Embedding Human Factors into High-Speed Rail Systems Integration

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SUMMARY

High Speed 2 (HS2) is building a new socio-technical system, and the complexity of the project requires early and iterative management of human risks. Collaborative working between Ergonomics and Systems Integration (SI) has allowed for end users to be considered in SI processes, which is critical when designing not only new rail systems and infrastructure, but also a new Infrastructure Manager (IM) organisation. This paper will discuss the development of the early ergonomics risk identification framework (EERIF) that has been developed to integrate ergonomics into functional integration activities that are used to support the design of technical systems. The EERIF will be iteratively updated throughout the design process to map to the maturity of the project and will be re-reviewed against existing HF taxonomies and methods.

KEYWORDS

Rail, Systems Integration, Human System Integration

Introduction

The High Speed 2 (HS2) project is one of the largest and most complex infrastructure projects ever undertaken in the UK. It will be a major addition to national public transport and is a system of systems, connecting to existing transportation networks. It requires a bespoke delivery organisation to execute the planning, design and integration of the component parts of the new high-speed railway.

HS2 is building a new socio-technical system, which includes designing and building new tracks, multiple rail systems, a control centre, depots and stations. In parallel, the project is also setting up a new infrastructure manager organisation (IM), with new end user roles and associated rules and procedures. In addition, HS2 must work together with third parties such as Network Rail, the British Transport Police and West Coast Partnership Development.

HS2 will be a highly automated rail system, which adds greater complexity, with potential unanticipated consequences. Furthermore, the sheer scale of delivering HS2 presents immense engineering challenges. Railways are complex socio-technical systems with humans at their core, and Wilson et al (2007) argue that rail systems engineering requires a strong integrated human factors (HF) contribution at its centre.

Consequently, humans are central to HS2 systems integration (SI) to ensure that the overall system supports the end users. HS2 end users include not only those roles associated directly with the operations and maintenance of the railway, but passengers are also a specific group of end users. The human system integration (HSI) strategy was developed at HS2 to describe a collaborative SI and ergonomics workstream, which is embedded and core to SI activities as well as other integration activities.

At the time of writing this paper, work had already commenced with some contractors including stations and civils, and the method has been deployed, with visible outputs, benefits, and lessons. This paper will focus on the ergonomics integration and risk management approach for rail systems, whose contractors are due to onboard shortly, as there are different ergonomics challenges to the design of infrastructure (e.g. stations and depots).

Technical Authority for Ergonomics

The HS2 ergonomics function plays an active role in co-ordinating ergonomics (human factors) across HS2 for an integrated outcome. The HS2 ergonomics and human factors team provides ergonomics integration and assurance across various contracts (e.g. civils, stations, depots and rail systems). The HS2 Technical Authority for ergonomics is required to satisfy its legal obligations for ergonomics integration in the design, maintenance and operation of the railway and demonstrate human risks have been assessed and managed throughout the HS2 engineering design lifecycle. Ergonomics evidence is required for the Authorisation of the railway and is written into legislation (Common Safety Method - Risk Assessment (CSM-RA) and Railways and Other Guided Transport Systems (Safety) Regulations 2006 (as amended - ROGS).

There are ergonomics requirements and a HS2 Ergonomics standard that are instructed across contracts, however due to complexity of the project, it is crucial to ensure that the design of the rail systems is aligned to the new roles, rules, procedures, and the IM organisation. Therefore, it is necessary to ensure ergonomics integration and that ergonomic risks are managed and assessed throughout the whole engineering design lifecycle.

Balfe (2023) developed the Human-Factors Impact assessment Tool (H-FIT) to support the early identification of the scope of HF issues generated by an individual rail project at Irish Rail. The H-FIT maps 14 design factors against 16 design outcomes, and uses a four-step process, as aligned to the ISO-9241-210 (ISO, 2010) process. Figure 1 shows the H-FIT design factors mapped against design outcomes.

	Design Outcomes															
	Visibility	Audibility	Thermal Comfort	Accessibility	Physical workload and stress	Mental workload and stress	Situation awareness	Usability	Human reliability and error	Fatigue	Quality of communications	Teamwork	Training needs	Motivation/job satisfaction	Risk awareness	Culture
F1: Environment	•	•	•	•	•		•		•					•	•	•
F2: Tasks					•	•			•	•			•	•		•
F3: Tools/equipment		•		•	•				•				•			
F4: HMIs	•			•		•	•	•	•				•			
F5: Alarms	•	•				•	•	•	•				•		•	
F6: Automation					•	•	•	•	•				•	•		
F7: Procedures						•	•	•	•		•	•	•		•	•
F8: Comms protocols							•		•		•	•	•			
F9: Staffing levels					•	•			•	•				•		
F10: Resources					•	•			•					•		•
F11: Roles									•		•	•		•	•	•
F12: Info provision							•		•					•		
F13: Supervision									•			•		•	•	•
F14: Working time									•	•				•		

Figure 1: H-FIT design factors mapped against design outcomes (Balfe 2023).

However, the H-FIT was designed to assess the likely human factors impact of proposed railway change projects in an existing railway. A different methodology is required for the HS2 project due to its complexity. The two methodologies were developed independently in parallel.

Human System Integration

The HSI workstream aims to ensure a socio-technical systems approach it taken in SI, and to ensure Ergonomics integration and co-ordination across SI processes. It is an iterative integration process throughout the entire HS2 design lifecycle (as shown in Figure 2). This is to ensure the design of the HS2 system matches the capabilities of its people and the end state IM, to enhance human safety and human performance. It includes timely ergonomics testing and acceptance, to ensure that recommendations can be made in parallel with, and as inputs to, system design and integration decisions, and production of operational rules and procedures.

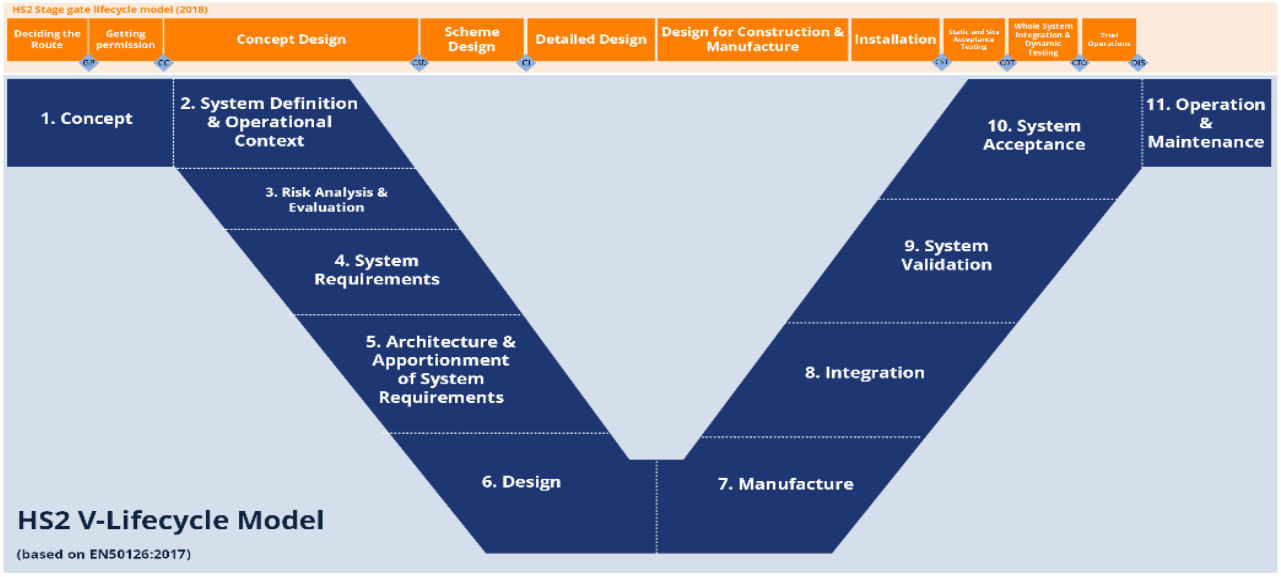

Figure 2: HS2 V-Lifecycle model

HS2 acts as the prime systems integrator (PSI), responsible for the technical integration needed to deliver the HS2 railway. HSI allows HS2 to understand the areas of human risk/ergonomics considerations in system level processes, whilst embedding ergonomics best practice. Ultimately supporting system level ergonomics technical assurance, which supports the HS2 safety case and the authorisation of the railway.

Methodology

To start early ergonomics risk management, HSI work has been conducted in collaboration with the functional integration (FI) team. The FI team has produced a 'railway functional description document' (RFDD) which defines a breakdown of the functionality to be delivered by the railway to support the operational concept (produced by the operations team). It provides a summary of how each function is delivered including identification of the railway sub-systems requirements and operational concept requirements that contribute to achievement of the function.

The RFDD lists a functional breakdown structure (FBS) of seven categories and their associated functions. The seven categories consist of:

- FBS-01 Planning the operation of the railway;
- FBS-02 Operate the network;
- FBS-03 Operate the trains;

- FBS-04 Operate the stations;
- FBS-05 Monitor railway assets;
- FBS- 06 Maintain HS2 infrastructure and rolling stock; and
- FBS-07 CRN only functions.

For each function a 'detailed functional description document' (DFDD) is produced in advance of the detailed design phase for the systems, to bring together both the associated system and end user requirements. The DFDDs include activity diagrams which show a sequence of steps that take place per function, their logical relationship and information flows between both systems and humans. A function can be made up of multiple activity diagrams. An example of an activity diagram is shown in Figure 3. Each activity diagram is composed of swim lanes with either a system or an end user, and maps the flow of information, as detailed in the requirements.

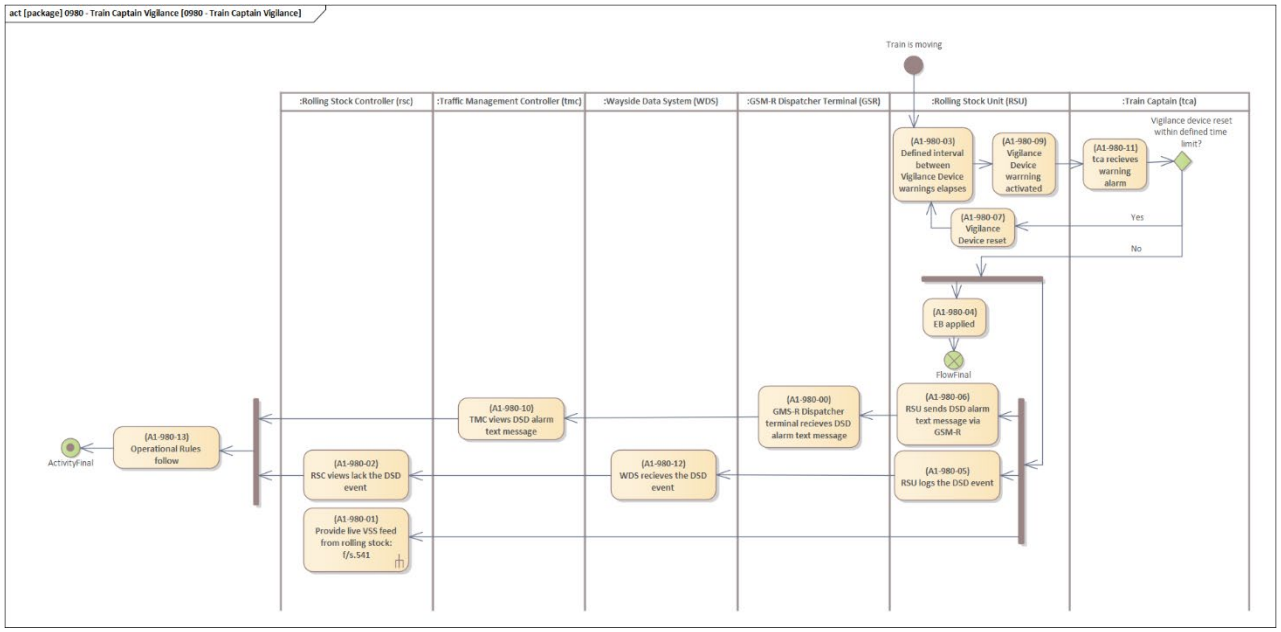

Figure 3: An example of an activity diagram

The generation of the DFDDs have involved collaborative inputs and reviews by FI, engineering, operations, maintenance, safety, stations, security and ergonomics teams. During peer review sessions the Ergonomics input has focussed on assessing the human-system and human-human interactions using the simple human information processing model (Parasuraman et al 2000).

An ergonomics early risk identification framework (EERIF) has been developed and validated to start considering early areas of ergonomics risks and areas of interest for each of the DFDDs. These have been included in an ergonomics section within the DFFDs, as part of the functional integration activities. These will be updated when the rail systems contractors come on board and the detailed design stage commences.

A bottom-up thematic approach was taken to generate the framework, initially using thirty DFDDs. The framework was validated using workshops with ergonomics and operations subject matter experts and agreed with the Head of Ergonomics. At the time of writing this paper 68 DFDDs were analysed in total, and the framework was updated to include any new emerging themes.

The EERIF will be used to identify where ergonomics evidence is required to demonstrate that both the system and the operational rules support the operators. Furthermore, it will provide traceability to identify where the system needs further design solutions to support the end users.

Framework

The EERIF is divided into three categories, which consist of 'Environment', 'System' and 'User'. Each category contains different themes that were developed when identifying the early ergonomics risk profiles. There are some overlaps with the themes, but they have been structured to meet the purpose of early ergonomics risk assessment at a very early stage in the engineering design lifecycle. Table 1 lists each of the different themes along with a brief description.

Table 1: Early ergonomics risk identification framework

Theme Number	Theme	Description
	Environment	
E1	Infrastructure design	Ergonomics considerations should include the design and assessment of any infrastructure that is related to the function.
E2	Depot design	The location, timing and content of the visual information presented at the depots should support the tasks and situation awareness of the end users in the depot.
	Control centre design	Ergonomics considerations should include the design and assessment of the control centre that is related to the function.
E3	Wayfinding	Design of information that relate to the customers should also consider Ergonomics assessments on wayfinding.
E4	Safe access	Ergonomics considerations should include safe access and other external environmental factors or included additional equipment required.
E5	Signage	Ergonomics considerations should include the design and assessment of any lineside signage related to this function.
E6	CCTV design	Physical design of CCTV monitoring should support the identified function, including methods of viewing and downloading data.
E7	Workstation design	Ergonomic consideration should also include the layout of the related workstations.
E8	Cab design	Physical design of the cab should support the identified function.
E9	Transitions	Ergonomics consideration to include the assessment of transitions (e.g. the OTMs transition from the Depot controlled area at Calvert onto the HS2 Mainline). This includes both system-based and environment-based factors that may affect workload.
E10	Equipment	The physical location of staff and the availability of equipment (e.g. laptop and storage media) should be considered when further developing a function and associated scenarios.
	System	
S1	Alarm Management	Alarm management in accordance with the HS2 Alarm Management Strategy, and associated Ergonomics requirements.
S2	Information Requirements	Ensuring the system provides information required by the identified end users, including the format and timely presentation of data to support end user tasks. Location of information (e.g. knowledge in head vs. manuals vs. systems).
S3	HMI design	Design of the HMIs required in this function should support the task and activities required to be performed by the end users. Considerations should

		include the presentation, location and timing of visual and auditory information.
S4	System feedback	Ergonomics considerations should ensure that the systems provide adequate feedback to the end users to keep end users 'in the loop'. E.g. receive feedback alerts when required and the design of visual and auditory messages.
S5	Mode confusion	Potential for mode confusion by end users needs to be assessed and designed out.
S6	Cybersecurity	Ergonomics considerations should be made regarding Cybersecurity.
	User	
U1	Communication	Ergonomics considerations should be made to further understand communication activities that may be required to support this function, as well as the form of communication. Any safety critical verbal communications between the end users need to be formalised.
U2	Situation Awareness	Ergonomics consideration for the situation awareness needs of the human actors in this function and associated functions, including any additional information required to keep end users 'in the loop'.
U3	Team Situation Awareness	Ergonomics consideration for the information required to co-ordinate activities and support a shared situation awareness. Any additional information that is required by users to maintain and update their team situation awareness.
U4	Team Co-ordination	Ergonomics consideration for the information required to co-ordinate activities and information requirements for the HS2 railway with third parties. E.g. to provide information and access to Emergency and Rescue Services (incl. Ambulance; Fire and Rescue; Search and Rescue) for safe intervention to assist with safe evacuation in the tunnel. Considerations should include the presentation, format, location and timing of information.
U5	Monitoring strategies	Ergonomics considerations should include identifying if monitoring strategies are required to support the end user.
U6	Decision Making	Ergonomics consideration should include supporting the human decision making process, including goal conflicts and joint decision making.
U7	Roles & responsibilities	As this function matures there needs to be consideration about the roles and responsibilities of the end users.
U8	Rules and procedures	The end users identified in this function should be provided with rules and procedures to support the activities related to this function.
U9	Training	Training should be developed to support end users in this function.
U10	Operational scenarios	Further analysis is required through the development of operational scenarios to understand the operations and maintenance responses in different scenarios.
U11	Workload	Ergonomics consideration should assess task demands and associated workload for end users.
U12	Human Reliability	Ergonomics considerations should be made to the management of human reliability and the development of the associated roles and responsibilities and their associated competencies**.**

Conclusions

The early ergonomics risk identification framework allows the early identification of ergonomics considerations, based on system and user requirements, prior to the onboarding of rail systems contractors. The bespoke framework allows for the complexity of designing a new socio-technical

system for a major systems of systems infrastructure project. The framework will be iteratively updated throughout the design process to map to the maturity of the project and will be re-reviewed against existing HF taxonomies and methods.

The framework is one of the methods in which ergonomics has been embedded into SI at HS2, to ensure human centred design. Collaborative working between Ergonomics and SI has allowed for end users to be considered in SI processes, which is critical when designing not only new rail systems and infrastructure, but also a new IM organisation.

In detailed design the identified Ergonomics considerations will be updated and human risk will continue to be iteratively mitigated in the HS2 design lifecycle. Currently the DFDDs only include normal scenarios, and these will be expanded in detailed design to also include abnormal, degraded and emergency scenarios.

Operational scenarios are currently being developed by the operations team. These will use the DFDDs and be used to further assess the impact of system design and the design of rules and procedures on human performance and safety.

Benefits of early ergonomics input will iteratively mitigate human risk in the HS2 design lifecycle. It also provides a mechanism for early engagement within HS2 with various disciplines, but also as a collaboration tool with contractors. Furthermore, it allows HS2 to be an informed and prepared client in the testing and commissioning phases.

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