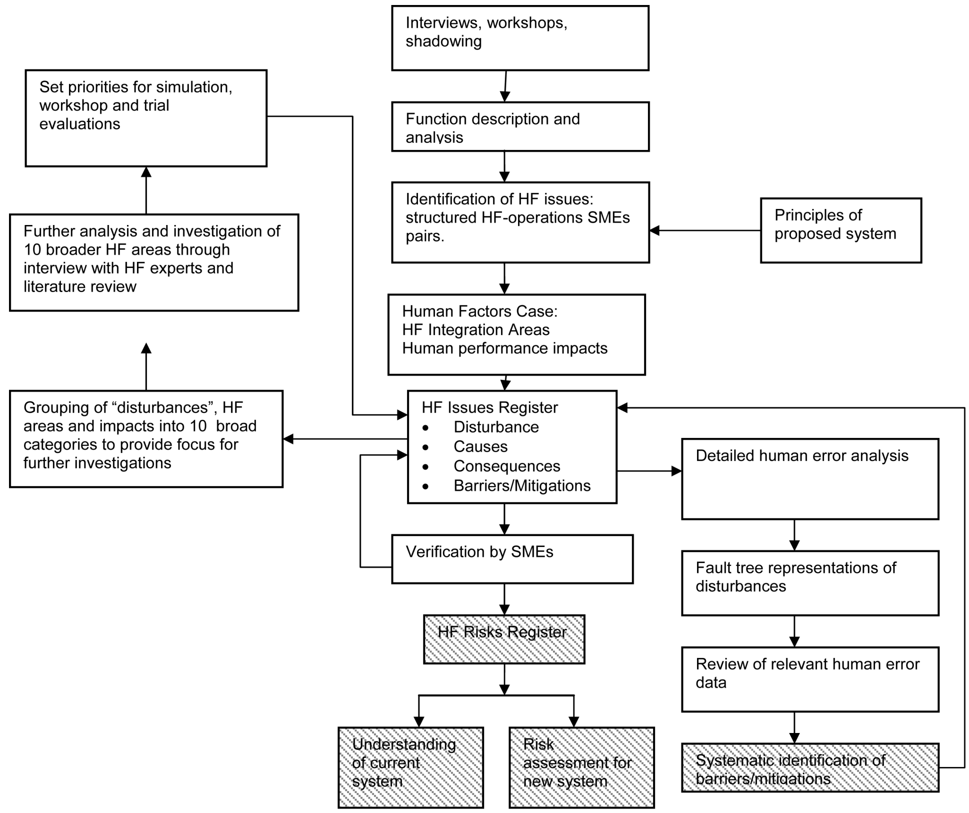

Figure 2. Human factors case programme for rail engineering (shaded boxes show work still to be completed at the time of writing).

across the UK, eight workshops with subject matter experts (SMEs – Cox *et al.* 2007) representing a range of roles and three internal workshops for verification and enhancement of the function breakdown.

The function description and analysis approach has been useful in identifying the goals that must be met and the operations and activities that must take place within the distributed system, at a less detailed level than a task analysis is normally considered. The large scale and complex nature of the distributed engineering system determined that the decomposition implied by detailed task analysis was not appropriate, at least at this stage; the system is so vast that analysis could not be justified at too fine a level. Also, it is felt that if the analysis was at too fine a level of detail too early in the system definition stage, it might be possible to lose sight of the most important and more global human factors issues. In performing the analyses, a stopping rule was required – broadly, when the authors felt able to adequately identify and describe existing and potential disturbances and risks. Higher level elements of the function analysis are shown in Figure 3. More detailed breakdowns were developed from this top level, representing what should be done to meet goals rather than what the rule book says.

The work in function analysis, issues identification and, subsequently, the identification of potential risks was supported by development of a series of visual scenarios and analyses. Microsoft Visio software has been used to present visual representations of different critical phases of work, considering both the current and proposed systems for protection. An example from one of the scenarios is given in Figure 4, providing a visual representation of a stage of work under the current system. Further details of this approach are given in Schock *et al.* (2008).

Since communications comprise a critical part of the work in rail engineering and related protection, they have been subject to additional analyses to feed into the other elements of the project. The requirements for exchange of information between relevant parties in the current and proposed systems were considered and discussed in detail at two whole-day workshops using a group of industry experts, focusing on the likely sequences of communications and the likely methods of communication. This prompted discussion on the potential for problems or sources of error within these communications. Communications within key elements of a specific rail engineering scenario were then analysed in detail and the assessed frequencies of

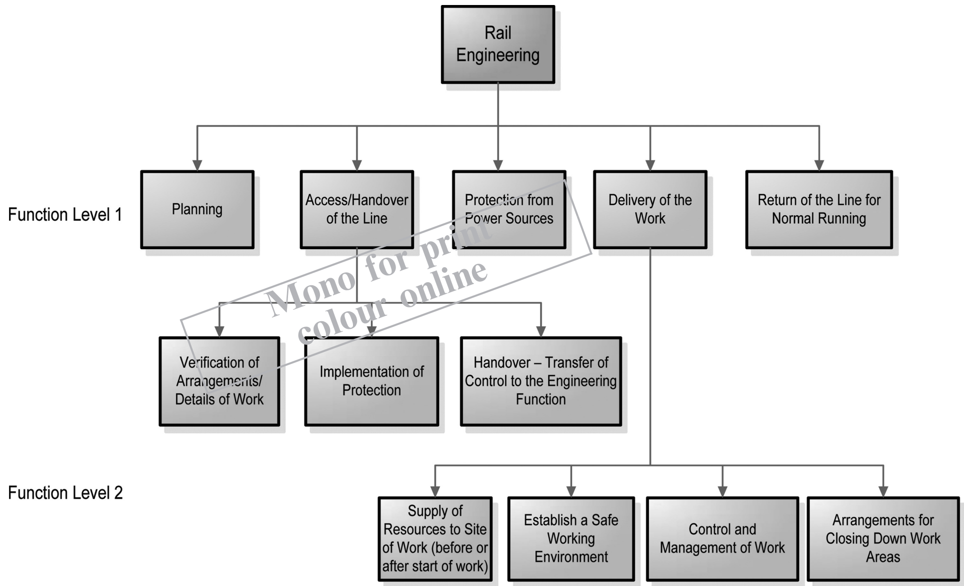

Figure 3. High level functions for protection of engineering works, expanded for all Level 1 function only.

communications for key staff in different elements of the scenario enabled comparisons between current and proposed protection systems.

In parallel to this, communications analysis is also being carried out using simplified logic trees to analyse the possible outcomes of communications for given circumstances/scenarios. Again, this is based on typical situations that, in the first instance, may occur during proposed trials of the new system of working. This work will demonstrate the range of errors that could occur and help to predict the potential effects of these on the system. The approach will also highlight areas where barriers or mitigations could be put in place.

4.3. *Identification of human factors issues*

A structured approach supported evaluation of the proposed new engineering access and delivery system alongside the current system for protection. Human factors issues associated with the different functions from the function analysis were identified through the examination, discussion and debate on the system and analyses with SMEs and the project team. The structured approach identified likely differences between systems and predicted both the strengths and potential weaknesses of the new system. The comparison between the existing and proposed systems was on a number of criteria: the objectives of workers; the information needed; equipment used; organisational factors; anticipated difficulties; controls and constraints (for safety or production). This comparison was conducted over a period of 6 days in one-to-one sessions with two operational experts from the project who had been developing expertise in the proposed system.

The findings from the comparative work with the operational experts were then summarised, identifying a list of human factors issues that were likely to impact on the proposed system. Broad groups of potential issues emerging included the effects of new site-based roles, effects on signaller time available and workload, potential for confusion in complex locations, changes in communication methods and protocols and being able to identify locations for the limits of protected areas.

4.4. *Human factors register*

The human factors issues identified were a blend of what might be termed performance-shaping factors, potential human errors and violations and unwanted outcomes. The human factors issues register was developed to define each of the human factors issues as discrete human failures that could potentially occur within the system. At this point, it is necessary to go back to one of the main themes of the paper – the joint consideration of ‘production’ and safety risk; ‘production’ in this context is to do with engineering delivery risk – the chance that the system will not perform and deliver as intended through significant problems with efficiency, reliability or quality. The parallel inclusion of both safety and production issues presents a danger of any risk analysis appearing too daunting since the numbers of potential risks could be much larger than looking at safety alone. However,

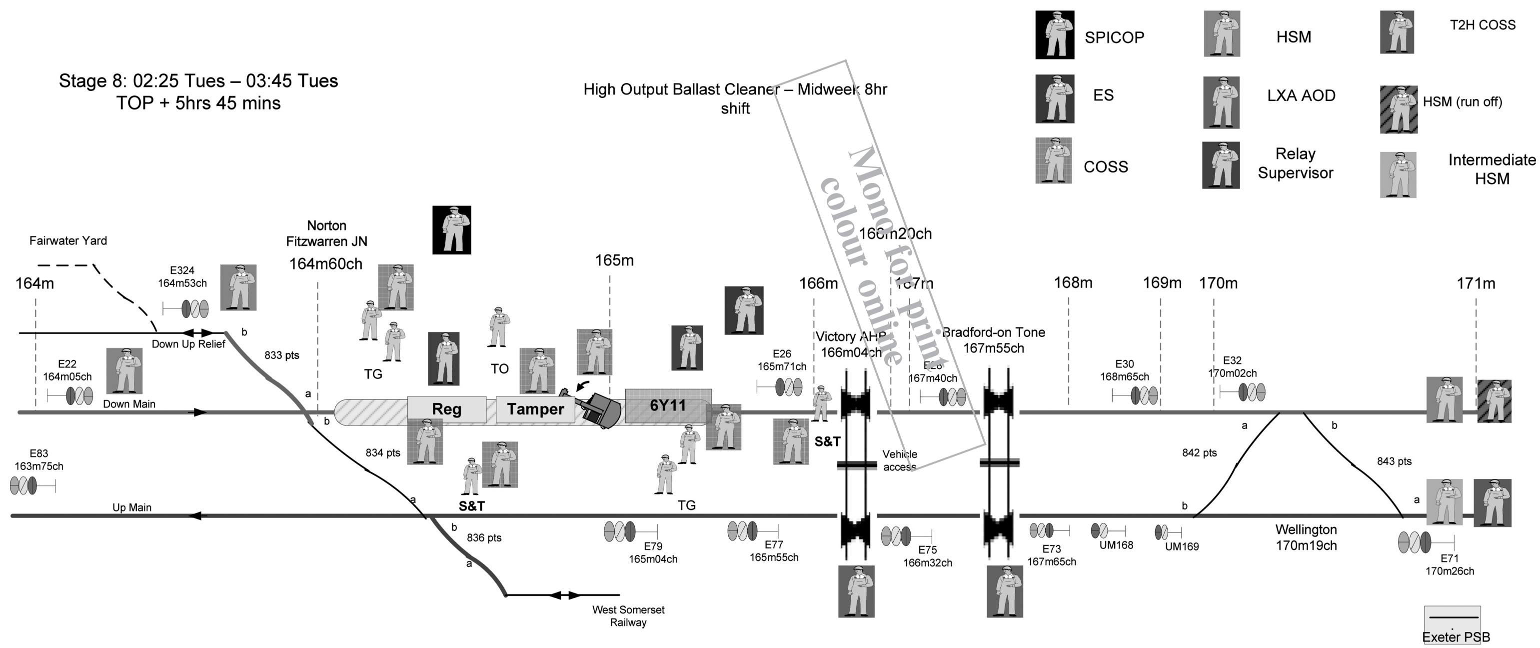

Figure 4. Example of visual scenario for one stage of rail engineering work.

given the objectives of the overall project, the authors wished to provide a joint representation and analysis and described each potential human failure within the system as a 'disturbance' (see also Leveson 2004) rather than a hazard, with the intention that anything identified here might be understood as disturbing the successful and efficient performance of the work whether through safety problems or not.

Each of the disturbances has been described within the register as a human performance requirement using a positive description of the disturbance (which is by its nature a negative event). For example, the disturbance 'signaller and site-based protection staff fail to reach an agreement on protection limits' has been written as 'signaller and site-based protection staff reach an agreement on protection limits'. This describes what is deemed to be success within the system and helps to remove some of what can be a sense of simply 'problem finding' in this type of work; the disturbances can then show potential deviations from the requirements.

The human factors register is an important project resource as a living document and repository of risk-related information. The main categories used in the register are: identified human factors issue; human performance requirement; disturbance; function; potential cause; potential consequences; mitigations/ barriers. A number of additional categories were included for classification of the data and recording of expert ratings or judgements and used as part of the analysis of the content of the register. These included categories for the theme/type of disturbance, project team rating of safety and delivery impact, mapping of disturbances to the safety risk assessment, opinions on suitability for monitoring in trials and judgements on priority for consideration in further work. Excerpts from two rows from the register are shown as Table 2. For the purpose of presentation, the table includes only main headings from the register.

Over 140 potential disturbances were recorded in the human factors register. More than half relate to communications, one-third to general movements of vehicles, one-fifth to the identification of the protection limits and a further fifth to the monitoring and use of documentation or other information aids. The disturbances subsequently have been allocated into 10 broad groups – communications, identification of protection limits, monitoring of the signaller's panel, operation of signals and points, control of movements of engineering vehicles, signaller and protection staff workload and responsibilities, instruction and supervision of site-based staff, training and competence and rule compliance. These groupings have been used to identify critical elements of the proposed system that are common across many of the disturbances and provide clear priorities for human factors work in the next phase of field trials and simulations.

The next step will be to take a systematic approach to the identification of the respective causes, preventative factors/mitigations and potential consequences for the critical disturbances. Provisional lists of causes have already been constructed for each of the disturbances and these were refined during work to verify the register with SMEs. These causes will be analysed with a rail-adapted version of TRACEr (Shorrock and Kirwan 2002) and initial fault trees will be developed to classify the error modes and performance-shaping factors and enable the systematic identification of appropriate barriers and mitigations. Likely consequences (relating to safety and production) will also be identified for each of the disturbances.

Any human factors work such as that reported here requires a great deal of on-going verification. The description and analysis work has a degree of verification built into the processes. The descriptions of how engineering work is carried out, the factors and issues involved and the identification of potential failures leading to engineering performance or safety degradation have been generated within field site visits, observations, interviews and workshops with SMEs. Regional variations in working practices have been identified in subsequent interviews and workshops with a wider range of railway employees.

5. Discussion

5.1. *Disturbance analysis in rail engineering*

This paper has drawn from a current project to analyse rail engineering work systems and particularly the processes and rules by which teams are given access to the track, take possession of the line, trains and on-track plant are moved and protection is provided for people, equipment and the infrastructure. The context has been proposals for fundamental changes in the way that possessions for rail engineering work are planned and managed and the approach taken has been applied to analysis of the current work systems as well as to predictive assessment of the potential future system. Methodologically, much of the basic knowledge, interpretation and verification in this study have come from use of workshops with small groups and then pairings of human factors and SMEs. Whilst labour-intensive, it is believed that the approach has been highly effective in establishing a robust description of engineering work functions, in analysing potential production and safety disturbances, and in embedding the human factors issues within the project development considerations. The notion of a human factors case was used to structure the identification of

Table 2. Examples of rows from the human factors issues register.

ID	Human Performance Requirement	Disturbance	Function	Theme	Potential cause	Potential consequences
6	Signaller and site based staff reach an agreement on limits	Signaller and site based staff each have a different understanding of the limits, but reach an agreement without realising that there is a difference in understanding	Access/ handover	Communication – agreement/ understanding	1. Violation – Readback not carried out. Could be complacency. 2. Design of Permit/Forms. Permit protocol is inadequate/not applied correctly. May result in failure to readback, ineffective readback. 3. Distraction/preoccuption. One or both parties may be distracted, interrupted (e.g. signaller may have to attend to other duties during the conversation) or preoccupied and therefore not paying attention appropriately 4. Communication – Protocols. Readback ineffective 5. Misunderstandings/inconsistencies. Due to inconsistencies in working ("I don't do it like that")/knowledge gaps ("I don't know that"), across different locations 6. Assumption/expectation. Person has an expectation of what they think they are hearing rather than what they actually hear, due to expectations. 7. Training/competence. Signaller and/or staff inadequately trained. 8. Workload/Pressure. Pressure on signallers to grant access, limited time between trains to get access. 9. Complexity of arrangements 10. Local Knowledge – Confusion. Confusion between parties on identifiable limits and actual locations.	– Both parties go ahead and operate with different understandings of where the limits are (mental models) – Inadequate work area protection; – Confusion/Work delays; – Worker injury/ fatality; – Collision; RRVs or trains.

(*continued*)

Table 2. (*Continued*).

ID	Human Performance Requirement	Disturbance	Function	Theme	Potential cause	Potential consequences
2	Site based staff able to observe members of a workgroup	Site based staff cannot observe members of a workgroup	Delivery of work	Rule/procedure – instruction/supervision	1. Roles and Responsibilities. Definition of role and multiple responsibilities – may not be possible for staff to multitask effectively. 2. Workload. May have too many engineering occupations/too many staff under their authority (workload) and may not effectively be able to monitor own effectiveness and realise when can't handle the situation. 3. Rules. Lack of clarity in the definition of what a separated workgroup is in the system. 4. Training/Competence. Inadequate training/competence. 5. Self regulation. Ability to effectively monitor and respond to own feelings of workload/pressure. 6. Perception. Staff may not be able to physically see all members of the workgroup (e.g. the view might be blocked by equipment, physical layout of location).	– Loss of control or coordination of team; – Work delays; – Worker injury/fatality – Collision; RRVs or trains

human factors issues that might impact on, or be impacted by, the system of work. Subsequently, the issues were assessed for their likely level of disturbance on the system, using the term disturbance to reflect the joint analysis in terms of safety and of engineering delivery (the key aspect of 'production' in this domain). A human factors register has been developed that identifies and expands on the disturbances, their potential causes and consequences and mitigations. By incorporation of estimates of likelihood and severity, this will become a human factors risk register and basis for a risk assessment.

The human factors register is a living document and will be updated over the lifecycle of the project. The joint representation of engineering delivery and safety risk will be maintained since the authors wish to try to provide a human factors contribution that supports joint optimisation across all major goals of rail network, the company and the staff. The present authors are not aware of any published work that does this explicitly and although they suspect that their colleagues in the consultancies do have available approaches and tools that are suitable for doing this, enquiries to date have drawn a blank. Although taking the quote a little out of context, in so doing the authors are trying to 'locate all risk analysis in a clear understanding of the processes which the system is trying to operate and manage' (Hale 2006).

It is believed that in future there will be value in linking the human factors case, human factors issues register and joint safety and production disturbance analysis with other knowledge-gathering approaches. First, if one wishes to better understand the information needs of the distributed track work teams and the implications for mobile communications design, then a link with the approach of cognitive work analysis (e.g. Naikar 2006) will be of value. Second, it would be of value to link the communications analyses, which are a key part of the risk assessment, to field study methods for distributed cognition such as that (from the rail domain) of Walker *et al.* (2006). Third, where the focus is on the strategies employed by skilled workers, for instance, in planning and problem solving, the link could be with the work analysis approach used previously in studies of rail control functions (e.g. Farrington-Darby *et al.* 2006, Wilson *et al.* 2007a).

5.2. *Potential relevance of resilience engineering*

The railway is a classical example of a complex system in which trade-offs must be made in its design and operation. This is not just the safety/production trade-off already referred to, but a best profile must also be found amongst several, often competing, attributes. These include use of capacity, reliability, quality of service and cost, as well as safety. Resilience engineering has therefore become of potential interest for the rail system as a whole and, in the context of this paper, for rail systems engineering and human factors risk assessment.

There has been much recent interest within human factors in the nascent movement of organisational resilience and resilience engineering (e.g. Hollnagel *et al.* 2006). This has grown out of recognition that performance conditions are often under-specified so that individuals and organisations must adjust their performance to match prevailing conditions and that many adverse events are the result of unexpected combinations of normal performance variabilities and so safety management must be proactive as well as reactive. Compartmentalised and linear thinking, a tendency to decomposition and the equating of human factors to technical factors in terms of failure probabilities have meant that:

> The main problem in industrial safety today is that the majority of safety management and risk assessment methods are from 20 to 40 years old . . . [and] . . . may have been adequate for the systems that existed at the time they were developed, but are inadequate for present day systems.
>
> (E. Hollnagel 2008, personal communication)

Views from throughout the first book on the topic (Hollnagel *et al.* 2006) are that for resilience the system '. . . reacts to and recovers from disturbance, early and with minimal effect on its dynamic stability . . .', '. . . survives occasional crises and prospers without changing basic nature . . .' and has the '. . . capacity to anticipate and manage risk . . . through adaptation . . . to ensure core functions continue effectively . . .'. Definitions include 'a system's ability to resist a wide variety of demands from its whole domain of operation' (Morel *et al.* 2008, p. 2) and 'the capacity (of an organizational system) to anticipate and manage risk effectively, through appropriate adaptation . . . so . . . core functions are carried out in a stable and effective relationship with the environment.' (McDonald 2006). These views appear to allow for the idea of balanced risk assessment and management, such that a rational approach is taken to the safety// production trade-offs. However, it is suspected that the main thrust is more of the fight for safety over commercial pressures to maximise production ('faster, better, cheaper' philosophy; Woods 2006) than vice versa. It could be argued that making rational safety// production trade-offs, and finding the best balance between safety and productivity within uncertainty and in the light of commercial pressures (Woods 2005), is just as important to ensure that effective systems can flourish within a sensible approach to safety.

There are a number of aspects or underpinning ideas of resilience engineering that make it appropriate to examine seriously as a framework for human factors and human factors risk assessment in rail systems engineering. The systems of interest for a resilience engineering approach are ones where organisations must create processes that are robust yet flexible and use resources appropriately in the face of disruptions or ongoing production and economic pressures; this describes the rail domain. There is an emphasis in resilience engineering on systems that show foresight and have an intrinsic ability to maintain or regain a dynamically stable state to continue operations after a major mishap. Also of interest to rail companies is the notion of managerial resilience, typified by Flin (2006) in relation to safety as comprising skills in diagnosis, decision making and assertiveness. Resilience engineering certainly resonates with the Network Rail approach to understanding how to improve the rail engineering system and processes across a number of performance criteria. Organisational systems have to find the right balance between safety and production within their operational, commercial, regulatory, governance, public responsibility and ethical framework; for rail this means a particular balance of efficient use of (limited) capacity, reliability of service, quality of service and safety. A vital outcome of being resilient should be the capability of systems to deliver acceptable levels of service with appropriate levels of protection and at a cost that can be afforded.

To be useful in practice within the railway there is a need to operationalise, represent and perhaps measure attributes of resilient systems. Here, the authors are thinking of Woods (2006) identifying attributes such as buffering (absorb or adapt to disruptions outside the known distribution), flexibility (restructure in response to events), margin (operating relative to boundaries) and tolerance (behaviour close to performance boundaries). Wreathall's (2006) identified characteristics of flexibility, opacity, preparedness, awareness, top level commitment, just culture and learning culture should also provide the basis for measurement. The functional resonance accident model (e.g. Hollnagel 2004) may provide a framework for measurement and assessment but in the meantime the present authors are exploring the use of a simple first representation, for rail, as shown in Figure 5. The figure shows each of the systems criteria relevant to rail and then the three regions of 'optimum', 'acceptable to over-specified' and 'danger'. The boundaries for these regions must be set by the organisation (with the regulator if relevant) in light of the safety/production trade-offs involved. Any particular subsystem may then be represented by a profile showing where it sits for each parameter. For example a new mobile information system might need to be over-specified at first in terms of safety-related communications and in terms of reliability, but may be seen as having few serious security or environmental implications and so require less investment in these and be specified closer to the danger boundary. Cost can be represented as one of the parameters (as here) or could be used to decide across trade-offs. In its dynamic form the diagram might be used to illustrate interactions between parameters (or criteria) in the way that the envelopes behave, especially close to the boundaries; for instance, if even greater margins for safety are provided, then capacity might decrease.

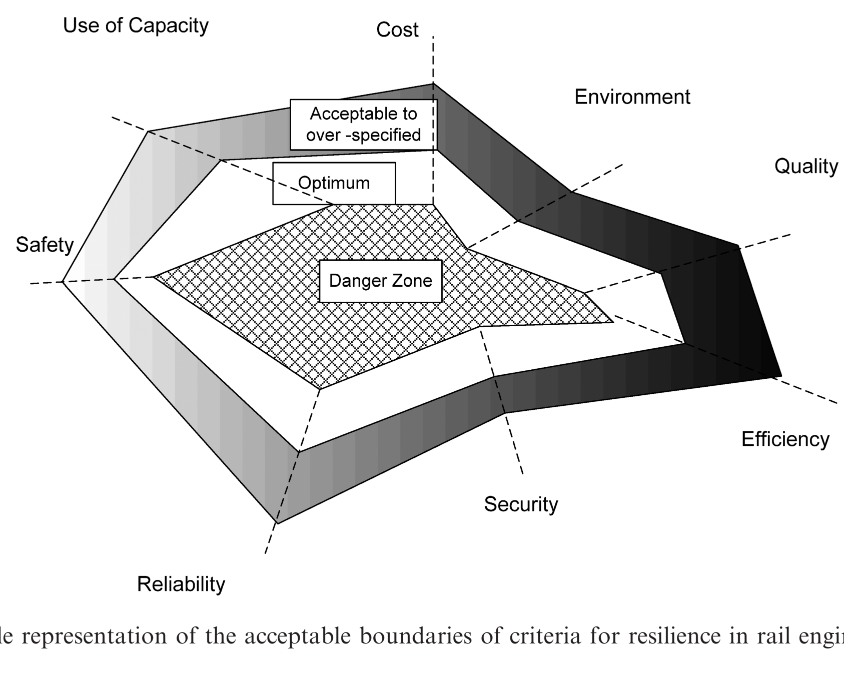

Figure 5. First simple representation of the acceptable boundaries of criteria for resilience in rail engineering.

5.3. Managing wider human factors risks in practice

The considerations in this paper of human factors risk generally and of the trade-offs involved in balancing safety and production risk lead naturally into a consideration of managing risk to do with people at an organisational level. For rail this means that the balanced use of procedures, automation, good job design and professionalism must be examined. Whilst all these are current issues within Network Rail (e.g. Balfe *et al*. 2008) of particular relevance to engineering and maintenance work on track are the use of procedures and the availability of experienced and expert staff.

One outcome of an emphasis on safety at all costs may be organisations and societies that are so scared of accident risk that they re-write, add to and strengthen operating procedures each time a new risk is identified. There is nothing the matter with well-founded, written and implemented procedures, of course, and they are a vital part of complex system design and functioning, it is just that so few of them are of sufficient quality (as Hale *et al*. (2004) and Dekker (2003) have pointed out, amongst others). The consequence of procedures that are poorly predicated, structured, written or implemented is that achieving any kind of acceptable performance (measured through quantity of work, timeliness, coordination, etc.) is close to impossible and the procedures may actually breed a culture of violations simply to 'get the job done'.

A culture of professionalism provides another route to reduction in safety risk and production risk, through supporting expert performance whilst allowing freedom from over-prescriptive procedures. Human factors has traditionally preferred design of enriched, responsible and learning jobs, giving people the responsibility to use skills to create a successful work system, with minimal controls and non-prescriptive and light touch procedures, rather than relying on technical systems controls and automation. This preference may have to be re-thought given the changing demographics at work and the changing expectations of society. Where are the experienced and technically and organisationally competent people of the future coming from? In many industries, including rail, a bulge of people aged between 45 and 55 years will be retiring soon and enormous loss of expertise and tacit knowledge will occur with their departure. Opportunities for learning slowly and thoroughly are limited in many industries, with few apprenticeships, very fast-track training and less observable processes with computer-based systems. In any case, few young people now start a job thinking they will stay there beyond a couple of years. This changing work demographic therefore may affect the whole human factors philosophy as regards work systems risk.

6. Conclusions

It is necessary to find a rational way to design systems of planning and protection for rail engineering work processes that do not rely over-heavily on working to tight rules, that recognise the needs for staff to match their performance to prevailing conditions, but that also recognise variability in the knowledge and skills of those staff. To do this, there must be a basis for making sensible safety/production trade-offs. It has been argued here that this will require methods and tools to carry out joint analyses of safety risks and production (in this case, engineering delivery) risks within a common format and based upon robust function analysis. The notion of the human factors case has proven useful to structure a programme of human factors analyses and specifically to transfer from a function analysis to a human factors register based upon identified or predicted disturbances. The human factors register will support subsequent development of a human factors risk register to feed into the project safety case. Beyond this, it is suggested that a framework of resilience engineering might allow proper consideration of the different trade-offs that must be made in proposals for new rail engineering systems of the future.

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