Rail Research UK

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Human Factors in Railway Systems: Implications for Safety

Prepared for The Railway Safety and Standards Board

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Summary

The report takes the form of an overview and appraisal of recent Human Factors (HF) research carried out on rail systems, focusing on selected key areas; e.g.; network control, communications, fatigue, signalling (SPADs). The aim is to consider this work from a whole systems perspective which forms the theoretical basis for the proposed RRUK projects B2 and B3, and to highlight the safety implications of the projects (a summary of the safety implications can be found in section 7). The report argues that neither the industry nor the Human Factors field has been advanced much by the piecemeal and ad-hoc way in which safety problems have been approached, and by the failure to develop a systematic strategy for research. This report considers what HF work has told us so far about these specific areas of rail operations, and how the proposed RRUK work will advance upon this. While the main emphasis of the proposed work will be on how an integrated approach to rail HF can be used to improve efficiency and reliability in the rail network, safety considerations are also highlighted. Finally, the paper considers what lessons can be learnt from other industries (e.g., aviation, process control) where more sophisticated whole systems approaches have been developed.

Contents

Introduction

This report outlines the findings from start-up work funded by the RSSB in preparation for two Human Factors (HF) projects supported by EPSRC under the RRUK programme. The two projects, both carried out in collaboration with Prof J. Wilson at Nottingham, are summarised below.

1.1 Whole systems performance

Project B2 is a 1-yr scoping study with the following goals:

- To assess the state of current human factors knowledge relevant to the railway network, and to identify gaps in this knowledge
- To assess current human factors integration plans and human factors integration standards in the railway industry and other related domains
- To make recommendations for improved human factors integration, and for human factors integration plans and standards.
- To prioritise and structure human factors research priorities for the railway network of the future.

Project B3 is a 3-yr programme with the following goals:

- To investigate the fundamental human factors issues underlying the effective, reliable and safe use of knowledge and skill in rail operations
- To carry out field, laboratory and simulator research that will provide a basis for a better understanding of interactions between key functions (e.g., driver, signaller, planner, maintainer).
- To develop a distributed cognitive model of rail operations that can be used to plan future design and implementation of technical and organisational developments in integrated train operations

The report for RSSB will aim to meet two objectives:

1) To provide a broad overview of the current status of HF research in selected areas relevant to the two HF projects; network control, fatigue, signalling (including work on SPADs), and driver-signaller communication
2) To illustrate the safety implications of the planned research and anticipated outcomes of the HF projects.

While the main emphasis is on research conducted on the UK rail system, HF research into foreign rail systems (such as US, Northern European, Japanese) is included in order to illustrate how this work can inform research within the UK. The findings are appraised from a systems perspective with comparisons made to other industries that have developed such an approach (e.g., aviation, process control). In doing so the report hopes to highlight the need for, and benefits accruing from, an integrated systems approach to railway research in the UK. For the sake of clarity only a few specific studies are referred to in this report, to serve as a focus for the main research issues. A full review of relevant rail systems research will be included as a deliverable under Project B2.

1.2 Research base background

Over the past twenty years there has been a considerable amount of research into human factors on the railway system (see [1]). However, there are still large gaps in our fundamental understanding and recognition by Cullen and others of an urgent need to address issues concerned with the way humans interact with technical and organisational aspects of rail systems [2]. The position taken in this report is that the reason for the lack of progress in railway Human Factors (HF) is the often piecemeal approach that has been applied to research in this area. Such work has tended to address short term problems in the network rather than creating a sound theoretical base allowing generalisation to new problems. A preliminary remedy is to systematise previous research to create a framework within which future HF work can be integrated more easily into the development of new rail systems. In doing so it is envisaged that the integration of HF into the development of railways in the UK will lead to improvements not only in reliability, quality of service and efficiency (the main targets for the RRUK programme), but also, and inevitably, safety.

1.3 Human Factors in network control within the UK

At present the traffic across the UK rail network is controlled at a number of different levels. The various functions in network control include; zone control, electrical control and signalling. The role of each of these functions can vary considerably across the rail network; for example the work of a signaller will vary dependant on the size of the area under control, the degree of integration with zone control and the type of electronic signalling display equipment used (VDU or NX). Quite apart from the variations in work across each of the functions, signallers, zone control and electrical control have very different work cultures. These differences in function and culture present obvious challenges for HF research. For example, is the effectiveness of communication between the functions hampered by differences in the terminology they use? While it is rare for zone control to take direct control of individual trains, Projects B2 & B3 will consider how the action taken at the level of zone control affects the action of signallers and subsequently the train driver.

In the UK little work has considered the human factors issues within network control. A notable exception is Wilson and his colleagues [3,4] who carried out a systematic programme of research in response to proposals to modernise network control, initially on the West Coast Main Line. The aim of the work was to develop an assessment package that would provide a systematic framework within which to assess current HF issues within the rail network and provide feedback to the development of future technical and organisational structures. Their Railway Ergonomics Control Assessment Package (RECAP) includes various audit tools such as the railway ergonomics questionnaire (REQUEST), railway ergonomics workload and staff loading (RELOAD) and railway ergonomics situation awareness (RESA). These consist mainly of measures that have either been borrowed from other industries where such integrated audit tools for process control already exist, or bespoke measures developed specifically for the project. The use of such an assessment tool within the RRUK projects B2/3 provides a systematic framework within which to evaluate the effects of the proposed work.

1.4 Network Control outside the UK

Although there has been a dearth of theoretically based HF work on UK network control, it is possible to draw valuable lessons from research conducted outside the UK. Lenior [5] found that Dutch dispatchers (signallers) tend not to plan ahead because of both the complexity of the network and the possibility of change. As a result their actions were mainly reactive rather than proactive, leading to a loss of the enhanced effectiveness normally possible when decision making involves a feed-forward (planning) element. This also highlights the problem of managing information flow within the network, and the "open" nature of network control in terms uncertainty over the outcome of actions. For example, can we reduce a dispatcher's uncertainty over whether a train really did depart after giving the departure signal? Due to this uncertainty, Dutch dispatchers utilised more channels of communication (such as verbal messages from other signallers) than was strictly necessary, leading to inefficiency and delay. Given the complexity of the UK rail network it is highly likely that similar problems would be observed in UK signallers.

In contrast, Roth et al. [6] observed that US dispatchers *did* plan ahead. One possible reason for this difference could be the use of open channel radio communications between dispatchers, drivers, station masters and engineers. Having such a radio system allows redundancy of information and enables dispatchers/signallers to selectively attend to information pertaining to their sections. It is highly likely that use of an open channel radio system enables US dispatchers to develop a higher level of situation awareness across the network than their counterparts in the UK or The Netherlands. Their increased understanding of system wide activities should allow them to respond more quickly and appropriately in the event of emergencies. The disadvantages of such a an open channel radio system were not discussed by Roth et al, but one major concern is that dispatchers could respond to the wrong information or give authorisation to pass a signal at danger to the wrong train. While such problems might be mitigated by adherence to strict radio communication protocols, further research is needed to understand the potential benefits of such an open channel system in the UK. Project B3 will develop a distributed cognitive model of rail operations to allow a greater understanding of how information flows between the various functions of the rail network. From this model it should be possible to gain an understanding of the potential impact of an “open” radio system on efficient operations and safety.

Communications

1.5 General problems in communication

While there are many forms of communication that take place within a railway system the work reviewed here is limited to communication between drivers, signallers and trackside workers. Potential problems and misunderstandings in communication can arise when two people who are separated by location (driver/signaller) are trying to talk to each other. The problem generally revolves around a misunderstanding of the intended meaning of the communication.

Gibson [7] reviewed the literature on communications in general although incorrectly assumed there was no previous work directly relevant to the rail industry (see report by Arthur D. Little Ltd. [8]). However, there is a general need to investigate a wide variety of communication processes within the UK rail industry (at present the focus has been SPADs). Gibson identified three sources of communication failure, associated with the sender, language used, and hardware. Only the first two of these lie clearly within the HF domain, and are relevant within a number of situations where railway personnel have to communicate with each other over the radio or telephone. These include driver-signaller communication and signaller-PICOP (Person in Charge Of Possession) or more recently signaller-COSS (Controller of Site Safety).

1.6 Driver – signaller communication

Arthur D. Little Ltd. [8] was commissioned to investigate communication risk between drivers and signallers. Unlike US systems highlighted above, in the UK drivers and signallers only communicate with each other when the driver has been brought to a halt at a signal failed at danger, or in an emergency. Three generic errors were identified in the scenario where a train has been stopped at a signal at danger, all encompassed by Gibson's framework: the driver mistakenly believes they have been authorised to pass a signal at danger; the signaller correctly authorises the wrong train; the signaller incorrectly authorises the correct train.

The impact of the first and third of these errors is potentially catastrophic. While the report by Arthur D. Little concluded that the current procedures were sufficient to ensure safe operation at minimal risk, the potential for error (and hence potential catastrophe) still exists. Project B3 will seek to gain a better understanding of the mechanisms of communication between drivers and signallers, where potential for error lies and the possible causes of deviation from correct procedure (e.g., fatigue, distraction). New technology (e.g., in-cab displays) will inevitably impinge upon the driver-signaller dynamic and Project B2 will attempt to assess how best to integrate this technology into the rail network from a HF perspective. Project B3 will potentially appraise these types of interventions in driver-signaller communication from a theoretical standpoint allowing an assessment of the potential benefits and costs to efficiency and safety.

1.7 Signaller – PICOPs/COSS

PICOPs, or more recently COSS, take possession of a block of track when maintenance work is required. This requires coordination between the signaller and COSS in order to ensure the safety of the trackside workers. Halliday [9] highlighted the problem that, at present, the procedures followed for the transference of information are informal and ad-hoc. To ensure safety, this needs to be structured and involve the use of correct radio discipline (such as using the phonetic alphabet) in order to minimise potential errors in communication such as those formulated by Gibson [7]. One of the aims of the proposed work is to gain a deeper understanding of how different functions within the rail system interact and how these interactions are influenced by the organisational context within which they take place. Improvements in communication between signaller and COSS (and hence the safety of trackside workers) may require alternative interventions that go beyond simply adhering to radio discipline.

As mentioned above, Roth et al. [6] highlighted the advantages of shared or “open” radio communication channels where all rail personnel can listen in and selectively attend to relevant information. In the US rail network, VHF radios use “open channels” to allow monitoring of background information keeping personnel up to date with what is happening across the system. Hence they can respond quickly and appropriately in emergencies.

It is not clear whether the US rail industry actively designed their communications systems in this way, or whether they just evolved. However, they exemplify the operation of a “whole systems” approach, as opposed to the isolation effect on different components that results from current UK Rail communication systems. As mentioned previously, situation awareness is likely to be greatly enhanced by the use of an open communication system. However, there may also be disadvantages for the UK (see section 2.2). Further research is needed to clarify these issues before any recommendation that such an “open” system be introduced in the UK rail system. It is envisaged that the proposed work will fulfil this need.

Impact of Fatigue on Driver Performance and Safety

1.8 Detecting fatigue states in drivers

Research on fatigue, within the railways as elsewhere, fails to distinguish the general behavioural outcome (tiredness) and the possible causes of the state. In particular, fatigue is often ascribed to sleepiness brought about by sleep deprivation or poor management of shift cycles, and the problem for performance typically identified with the increased risk of eye closure or actual sleep. It is important to recognise that mental fatigue can result entirely from overwork, in the form of sustained cognitive operations, even with normal sleep and well-adjusted shift cycles. Hockey & Meijman [10] have identified at least three different forms of fatigue – mental, sleep-based and physical, which have quite different origins requiring different management solutions and countermeasures. We have, so far, considered at least some of the issues relating to sleep loss and shiftworking, both of which can cause dramatic losses of attention, but largely ignored the problem of fatigue from sustained demanding cognitive work. These other effects are more subtle, and their effects therefore more insidious. They affect information processing strategies by reducing the operator's commitment to high effort attention states.

Within rail systems research, the notion of the train driver as an information processor (rather than someone engaging in heavy physical work) was introduced over 30 years ago [11]. Grant's suggestions for research on mental fatigue include simultaneous capture of behavioural observations and physiological measures. This is the approach taken in major recent programmes aimed at identifying markers of strain as a basis for predicting performance breakdown in aviation (e.g., [12]), and recognise that risk is related to a progressive effect of the onset of fatigue. However, over the intervening period since Grant's report, little or no work has been conducted using this methodology. Instead the main emphasis has been on inferring causal patterns from accident data and shift work patterns. This is still a viable approach, but an analysis of fatigue requires much better predictors than can be gained from overt performance measures alone. The use of failsafe devices (such as ATP or TPWS for SPADs) is an extreme technical response to failure of the driver's concentration, bringing the system to a halt and necessitating considerable disruption, as well as reducing confidence in the driver. Although such systems are necessary as a last resort, it would be better if we could detect states of increased risk at a less critical stage (before eyelid closure or complete loss of attention), reducing the risk of unnecessary deployment. One of the approaches of the B3 project will be to develop psychophysiological methods for detecting high risk strain states, and using derived indicators to alert and inform drivers so that they can regain an effective state. It will also explore non-intrusive ways of implementing physiological monitoring in cabs.

1.9 Impact of shift work on fatigue

Shift work is identified as a major contributory factor to fatigue as the internal body clock fails to adjust to shift work and leads to an accumulation of sleep loss due to working shifts. A number of the major findings from examining shift work patterns and their subsequent impact on fatigue are reported by Folkard & Sutton [13]. During nightshifts one of the major findings is of reduced alertness and performance due to the internal body clock gearing up for sleep rather than work. The literature also suggests that night-shift workers lack sleep during the day prior to first night shift and that successive night shifts lead to cumulative sleep deficit. In order to overcome the effects of night shifts workers require at least 2 days rest and should avoid an early shift on their return to work. Taking a nap of up to 1 hr has been shown to reduce fatigue on night shift.

During the early shift there is a tendency for reduced sleep duration because early bedtimes are made difficult by the “forbidden zone” effect and social pressure. The fear of not waking up in time can also lead to waking up earlier than planned, reducing the duration of sleep. Possible long commuting times to and from work (especially in London) can exacerbate these effects and lead to even less sleep. On afternoon shifts the “post-lunch dip” reduces levels of alertness, though this is related more to endogenous effects of the internal body clock than lunch per se.

The duration of shifts is also seen as an important contributory factor to the level of fatigue. However, there is no strong evidence that 12 hour shifts are any worse in terms of inducing fatigue that an 8 hour shift, except when these shifts disrupt the sleep/wake rhythm at either end of the working day. Many workers and managers have a preference for 12 hour shifts, and while there is contradictory evidence about optimum shift length, evidence suggests that the greatest decrement on performance occurs between the 2nd and 4th hour into the shift with no subsequent degradation up to the 12th hour of the shift. However, overt performance measures used to detect the decrement in performance (such as rate of SPAD) are poor at picking up underlying fatigue that can occur within much shorter periods.

In order to recover from the effects of shift work the main consensus of opinion is that the recovery period should allow sufficient time to recover from accumulation of fatigue. The research shows this to be 12 hours before a 14:00 start, 14 hours before a 16:00 start and 16 hours before a 19:00 start. The planning of shift patterns should restrict the number of night shifts to two or three consecutive nights in order to prevent the accumulation of fatigue. However these guidelines suggest that it is acceptable for permanent night workers to work up to six consecutive nights. In order to recover fully from a consecutive night shifts workers should be given 54 hours rest period between end of the last night shift and start of next shift. However, while the review by Folkard and Sutton is extensive it is in contrast with the findings of Wharf [14] who found that while the consensus is that there is a decrement in performance during the night shift, after statistical analysis, the night shift was *not* a significant predictor of SPAD incidents. Furthermore she advocates that drivers selecting to work shifts longer than 9 hours may be “safety positive”. The findings of Folkard and Sutton also contrast with those of Dray, Sutton & Menter [15] who found an increase in SPADs during quiet midday period on the London Underground rather than peak periods. Can this finding be explained by fatigue caused by shift work patterns or are there some other causal factors? These questions as yet remain unanswered and highlight the need to integrate findings from research on fatigue and shift work with other possible causal factors that impinge on performance.

Signal Perception

1.10 General findings from sign perception literature

At present little work has been done on sign detection and perception in the rail industry. The majority of the received wisdom has been lifted from research into road sign detection [16-18]. Rail Safety Standards set the minimum time that a signal must be visible to the driver at 7 s, with 4 s uninterrupted viewing. However a number of factors can reduce these timings – inclement weather, curvature of the track, location of signal in the visual field, proposed increases in speeds on certain mainlines, etc. Merat et al. [19] found that the aspect of the previous signal influences how drivers organise their visual attention for upcoming signals. This adds further empirical evidence to the suggestion that drivers anticipate signal aspects based on route knowledge and the aspect of the previous signal.

Wright & Embrey [20] outline a three stage model of sign information processing that includes; detection (of sign), decision and response. Factors that can impact on this may be external to the driver as those mentioned above, or they may be driver related such as “attention focus”. While the impact of external factors may be well understood, from a HF perspective what is less clear are the driver related factors that can lead to signal perception errors. Buck [21] defines the type of errors that may occur in perceiving railway signs. While Buck suggests potential causes for these errors they do not go beyond the capacity of the driver to consider potential external factors leading to perceptual error.

1.11 SPADS

The majority of outcomes of such errors are SPAD incidents (Signal Passed at Danger) where the train passes a signal when the signal displays a stop aspect. This is one of the major causes of accidents on the UK railways. In reviewing UK railway accident data, Andersen [22] found that between 1970 and 1997, 30% of accidents were due to SPADs. While SPADs are seen as an important issue in terms of rail safety due to the catastrophic potential outcome, there is still no clear systematic picture as to what the root causes of SPADs are or what effective measure may be taken to eliminate them. Given the delay in implementing ATP, understanding SPADs within a systematic framework is urgently required.

In an attempt to systematise the investigation of SPAD incidents Wright & Embrey [20] present a Model for Assessing and Reducing SPADs (MARS). Within each of the three stages of signal information processing (detection, decision, response) they produce influence diagrams that link the causal factors in a hierarchical manner to represent their effects on the likelihood of failure of that stage of processing. What is important in their approach is that multiple causes are considered at the outset and that potential root causes go beyond the driver to consider wider scale organisational factors such as training or safety briefings etc. This is one of the few pieces of work on SPADs that considers these incidents in terms of a systems perspective although the authors do not allude to their work in such terms.

1.11.1 Pattern of SPAD incidents

A number of studies have looked at incident data in order to understand when SPADs are likely to occur and which drivers are most at risk of committing a SPAD. For example, Dray et al. [15] looked at SPAD incident data on the London Underground. Their findings are similar to those that have looked at the influence of shift patterns on driver error but also show that young drivers are more likely to commit a SPAD but that experience dominates over age in being a significant predictor of SPAD. The most common cause of SPAD incidents is disregard, followed by misjudgement, misread, and miscommunication/ technical failure (see [15] for further details).

The rate of SPAD incidents fell between July 1999 and June 2000 [23]. To try to understand why this was, Robinson and Sutton distributed a questionnaire to train drivers across the UK rail network. They found that three quarters of train drivers had a personal reaction to the incident at Ladbroke Grove and were concerned that such an incident might happen to them. However, it was felt that of greater importance in the reduction of SPADs were the new initiatives implemented by management such as defensive driving awareness and modifications to signals that were at high risk of SPAD incidents. Unfortunately, over 70% of drivers felt that the SPAD rate would rise again due to complacency and the impact of Ladbroke Grove wearing off over time. While drivers complain in the study about long shifts and high workload this seems to contradict anecdotal evidence that they find driving monotonous with cognitive underload, as well as preferring long shifts because of the increased time off it gives them. It is clear from the section on fatigue that risk of SPADs is also likely to increase under high workload and sustained mental work. Detecting these early fatigue states using physiological markers will be a part of the proposed RRUK work.

While many studies have analysed incident data and drawn conclusions as to when and where SPAD incidents are more likely, very few have experimentally tested countermeasures to prevent SPAD incidents. Haga [24] conducted a series of studies that investigated a particular form of SPAD that occurred on the Japanese Railway, namely the SPAD incident when leaving a station. They found that presenting a written or auditory signal that directed the driver's attention to the track signal after the "ready to depart signal" significantly reduced the number of SPAD errors in this scenario. It is not clear whether such recommendations have been implemented in Japan. The proposed RRUK work will also develop a sound theoretical rationale for empirically testing potential interventions that increase safety.

Conclusions: Integrated Systems Approaches

The previous sections of this report have focussed on a number of studies that highlight the unsystematic nature of HF research in rail systems. For example, it often provides detailed knowledge about very specific aspects of driver behaviour (e.g., [19]) but little general understanding of how drivers interact with other functions of the rail system. Recent work by Wilson and colleagues [3,4] illustrate the benefits of adopting a systems approach to understanding the relationship between components of the rail network (driver/signaller/controller). Understanding how the various functions within the rail system interact will shed light on how changes in working practices within one function (e.g., signalling) will impact upon the effectiveness and reliability of the overall system.

In the aviation industry, a systems approach to human factors has been recognised as an important way of understanding the development and implementation of new technical solutions. For example, air traffic control can be seen as prototypical of a complex system [25] with various sub-systems that operate within the larger system of air traffic management. The most obvious element of this system is the aircraft itself; others include surveillance systems that allow observation of air traffic beyond direct view of the controller, navigation systems allowing the aircraft to fly without direct visual contact with its destination, and communication systems that enable pilots and controllers to exchange information relevant to goals and make changes required to achieve desired levels of efficiency and safety.

One consideration when adopting such a systems perspective is the level at which to consider the problem. As Sheridan [26] points out while discussing the aviation industry, a system analysis that responds to the complex demands of the aircraft cannot at the same time be ideal for modelling the whole national airspace system. Yet the interdependencies of these (and other) levels need to be recognised, or solutions at one level will be incompatible with problems at another. The proposed RRUK work will be constrained through a focus on the system that incorporates drivers, signallers, controllers, trackside workers and how these functions interact within rail network operations. The key thing is to recognise that these have different problems and solutions, but are, ultimately, part of the same system.

While considering the potential impact of the new centralised control centres on the UK rail network, Wilson et al. [4] recognised that the network controllers work in a system of distributed cognition. Information within such a system will be distributed widely across signallers, controllers, drivers and trackside workers as well as potential in-cab information systems and train operating companies (TOCs). Information regarding the state of the network will flow between all these agents in the systems and will be represented not only externally (in the form of signals, information displays etc) but also internally (in terms of the cognitive processing of the controller/driver/signaller etc). Fig. 1 shows a simplified representation of such a system, highlighting the flow of information

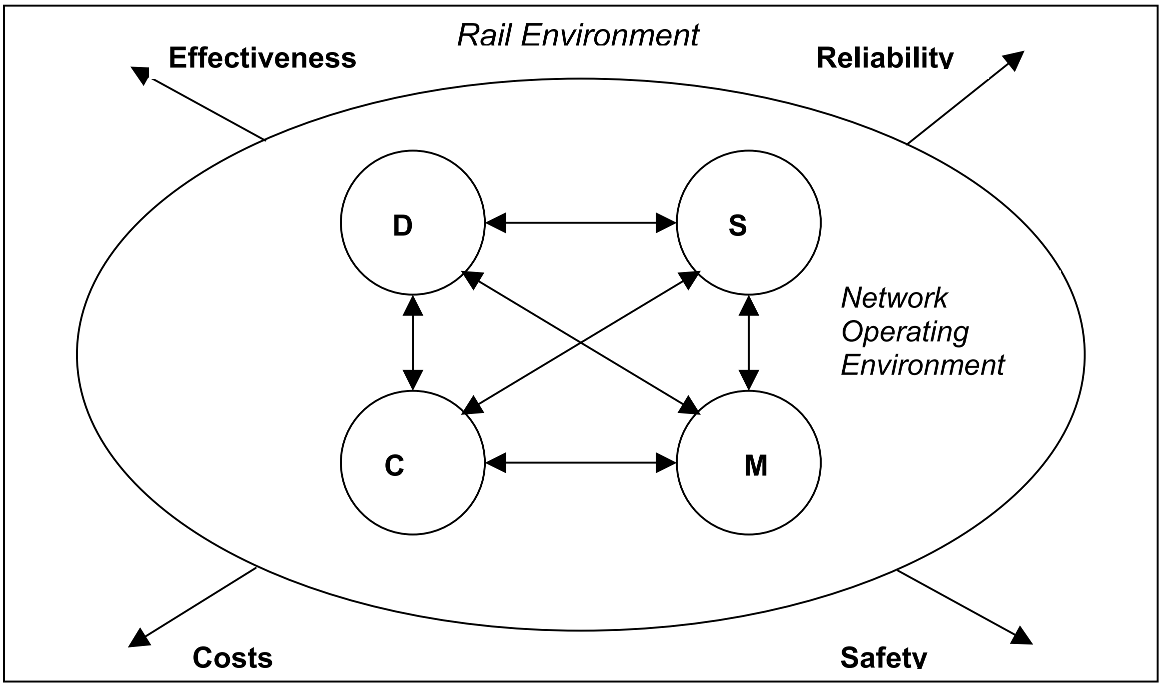

Figure 1: A model of the network operating environment within which drivers (D), signallers (S), controllers (C), and maintenance workers (M) function and the implications of this for the rail network.

between the various functions/elements of the network operating environment and how these interactions bear directly upon the effectiveness, reliability and safety of the broader UK rail environment, as well as the costs (financial, resources, and other) of these oucomes.

Of course, not all the links shown in Fig. 1 are equally important or prominent in practice. The most relevant for the work envisaged under the RRUK HF projects will involve interactions between drivers (D) and signallers (S), and with the further constraints imposed on these by controllers (C). In addition, however, we plan to consider the way in which information about maintenance activities (M) impinge on this distributed cognitive system. As with any systems approach, it is possible to zoom in or out to focus on a different level of analysis to the one shown in Fig. 1. On a more macro level, for example, some research within RRUK will consider the relationships between network operations (in general) and other higher order systems, such as transport economics or environmental impact. For the HF projects, in addition to the level shown, we will need to adopt a more micro-level analysis (the *within-person* cognitive system), in order to model the performance, knowledge use, etc. of individual drivers or signallers. Adopting an approach of this kind to railway HF issues will allow a much broader understanding of the processes taking place within the system, as well as providing a more supportive explanatory framework for determining the origins and solutions of the problems of inefficiencies and error.

Safety Implications

The main implication for safety from the proposed work will be through a greater understanding of the system within which drivers, signallers, controllers and maintenance workers operate and interact. Through the use of field, laboratory and simulator research the proposed work will take a broader perspective than most previous HF work in rail systems and hence will provide a framework within which to assess the repercussions of interventions to improve safety at the system level rather than just their local impact. An understanding of the use of knowledge by operators across the rail system through the development of a distributed cognitive model will improve the planning and design of future safety technologies. At the more micro-level of analysis, the RRUK projects will also attempt to model the performance and use of knowledge by individual drivers, signallers, maintenance workers etc. allowing a more detailed framework for determining the cause of, and solutions to, unsafe performance.

Within this proposed framework for the research the areas of the project work that have specific safety implications are:

- An understanding of the communication processes between various functions that operate within the railway system (e.g., driver, signaller, controller). For example, what are the causal factors leading to misunderstandings between drivers and signallers that can potentially have catastrophic consequences (i.e., SPADs)?

- Theoretical and empirical validation of interventions designed to improve safe communication processes (e.g., “open channel” radio systems, in-cab displays).
- The development of psychophysiological methods to detect indicators of fatigue (and appropriate interventions) at earlier and less safety critical stages of driver operations. This could potentially reduce reliance on safety systems such as ATP that are expensive to deploy, leading to greater efficiencies within the network.
- The integration of research on fatigue in general with the work conducted within rail systems to investigate alternative contributing factors other than shiftwork to decrements in operator performance.

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