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ORIGINAL ARTICLE

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# Human factors in support of a successful railway: a review

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**Abstract** One of the critical infrastructure components in most economies across the world is the rail network. In different nations rail is responsible for ensuring that there is not complete gridlock on the roads in commuter hours, and for moving both people and freight for long distances in an as efficient manner as possible. This critical role, a number of high profile accidents and proposals for new network control philosophies and systems have led to a great upsurge in human factors rail research and applications in the past few years. This paper provides a retrospective on rail human factors research covering driving, signalling and control, maintenance, incident reporting systems, passengers and the public, planning and technical systems change. This research foundation, and also current major rail human factors programmes, are placed in the context of technology, investment, competition, cultural and safety requirements and constraints. The paper concludes with an examination of where rail human factors should and will be going into the future.

**Keywords** Human factors · Railways · Safety · Trains · Signalling · Centres

## 1 Introduction

Rail human factors research has, to an extent, been the forgotten branch of transport ergonomics, at least in comparison to aviation (cockpit and air traffic control) and road driving. Good research has been carried out over the years, for instance, in Sweden, Germany, The Netherlands, Japan and the UK, but not to the extent—in funding programmes, numbers of researchers or publications—of other transport sectors. (Note that ergonomics and human factors are synonymous terms within many rail organisations, are for these authors also, and so will be used interchangeably within this paper.)

In the UK there was a good deal of rail human factors research carried out in the 1960 s and 1970 s largely through the British Rail Research Centre. Unfortunately, at least some of this research is no longer available to us, although the human factors research catalogue produced annually by Rail Safety and Standards Board (e.g. 2004) has managed to retrieve a part of it. Although research did continue through the 1980 s and 1990 s, the small amount of this compared to that for other transport industries paralleled some general lack of interest in investing in the railways. For the human factors community as well, it is possible that the railways did not seem to provide as exciting a domain to work in as aviation, and perhaps did not seem as high a priority to research funding bodies as road transport, at least in terms of accident rates or passenger miles.

This relative neglect—by the human factors community, by researchers in other domains such as engineering, and by society as a whole—has changed markedly since the mid to late 1990 s. For many years, rail was a business that evolved slowly and where, despite occasional disruptions and major accidents, things appeared to run relatively smoothly. Recently however, the Chief Engineer of Network Rail highlighted the influence of radically changing public and government perceptions and relatively fast changing technical systems in an industry where nothing much had changed for 150 years (McNaughton 2003). He highlighted also the very different demographics and workforce nowadays: no one any longer expecting to be in a job for 40 years, more like 2–5 years; much greater population mobility; less willingness to work within a structure; new entrants with less time and supervised experience to pick

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up key technical, organisational and especially tacit skills; and a bi-modal population of 16- to 25-year-olds either with degrees or with few qualifications and competencies. These are human factors of great importance for the rail industry, which he typified as the human at the centre of a complex engineering system. He saw ergonomics as helping bridge some of the gaps between what the industry has and what the industry and wider society actually want. He also believed that ergonomics can contribute greatly to ensure that existing and new systems meet the needs and capabilities of passengers and staff.

Interest in the human factors of railway operations has never been greater amongst the governments, the media, the public, the rail industry itself and the academics and the practitioners. Of course, fatal accidents (and subsequent inquiries) have encouraged focus on safety, and on the contributions of human error, poor communications, maintenance procedures and other central topics in ergonomics (see HSE 2001a, b). But in parallel, the need around the world to shift passenger miles from private to public transport, the increased potential performance of trains and the changing nature of railway ownership and organisation have encouraged focus on a systems ergonomics view of total rail network performance. This and other contextual influences are discussed next.

## 2 Context for human factors in the railway

Any useful ergonomics contribution in any domain must reflect its setting, and some of the relevant context was alluded to above. The very environmental and internal factors that generate the need for thorough human factors investigation in the railway network also provide the very issues, difficulties and challenges for such research. The context discussed below is drawn from the UK experience but will be relevant across many other countries and rail networks as well.

There will be considerable changes in the *technology* used to identify which trains are on the track and where they are, control their progress keeping safe but efficient separations, and communicate between train and signalling and control functions. Design, implementation and operation of new systems will generate a host of new human factors problems (and successes!) and will require fundamental and applied understanding. Future control of the railway network will probably be much more centralised, with many of the functions and operations currently carried out at numerous small and large sites being brought into fewer centres. The integrated functions may include route control, electrical control, signalling and possibly train operating control. There will be opportunity for new display and communication systems to reflect the increased information that the driver can have in-cab. As a consequence of the integration of functions and the new technical systems, there will be changes in the nature of the roles and organisation of work for staff in the control centres.

At the same time, the UK rail business works with a great variety of *legacy systems*. Even the newer Integrated Electrical Control Centres (IECCs) can appear dated alongside modern control rooms in other industries. Alongside IECCs there are still many entry–exit (NX) panel control systems and old lever boxes, and these will co-exist for many years yet. As with many industries another legacy is the incorporation of original techniques or tricks of the trade (such as memory aids and failsafe or interlocking systems) into modern systems through development of a computer equivalent, often without questioning whether this is an appropriate way to do things.

Any severe constraints on *investment* in transport and other infrastructure service industries will always make themselves felt in time, in terms of customer service, performance quality, reliability and safety. No business has unlimited resources, and the careful identification of priorities for investment, and the total systems analysis of consequences of different investment levels, will help decision making. However, any reduced investment in the railway business historically, leading to deterioration of the infrastructure and inadequate rolling stock, can become apparent years later in terms of recurring faults and restrictions on optimum performance. We hardly need to point out the impact that inadequate investment—and the public awareness of this—can have upon morale amongst employees. Related to this, the change of ownership of the business and more rapid turnover of staff, there is a danger that the culture within the railway business could change markedly, with less people aware of what it is to deliver rail transport as distinct from burgers or insurance. These dangers can be addressed through policies on competences, job design, training and procedures, all of which require substantial ergonomics input.

Critically, and of great interest from a systems ergonomics viewpoint, the rail network and business comprise a system that must balance *competing pressures*—reliability of service, quality of service and safety of staff and passengers—in a situation of limited capacity. Passenger numbers have increased in recent years, and companies wish to run more trains in the same envelope of time. However, faster long distance trains must share track with slower commuter and cross country services, which runs up against capacity limits and gives difficult timetabling; the slightest delay ends up with faster trains following slower ones, causing timetable difficulties for some time afterwards. At the same time there are government requirements to increase freight capacity radically, and the only way to achieve this is to run more freight at night. However, accidents such as Hatfield and Potters Bar have thrown the spotlight onto *maintenance*—inspection, repair and renewal—which must either take place at night or else take possession of the track during daylight hours and thus share the infrastructure with several trains per hour, which may decrease efficiency and increase safety risks. Planning and management of possessions and control of engineering work are key areas for future improvements and human factors are central to these.

With the change of organisation and ownership of the business, there is a need to preserve the best of the *culture* within the railways, generated over many years, whilst recognising and modifying culture which is not appropriate to modern systems of working. As many new people join, staff should all be aware of what it means to deliver rail transport as distinct from other products. Railway culture is highly evident in the *procedures* by which railways are operated ('the Rule Book'), and in the *tacit knowledge* held by experienced staff which includes them knowing which rules are vital, where there are 'grey areas' and even which rules are counter productive. Cullen (HSE 2001b), for instance, found evidence of confusion amongst signallers over standing instructions (clause 12.2). The break-up of the UK industry during the 1990 s into (initially) more than 100 different businesses and the initiation of major renewals such as West Coast Route Modernisation (WCRM) and the prospect of European initiatives in train and track control (ERTMS—European Rail Traffic Management System), have prompted considerable analysis of how the rail network runs and should run, what systems have to be in place to achieve this, and what the new railway culture should be. These debates continue.

*Safety* on the railways has been seen in a very different light in the last few years, by the general public, the governments, the media, the passengers and the industry itself. There is little understanding outside the industry that the vast majority of what are anyway relatively few fatalities are due to trespass and suicide and that a substantial proportion of signals passed at danger (SPADs) are engineering trains running at night. Like many other organisations or industries—the Health Service, for instance—there is a constant trade-off between safety, efficiency (embracing cost considerations), quality and reliability of the service, all in the context of a system with limited capacity. The reaction in the UK to incidents such as Ladbroke Grove, and particularly following Hatfield and Potters Bar, could have caused even more problems for the network. Although it is difficult for people in authority to say this publicly, it is impossible to have 100% safety, neither on the railways nor in general, and certainly not at a realistic price. This is why calculations are made for the value of a life or serious injury saved in order to make rational investment decisions (see RSSB 2005). It is this debate that lies at the heart of difficult decision-making over investment in train warning and protection systems (to reduce the likelihood of SPADs) and train control systems generally, with the more expensive systems perhaps meaning that the railways will be priced out of the market on worst case calculations. It is also at least questionable whether it is sensible to run the railways so carefully (e.g. after Hatfield) that disgruntled passengers drive on the roads instead, which is arguably a less safe form of transport. Procedures which are brought in which are intended to be related to safety, if this is done reactively in a panic, may not actually improve safety and may impair effectiveness and performance, which in turn may promote a culture of violations.

Safety on the railways has many facets. The behaviours of one group, say track workers, can impact on the safety of the network as a whole (for passengers, drivers, public, etc.) as well as on the safety of themselves and their colleagues. To expand on this, in the specific case of safety, rail ergonomics is concerned with: safety of rail company staff (e.g. a trackside worker being hit by a train); reliability of rail staff which effects safety of passengers or other staff (e.g. a driver committing a SPAD); organisation failure affecting passenger and staff safety (e.g. planning a possession of the track, for maintenance); behaviour of the rail-using public (e.g. passengers alighting a train); and behaviour of unauthorised network users (e.g. children trespassing and sabotaging the track, or suicides).

In the circumstances which result from the effects of all these context factors, one way to make improvements is to understand the performance of key railway staff and to provide better designed equipment, interfaces, jobs, communications, training and planning systems. Much of the work being carried out by human factors groups is aimed at supporting just such improvement, for the work of signallers, controllers, planners, drivers and maintainers. The human factors contribution must be multiple. First, we need to understand how the performance of stakeholders working in the rail network can effect (for good and ill) the performance of the network as a whole and the well-being of all other users or stakeholders. Second, we need to understand the potential effects of rail systems and jobs on the people working there, in terms of health and safety, attitudes and satisfaction, competency and skill development. Third, we need to identify and communicate the characteristics of people which are relevant to design, implementation and operation of rail systems, equipment and jobs. And finally, we need to support (re)design that better meets the needs of all users and meets the goals of the operating companies through human factors integration plans, policies and processes.

## 3 Rail human factors research to date

The rail system is a classic domain for human factors contribution. It includes work of all types, from vehicle control, to monitoring, planning and physical work with tools. Its settings vary from vehicle cabs, to control rooms, to outdoors, to large buildings and spaces. The artefacts that stakeholders use vary from VDUs to handheld equipment, from signals to paper and from CCTV to hard wired controls. The stakeholders themselves include signallers and controllers (electrical and traffic); drivers; station and on-train staff; planners, engineers and managers; track (maintenance) workers—mechanical and electrical, lookouts and safety controllers; passengers and the general public (the latter legitimate—e.g. at level crossings, and illegitimate—suicides and trespassers).

Although the leading international scientific journals are yet to reflect this, there has been a real renaissance in rail human factors research in the past 3 or 4 years. Some critical human factor issues to do with the railways have been the subject of continual (or at least semi-continuous) research down the years, whereas other areas have only been researched relatively recently. In this section we provide a flavour of the published research on some major rail themes, concentrating generally on that carried out and published within the last 10 years or so (as indicated already, the annual *RSSB Human Factors Research Catalogue* has collected together a part of the early literature).

The most recent overview of rail human factors research and practice has been provided by the First European Conference on Rail Human Factors, held in York, UK in October 2003. Over 50 papers covered a wide range of topics, and open discussion at the meeting revealed much else going on. One difficulty is that much good research has until recently either been commercially confidential or else carried out by consultancies with less vested interest in (scientific journal) publications. To rectify this, papers given at the conference have been published in book form (Wilson et al. 2005a) and selections of papers from the conference are appearing in extended form in this special issue of *Cognition, Technology and Work* and also one of *Applied Ergonomics*.

There is a broad and relatively well-researched area embracing train driver vigilance and perception, their recognition and acting upon signs and signals. This includes also investigations into SPADs and the appropriate design of signage and signalling systems. Of all rail human factors topics these probably have been the most studied over many years (e.g. Branton 1979, 1993a; Buck 1963; Collis and Schmid 2001; Embrey and Wright 1999; McDonald and Hoffman 1991; van der Flier and Schoonman 1988; Wilde and Stinson 1983), perhaps because of the connection with the strong research programmes covering the same topics related to car driving. More recently, we have certainly seen more sophisticated examinations of SPADs (e.g. Pasquini et al. 2004; Turner et al. 2003), and tools to identify the risk of SPADs at different signals (Holywell 2005; Lowe and Turner 2005). Related to this is research into the use of vigilance devices and reminder appliances (e.g. McLeod et al. 2005; Whitlock et al. 2005). Modern observation techniques such as eye movements and direction of gaze allow interpretation of drivers' behaviour and reasons for it (e.g. Itoh et al. 2001b; Merat et al. 2002). One use of eye tracking is as another way to investigate the onset, manifestation and consequences of fatigue (e.g. dwell or fixation times will become longer as people get fatigued). Research related to fatigue has also examined the effects of work rosters (Howarth and Tepas 2001), used observation and self-report to study the effects of long (6+ h) journey times (Gouin et al. 2001), used simulator studies (e.g. Roach et al. 2001—who also studied the related effects of alcohol consumption) and developed checklist tools such as the Fatigue Index (Cotterill and Jones 2005).

There have also been systematic attempts to understand and model the driver's activities in detecting, recognising and acting on signals and signs, and consequently to provide a rational basis for positioning of lineside information (Hamilton and Clarke 2005; Li et al. 2005). In designing those signs, much might be learned from experience with road signs (see Castro and Horberry 2004). Thinking about design there have been many recent efforts to improve design of train cabs (e.g. Grabarek 2002; Mack et al. 2004; Steinicke and Meissner 2003) and of the information interfaces within them (e.g. Gerbino and Strano 2002). A further contemporary development has been the transfer of human reliability frameworks and methods to identify potential for error in the train driving domain (e.g. Holywell 2005; Kecklund 2002; Vanderhaegen 2001). A critical part of reducing potential for driver error and of increasing their effective (on-time) performance lies in the design of their jobs and job aids, and understanding and optimising—neither too high nor too low—their workload (e.g. Kecklund et al. 2003; Torsi et al. 2003). At a top level above all this, current research is addressing the fundamental elements of the train driver's role and performance (Farrington-Darby et al. 2005a; Jansson et al. 2005; McLeod et al. 2005b).

From the point of view of signalling and control, interest (at least as reflected in published work) was probably less in the 1960 s to 1980 s than it was for driving, but there have been a number of different contributions since (Collis and Schmid 2001; Cordiner et al. 2001; Fay and Schnieder 1998; Lenior 1993; Luff and Heath 2001; McDonald 2001; Nichols et al. 2001; Olsson et al. 1996; Reid et al. 2000; Vanderhaegen and Telle 1998; Wilson et al. 2001). A good deal of this research has dealt with the mental workload of signallers, most recently by Pickup and colleagues (e.g. Pickup et al. 2005a, b, c; Mitchell et al. 2005; Morrisroe 2005; Wilson et al. 2005b). There are also contributions to do with information interfaces (Jorna et al. 2005; Kauppi et al. 2005), team-working and situation awareness (e.g. Bristol 2004; Dobson et al. 2001; Heath et al. 2002) and expertise and competences (Farrington-Darby et al. 2006 (in press); Skjerve et al. 2002). (Note that those involved in controlling the movement of trains are called variously in different countries controllers, signallers, planners and dispatchers.)

Another relatively neglected area of rail human factors, at least until recently, has been inspection, maintenance and renewals. The contracting out (and sub-contracting and sub-sub-contracting) of this in the UK, and the accidents at Hatfield and Potters Bar, turn a spotlight onto the area and there has been a renewal of research with a variety of approaches and methods being used (see Itoh et al. 2003). Examples are assessment of maintenance communication errors (Gibson et al. 2005), track workers' safety culture (e.g. Farrington-Darby et al. 2005b; Itoh et al. 2001a—see also Clarke 1998 on rail safety culture), attitudes to work (and their relation to accident rates—Itoh et al. 2004), and use of modern and personalised IT to support maintenance work (e.g. Rich et al. 2002; Sheridan et al. 2001).

Because of the recent great public, media and government concern over rail accidents and safety, we are seeing this application domain provide a focus for advances in human factors to do with reporting systems (e.g. Wilsdon and Muir 2005; Wallace et al. 2003; van der Schaaf and Wright 2005; Wright and van der Schaaf 2005) as well as in greater understanding of violations (Lawton 1998) and safety culture both within organisations and also across national or company boundaries (e.g. Johnsen et al. 2005).

When we move away from rail staff and look at other stakeholders, a reasonably long-standing and continuing theme of rail human factors research has been in ride quality and passenger comfort (e.g. Branton 1993b; Forstberg 1997, 2000; Forstberg et al. 1998; Suzuki et al. 1999; Suzuki and Shiroto 2002; van der Weide 1999). Support for passengers also comes through the interfaces to the information and ticketing systems with which they are provided (Davis and Mills 2005; Garnerin 2001; Lamel et al. 2002; Thimbley et al. 2002), and with designing for their movement around stations and in boarding and alighting trains (Morlok et al. 2004). In less positive circumstances, there is also a need to understand how people behave in emergencies and how to best help them evacuate carriages when necessary and to support their rescuers (e.g. Boer 2005; Dicke et al. 2003; Zarboutis and Marmaras 2004), and to design carriages to reduce the chance of injury (Ilkjaer and Lind 2001). Even more removed from the proper functioning of the railway, it is a sad fact that for some in society their contact with the railway is through trespass, vandalism and suicide (which added together comprise by far the greatest cause of deaths on the railway)—see Lobb et al. (2001). This is much related to a current area of great concern and human factors attention, where the public and the railways interface at level crossings (see Cairney 2003; Henderson et al. 2003; Rahimi and Meshkati 2001; Wigglesworth 2001).

As indicated earlier in the paper, a number of new technical systems are in proposal, feasibility testing or pilot implementation phases, for example, all the systems to do with ERTMS, and this will mean radical changes in the work and roles of rail staff. Human factors contributions to the debate and, hopefully, to systems design and implementation are appearing (e.g. Foulkes et al. 2004) and a particular key contribution will be in migration and parallel running with old and new systems (e.g. Rookmaaker et al. 2005; Zwartenkot et al. 2002). More generally, we are seeing considerable debate about how to integrate useful components of automation (for instance, in decision support) with human skills on the railways to provide more reliable and effective total systems (e.g. Collis and Robins 2001; Dufresne 2001).

At a level in the railway system above signalling and control, human factors is also now beginning to study and understand the work of planners, for instance, in timetabling, organisation of possessions (of the track, for maintenance) and for emergency handling (e.g. Rosmuller and Beroggi 2004; Slamen et al. 2004). In order to do this we also need systems level models including those of distributed cognition) of the whole rail system and human–human and human–artefact interactions and representations (e.g. Hale et al. 2003; Lepreux et al. 2003). Guidelines and standards will be needed increasingly to be appropriate to rail application and to guide those planning and engineering the networks of tomorrow (see Slamen and Coleman 2005; Wood 2005). Very related to this overall systems ergonomics approach, rail human factors have also further developed the notion and practice of human factors integration in systems development. The advances here are often hidden in commercial project documentation, but see Bourne and Carey (2001); Davis (2001); Pledger et al. (2005) and Wilson and Morrisroe (2005).

## 4 Current major rail human factors programmes

We have seen the base for rail human factors research and application; now what is the situation today? We briefly describe here some current relevant programmes of work.

In the UK, both Network Rail and the Rail Safety and Standards Board (RSSB) have initiated large programmes of ergonomics/human factors research, admittedly more with consultancies than universities but with fundamental contributions nevertheless. The topics for these research programmes reflect the fact that both organisations have multiple remits to deliver. For instance, the Ergonomics National Specialist Team in Network Rail must create a foundation for ergonomics/human factors through small wins, providing key advice or research evidence to projects. Then they want to spread human factors via generation of new research deliverables and production of guidelines and standards. Once this process is more mature they want to embed human factors within the organisation and the industry network, through involvement in inquiries and working parties and through the collected evidence of the small wins and use by key engineering and operations staff of the research and guidelines (see also Kirwan 2000; Wilson 1994). The team also attend or support various inquiries, and sit on many working parties from operations and engineering, obtaining an influence for ergonomics which is keyed into the fabric of the company.

For Network Rail, with its focus as a commercial group which controls the rail infrastructure, ergonomics priorities over the past couple of years and into the present include:

- Establishing an acceptable and deliverable policy and strategic plan for ergonomics in the company
- Producing advice, guidelines and standards to support the work of the engineering, operations and safety groups
- Providing better systems for signal and signage siting and sighting
- Understanding and improving signaller mental workload and situation awareness
- Establishing causes of irregular working
- Implementing human-centred interface design and workplace layouts in signalling facilities
- Understanding and optimising competences, experience and expertise in signalling and control
- Improving the use of CCTV at station forecourts, platforms and level crossings
- Assessing the effects of new communication systems such as Global System for Mobile Communications—Railways (GSM-R)
- Developing new tools for human error identification in signalling and maintenance
- Improving collocated and distributed team working
- Evaluating the systems of inspection by patrol and automation
- Improving planning and management of possessions
- Enhancing the reliability and effective performance in track maintenance
- Examining and supporting passenger behaviour at stations and on the train
- Improving safe behaviour at level crossings

RSSB Human Factors Group on the other hand is primarily (although not solely) charged with a safety agenda, and for the whole industry not for any one part of it. The group acts as a resource of human factors knowledge throughout the industry, either identifying relevant knowledge from existing sources or carrying out and funding new industry-relevant research when desirable. They provide input into formal inquiries and into the development of Group Standards. As part of their knowledge dissemination role they produce a very useful annual catalogue of rail human factors research, which contains details of studies over a number of years, some in the grey literature and harder to find (e.g. RSSB 2004).

For RSSB, with its industry wide focus on safety and related human factors, recent and current priorities include:

- Impact of new control and communications systems on train driving
- Studies of train driver attention and driver eye movements
- Effects of fatigue and shift patterns, and related management programmes
- Alarms, alerts and warnings generally, and especially use of reminder appliances in cabs
- Understanding driver route knowledge and driver experience, and the future role of the train driver
- Assessing driver mental workload
- Establishing driving error data
- Train cab design and environment
- Use of level crossings
- Rail worker competences
- Vehicle maintenance
- Station design for support of passengers and staff
- Safety culture across the railways
- Integration of human factors into the standards programme
- Best use and design of procedures, and re-design of the rule book

Recently, as a part of the resurgence of interest in rail research, the Engineering and Physical Sciences Research Council (EPSRC) network of several UK universities has been launched as Rail Research UK (www.railresearchuk.org.uk). Although the network is dominated by engineering concerns, there is a distinct human factors component organised by Universities of Nottingham and Sheffield. A particular programme of research within this is to produce models of the distributed and collaborative performance of controllers, signallers and drivers. In future work there will be strong integration of the engineering and human factors perspectives in a socio-technical systems approach.

Across Europe, too, there are increasingly strong ergonomics/human factors contributions to the railways. Publicly funded rail research programmes in France, Sweden and the UK explicitly identify human factors, those in The Netherlands, Germany, Portugal and Spain emphasise safety in many forms, and in Austria and Finland a human factors perspective is implicit (ERRAC 2004). Current major European Framework research projects funded by the European Commission (with some contribution by industry) which have ergonomics components include MODTRAIN (Innovative Modular Vehicle Concepts for an Integrated European Railway System—www.modtrain.com), UGTMS (Urban Guided Transport Management System—http://ugtms.jrc.cec.int) and MODUrban (Modular Urban Guided Rail System—www.modurban.org). With a very wide span there is the relatively new European Network of Excellence (EURNEX—www.eurnex.net), with approaching 100 institutions as members. EURNEX has various 'poles of excellence' to pick up and integrate at a European level on key themes, and Pole 9 is Human Factors.

## 5 Future rail human factors research and transfer of human factors knowledge

As we have seen in this paper, we are at something of a cusp in rail human factors—in its research and its application. After something of a barren period there has been a rapid growth in initiatives in the industry, with many of the businesses involved recognising the vital role of human factors in the way they run their business. People are central, both because a large part of the rail business is to move people from place to place in an effective and affordable manner, thus meeting some of the goals of any society, but also because the reliable, safe, high quality and efficient railway of the future will depend upon the workforce together with the artefacts and systems that they use. This means that there are great opportunities for ergonomics in several areas of support, but chiefly in research to generate new knowledge, develop and transfer standards, guidance and analysis/assessment tools, and establish processes to integrate human factors within the total rail systems life cycle.

New knowledge is still needed, to support systems design, implementation, operation and management, and this will require substantial research programmes. Whilst there is some room for good quality laboratory research it is our contention that the principal need is for good quality, supportable and transferable field research, backed up by high quality simulations, for instance, for train driving or signalling. Of course, there are a number of human factors issues investigated over the years that still require research contribution: computer interfaces for signallers, controllers and technicians; information displays in the train cab and lineside; effects of fatigue and shift rosters on performance; engineering plant and road/rail vehicles for maintenance; track inspection systems. But there is a particular requirement for human factors to understand groups of people interacting with multiple interfaces and performing multiple tasks, and especially when these groups are distributed over space, time and function. Every passenger journey involves stakeholders from the general public cooperating with station staff in purchasing a ticket and finding out where the train(s) is(are), with fellow passengers in boarding, finding a seat and completing their journey, and with the operators of other transport systems in arriving or departing the stations. Every train movement involves planners setting routes and the timetable, drivers reacting appropriately to a route set by signallers, controllers and signallers establishing alternative plans if there are perturbations, business managers agreeing responsibilities where there are problems. Every maintenance job involves a gang of track workers cooperating together, coordinated by the person in charge of possession (PICOP), engineering supervisor and controllers of site safety (COSSs), and liaising with signallers and train drivers (engineering, passenger, freight).

In addition there is a need for a practical human factors support effort, in particular to ensure that all of the human factors integration plans and sets of guidelines and standards actually support rather than stifle the human-centred successful operation of the railways. Also, we need to ensure that the ergonomics processes and methods are in place to assist designers, engineers and operators in human-centred systems development and management.

The future rail human factors research programme—not only in the UK from the direct knowledge of the authors but also in the Netherlands, Italy, Germany, Australia, Sweden and many other countries where the authors have colleagues—looks very exciting. People are still at the heart of the railway—engineering it, operating it, maintaining it and being transported by it. There are enough total systems issues to be investigated in today's railway never mind those for the new systems of tomorrow. A major requirement for the future is to understand how best to integrate the skills of the rail workforce with new technical systems at various levels of automation and with new organisational systems including those to do with inter-operability. Understanding the skills and expertise of key workers becomes even more critical with the implementation of new rail management systems, which may range from partial levels of automation (for instance, the existing automatic route setting for signallers, or automatic warning systems for train drivers) through to various forms of intelligent decision support system and new communications networks. The advent of ERTMS in many European railways, with its European Train Control System (ETCS) and GSM-R may have much support because of the anticipated benefits of increases in capacity and safety, but they will radically change the way the networks operate and the work of rail staff (Traverso 2000; UIC 1998). The aim of ergonomics arguably should to define the technical and organisational systems which will best allow hybrid control, whereby safe, efficient and reliable network control is achieved through well-designed collaborative partnerships between human operators and various types and levels of automated system, and at the same time to help with migration to new work systems and with the parallel running with older systems that will take place for many years yet. Ideally, as in many domains, the technology will provide decision and communications support in a systems design that makes available the abilities of the people to interpret, prioritise, intervene and optimise.

An interesting systemic outcome of the increasingly large human factors rail agenda and research programme may be advances in general ergonomics/human factors theory and methodology. Real problems in particular domains have long driven (partially if not wholly) advances in the theory, models and methods of the human factors discipline: for example, user trials in consumer ergonomics (long pre-dating user tests in human–computer interface); vigilance in naval studies; fatigue, attention and signage in road driving; human reliability in the nuclear industry; mental workload, situation awareness and cognitive ergonomics generally in aviation; and cognitive models in human–computer interface. All these domains had real user needs and reasonable funding programmes, as well as interesting problems for human factors specialists to address.

The railways throw up just about every type of human factors concern and therefore research approach. One of the authors recently attended, within the space of half a day, meetings about signalmen's injury potential in pulling levers, use of analytical models in understanding driver behaviour at signs and signals, virtual teamwork in signalling and control, and the impact of organisational interfaces on reliable and efficient planning of maintenance. All branches of ergonomics—physical/biomechanical, cognitive and social/organisational—are therefore of great relevance.

One problem faced by ergonomics/human factors is the transferability of its approaches and knowledge. This is often alluded to in the transfer of design guidance. A good example is in human–computer interface design where it is all too easy to end up with guidelines that are too general or too specific as we try to transfer them between system designs. A more global issue is transfer across domains, cultures and setting; how well will models and methods from cockpit ergonomics or nuclear human factors transfer into, for instance, manufacturing industry or non-aviation transport? Given a desire to minimise any reinvention of wheels, how well does knowledge of safety culture, working to procedures, notions of expertise, understanding situation awareness and measuring workload (and countless other examples) transfer to the railways?

We believe that rail human factors has much to tell us about the transfer of ergonomics models and methods from the domains of aerospace and continuous process control (especially nuclear power plants) into the more grounded home of heavier industry and transport, manufacturing and construction. What much of the current rail human factors research has in common is that models or methods that have been in the ergonomics/human factors community for some years are being re-examined and made more relevant to use on the railway as well as hopefully improved for general use. Also, methods from other disciplines, especially anthropology/ethnography, sociology and engineering, are being adapted for rail human factors use especially where there is emphasis on field study.

At the same time there should be transfer in the other direction. All this concentrated research effort by many different groups in one application domain should provide advances in our fundamental knowledge. Already we are seeing adaptation and development of: human error identification and human error probability systems and tools; train driver cognitive and performance models; a suite of workload tools with underpinning justification; control room ergonomics audit tools; qualitative methods to investigate safety culture and deeper influences on performance, understanding of the development and role of experience; a set of electronic ergonomics analysis tools; and models to understand joint cognitive systems and distributed complex socio-technical systems.

All the recent investment in rail ergonomics/human factors research must have practical benefits of course. The bodies financing it want to see advice, recommendations, guidelines and standards emerge that can have a demonstrable effect on the efficiency, effectiveness, reliability, quality and safety of the railways. Such outcomes can be used in different ways by different rail industry stakeholders.

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