EFFECTIVE HUMAN FACTORS INTEGRATION IN THE DESIGN OF A SIGNALLING AND TRAIN CONTROL SYSTEM FOR THE METRO RAIL INDUSTRY

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Abstract

This paper describes an approach to Human Factors Integration (HFI) in a Metro based context where assurance standards based on goals and process are used. We describe how different elements of a HFI programme can be united into a successful approach that is compatible with the wider processes in engineering and assurance. Central to this process was the Human Factors Integration Plan (HFIP) and engagement of the user group through structured and incremental operability evaluation.

We found that the HFIP must remain flexible to the inevitable changing project circumstances and management and engineering demands. Thus helping to keep the HFI timely and effective and responding to current and future project concerns. This maintained project acceptance and belief in the value of Human Factors (HF).

Keywords: Human Factors Integration, Assurance, Requirements.

1. Introduction

The Victoria Line is part of the London Underground metro system, and is one of the busiest lines in the network with approximately 161 million passenger journeys per year. Since the early 2000's the line has been undergoing a significant upgrade that is due to introduce new rolling stock, new signalling, and improve and renew stations and other infrastructure. These upgrades will deliver increased capacity to the line and lead to shorter journey times and more frequent trains for passengers. In addition, replacing the service control centre, signalling and train control system, and training simulators should improve operational management.

To ensure that the required operational and safety benefits are realised, the Victoria Line Upgrade (VLU) project supply chain is conducting Human Factors Integration (HFI) as part of the wider Systems Engineering (SE) activities.

In this paper, Human Factors Integration (HFI) is defined as a management process for addressing human-related risks in the broader context of system design and operation.

Westinghouse Rail Systems Limited (WRSL) is supplying the Signalling and Train Control System (STCS) for the VLU project. This comprises many Human-Machine Interfaces (HMI), computer and mechanical, placed in many different locations across the line and used by many different roles to complete disparate activities all with the same aim of keeping the train service running efficiently and safely. Part of this scope involves providing HF assurance according to the LU standards, which generally give goals or process requirements rather than specific human performance guidance. This means that the HFI programme must address issues of interpretation, management, and communication in order to achieve the HF goals and requirements of the project.

Given this background, the purpose of this paper is to present a case study of HFI as applied to the signalling and train control aspects of the VLU, to discuss some of the challenges that were faced, and present the lessons learned from conducting the integration activities.

2. The Context for Human Factors Integration and the Victoria Line Upgrade

2.1 Background to VLU project

The process of applying the WRSL STCS products to the VLU project started in 2002. Progress on the signalling elements of the upgrade have followed the overall project developments such as the construction of the new Victoria Line (VL) rolling stock (the 09 stock) and the development of Osborne House, the new VL Service Control Centre (SCC).

The STCS supply chain, with particular emphasis on the Human Factors Engineering relationships, can be seen in Figure 1 below:

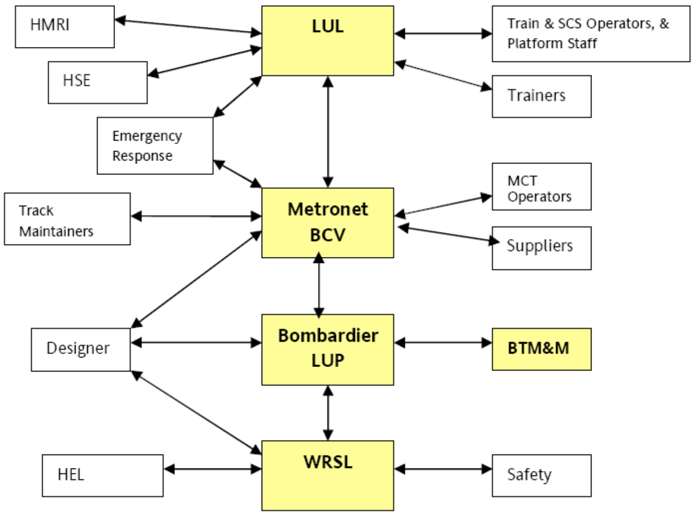

Figure 1 - Project Human Factors Relationships

The project relationships diagram shows that there are a significant number of stakeholders involved in the HF Assurance process. This is a significant issue that will be discussed in more detail later in this paper.

A technical solution to the renewal of the STCS was defined by WRSL. This includes the WRSL Distance-to-Go Radio (DTG-R) Automatic Train Protection (ATP), Automatic Train Operation (ATO), and WESTRACE interlocking systems. Computer-based control centre software and trackside display and control devices (such as Staff Protection Keyswitches and lineside signals) provide Operator Human-Machine Interfaces (HMIs).

The broad scope of the STCS introduced a number of different end-user populations (such as service control staff, station staff, and maintenance technicians) and operating environments (including control centres, signalling equipment rooms, station platforms) that needed to be considered. These considerations would need to be addressed by the HFI programme.

The system is to be delivered by WRSL in two stages: overlay (the existing signalling is used in conjunction with the new train control capability) and final (new signalling implemented and integrated with the train control capability introduced during the overlay phase).

The phased introduction of the signalling system will allow for the introduction of test trains in traffic hours, but it does introduce some unique HF issues that have to be taken account of by the HFI programme.

2.2 The Idea of 'Human Factors Integration'

The immediate origins of HFI are generally agreed to be the US Army MANPRINT initiative from the middle of the 1980's. MANPRINT was intended as a response to shortfalls in the expected performance of equipment when utilised in the intended environment (Booher, 2003). The response was centred on six domains (personnel, manpower, training, HF engineering, system safety and health hazards) to take account of the capabilities of the human within the wider military system.

Many industries and domains have approaches to HFI (for example, the HF Case process in European air traffic management (EUROCONTROL (2007), Dehn and Mellett (2008)). These approaches have differences but in general they stress that the important themes of HFI are:

- Integration with other engineering disciplines.
  Emphasis is placed on establishing the means by which the outputs of HF work packages can be understood and utilised by other engineering functions such as safety assurance, system engineering, and software and hardware engineering.
- Timeliness of HF technical activities in relation to the overall project plan.
  The HF Engineering effort should be integrated into the overall project plan, and be consistent with the milestones, gates, design reviews and deliverables associated with the main engineering programme.
- Iteration in process.
  The concept of 'iteration' is stressed in many approaches to HFI, and in particular approaches based on international ergonomics standards.

It is against this background of concepts and guidance that the London Underground HFI standard should be viewed.

2.3 Background to LU standards

In common with many large undertakings, LU has a suite of standards and manuals of best practice that are used to place requirements or recommendations on the functions and behaviour of elements of the railway. A series of these standards are concerned with the processes of safety assurance engineering and systems engineering, and within this series is the LU HFI Integration standard (Integration of Human Factors into Systems Development, 1-217 – referred to as the LU HFI standard in this paper).

The LU HFI standard is a short document that is intended to be relevant to HF Specialists, Project Managers and Safety and System Engineers in equipment, system, infrastructure and service supplier organisations. It relates to assets operated by LU staff (a separate HFI standard applies to customer-facing systems).

During the STCS VLU project, we learnt to characterise the LU HFI standard in the following way:

- It is a process-based standard.
  The standard is not a HF Engineering standard, such as those found in the defence domain (MIL-STD-1472 (Human Factors for Designers of Equipment) for example).
- It is mandatory.
  The LU HFI standard is a 'Category 1' standard. When applicable, suppliers must comply with the requirements of the document.
- It is intended to be scalable and flexible.
  LU operates different types of assets and the standard has been designed to be flexible enough to apply to different types of project.
- It places no specific requirements on system qualities or performance.

The standard relates to process rather than directly to the desired qualities of any target system. The standard does not specify, for example, the interaction design details of a particular HMI.

- It introduces specific roles and responsibilities.
  The LU HFI standard requires that projects appoint HF Delivery roles in both the customer and supplier organisations. We have found this requirement to be beneficial while conducting the VLU HFI programme.

As quickly became apparent when attempting to work with this standard on the STCS VLU project, the main requirements of the standard relate to the production and management of a Human Factors Integration Plan (HFIP).

3. Victoria Line Upgrade Signalling and Train Control System Human Factors Integration

3.1 Introduction

As demonstrated in Figure 1, designing and developing a new signalling system and control centre is a complex activity that tends to involve a substantial hierarchy of companies who need to work together in order to produce a coherent, efficient and effective system.

Given this, and the complex nature of the project, it was apparent that HFI should be applied with emphasis placed on management, technical content and deliverables, and communication.

The remainder of this paper describes how these elements can be united into a successful approach to HFI that is compatible with the wider processes in engineering and assurance. Central to this process was the HFIP and associated management activities.

3.2 The Human Factors Integration Plan

Central to the VL STCS HFI process was the generation of a management plan that helped to co-ordinate not only the intra-company but also the inter-company activities.

In common with other projects (e.g., Lowe et al (2007)) the HFIP was produced at the beginning of the project and provided details on: the aims of the project, those actively involved in HF activities, the coordination procedures and communications structures, issues recording and close-out procedures, integration with other stakeholders and teams (such as systems development and end-users), and detail of the activities to be undertaken and how these will assure the acceptability of the human-related characteristics of the system.

For the VLU project, all of the stakeholders in the supplier hierarchy produced a HFIP that included the above sections. This suite of plans detailed the formal approach to coordination and the intended activities.

3.3 Human Factors Management - Keeping Human Factors Integration Alive

A HFIP is just a document. We found that in order for the HFIP to be effective it must remain flexible to the inevitable changing project circumstances and be the basis for proactive activity. This was achieved by being aware of the management and engineering demands, shifting project requirements and changing programme. The HF programme was maintained monthly to stay in tune with project circumstances and the HFIP updated regularly in response to progress against deliverables, variations in project requirements and scope, changes in HF organisation, and changing phases of development.

HF is a technical discipline and as with any technical discipline there can be a tendency to focus on the technical activities that it needs to achieve. In order for HF to be integrated into the project it is necessary to maintain a visible presence with other teams of different disciplines and within different organisations in the supply chain (Bourne and Carey (2001), Dooley et al (2007)).

Maintaining a visible presence does not mean merely attendance at meetings, it has also meant promoting the value of HF, being open to change in demands and requirements, being accessible and available as required for queries and support, understanding the priorities of other teams and most importantly providing feedback on progress. Feedback on progress has included that which is obvious i.e. close out of issues, completion of activities shown in the programme, delivery of documents, and production of a HF case, and subtle i.e. improvements to the system identified by HF have encouraged an appreciation of HF as the developers and user groups have experienced the improved operability i.e. speeding up of tasks and the elimination of irritating actions and difficult to use functions.

All involved in the project adopted the coordination procedures wholeheartedly. These procedures promoted positive relations between teams and stakeholders.

3.4 Technical Content and Deliverables

HF was integrated with the systems development and assurance lifecycles. In terms of technical content and deliverables, this was mainly achieved by aligning the HFI programme with the project key milestones and the other stakeholder programmes of activities and requirements. The basic HF lifecycle that was followed can be seen in Figure 2 below:

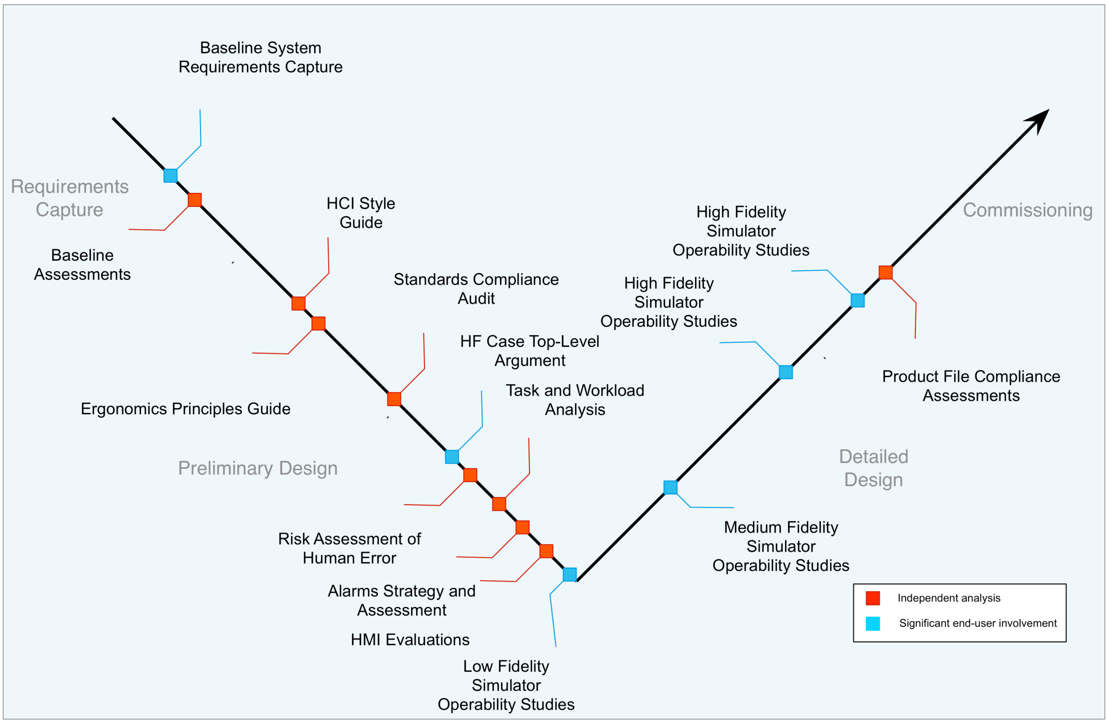

Figure 2 – Human Factors Integration 'V' Lifecycle Diagram

Figure 2 demonstrates that, through flexible planning, the HFI programme was able to deliver key inputs when they were needed by the project.

Within the HFIP itself, activities were defined using a standard template as illustrated in Figure 3.

Aim: To provide more detail on the alarms approach taken for the Signalling Control System (SCS).
Input: Core Signalling and Train Control System (STCS) alarms strategy. STCS Simulator. Alarms database and configuration data.
Detail: The document will detail the STCS alarms presentation including priority levels, colour codes, and acknowledgement strategy. This will involve a review of the alarms strategy, the STCS simulator and the alarms database and configuration data. The document will be a description of the HMI and will not include any review against HF standards or best practice. The purpose of the document is to support MRBCV in their integration activities and WRSL in future development activities, to ensure consistency across WRSL HMI and other HMI in the SCC.
Stakeholder Input: None
Output: External: Alarms System Rationale Document
Constraints: This document will reflect the alarms interface at the time of the review and hence may not reflect the system in current use.
Dependencies: None.

Figure 3: Example of the Work Package Descriptions given in the HFIP

Providing detailed technical content in the HFIP at all levels of the supplier hierarchy also meant that it was easy to identify gaps within the activities to be conducted by the different parties as a result of incomplete scope.

Deliverables were divided into internal and external. An internal deliverable was produced to be used only by the originating company. These deliverables have been sent occasionally to other stakeholders for information only. External deliverables are those that are sent out to other stakeholders for comment, review, and acceptance.

3.5 Communication

The formal communications process (e.g., requests for information, concessions against standards, etc.) in any large project with many contractors and sub-contractors is very important to the functioning of the project. However, formal communication procedures can slow the progress of a project and can cause a feeling of 'them and us'. On the VLU project the formal communications process meant that any significant communications needed to pass through three systems before reaching the final customer (Figure 1).

A process was agreed such that as well as being sent formally, communications could be sent informally by email as long as all the relevant stakeholders were included on the email so that the formal chain was preserved. This has proved an invaluable tool to maintain steady progress and build positive relationships throughout the chain.

In addition to this, regular working group meetings involving stakeholders at all levels were held to provide technical coordination and guidance for operations and HF issues and queries across the VLU project. Due to the commitment shown by the attendees, this has become a forum where Operations and HF issues that span organizational boundaries can be discussed and resolved.

This positive relationship throughout the chain has enabled the engagement of a representative user group. The participants in the user group have remained with the project for some time. This has meant that they have been fully engaged in the process and appreciate how their requirements and comments have been captured by the improvements to the system. Users were engaged in operability evaluation of all aspects of the system including HMI presentation (colour, terminology, layout and navigation), alarms presentation and content, and functionality.

Communication of technical progress has also been an issue that the project needed to address. The LU HFI standard, being a goal and process based standard, does not specify acceptance criteria or a route to the 'sign-off' of the HFI programme.

To deal with this specific nature of the LU HFI standard (as discussed in Section 2 above), we found it useful to produce a 'Human Factors Assurance Case' as a communication tool.

A HF Assurance Case is a type of 'operational readiness report' that shows how HF requirements have been addressed through the completion of work packages and the generation of engineering process and system performance evidence.

Goal-structuring notation (GSN) was used to create the structure of the HF Assurance Case. GSN is a set of diagramming conventions that can be used to express the logic within an argument (Kelly and Weaver (2004)). An argument in this sense is just a claim about the properties of the system (STCS) that is supported by evidence.

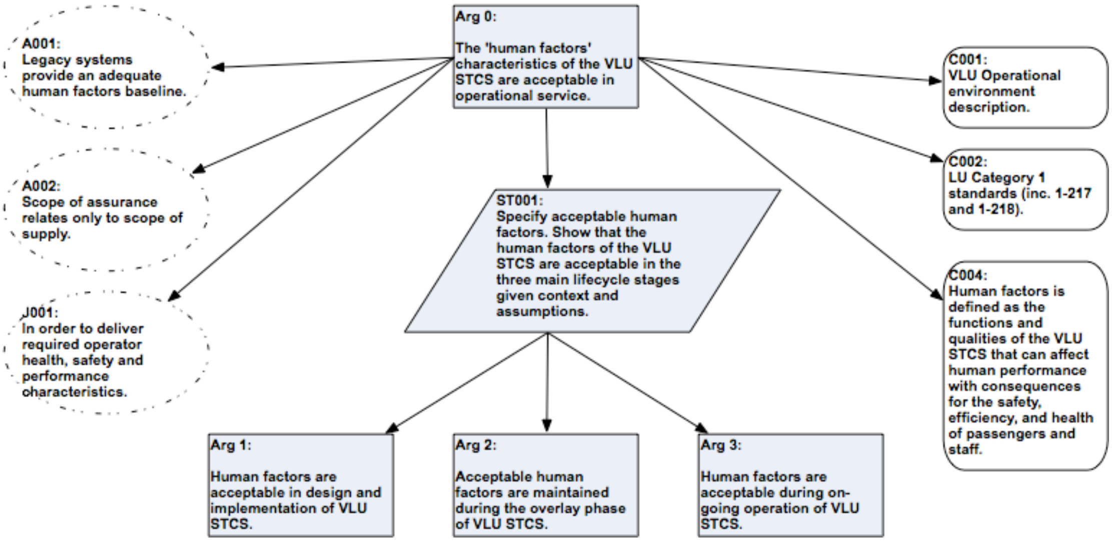

Figure 4 – Extract from VL STCS Human Factors Case Argument Structure

The GSN makes clear the argument strategies adopted (for example, whether absolute or comparative evaluation criteria have been used), the rationale for the approach (why a particular strategy was adopted), and the context in which goals are stated (such as scope of analysis).

3.6 Outcomes

The outcomes and benefits from the HFI programme have been seen in both progress against requirements and in an increased sense of involvement from operational stakeholders.

Part of the argument for the completeness of the STCS HFI programme is based on compliance with applicable standards and requirements. Following the HF Assurance Case approach has allowed us to be clear on this progress, in a format that can be understood by the relevant stakeholders.

Operability testing and end-user involvement proved to be an effective focus and risk reduction tool for HF across the project. These events were well attended and enhanced the working relationships and confidence between stakeholders, technical developers, and operators. Involving developers in this process helped build their understanding of the users and their needs.

4. Conclusions

We found that the HFIP must remain flexible to the inevitable changing project circumstances and management and engineering demands. Therefore the HFI programme was timely and effective in responding to current and future project concerns. This maintained project acceptance and belief in the value of HF.

The VLU will soon begin to deliver its capability enhancements to passengers and employees. An important element of this is the STCS to be delivered by WRSL. This paper has presented a small number of management strategies and techniques that we have used to achieve significant HF benefits as part of this integrated effort.

References

Booher, H. 2003, *Handbook of Human-Systems Integration,* John Wiley and Sons Inc.

Bourne, A., and Carey, M. 2001, Integrating human factors into the development of railway systems. In *People in Control: An International Conference on Human Interfaces in Control Rooms, Cockpits and Control Centres, June 2001.* IEE, London.

Dehn, D., and Mellett, U. 2008, Integrating HF Throughout the Concept Lifecycle: Experiences from EUROCONTROL Projects. *Presented at: 28th Conference of the European Association for Aviation Psychology: The Future of Aviation Psychology*. 27-31 October 2008, Valencia, Spain.

Dooley, M., Hickling, N., and Stephens, P. 2007, Focussed and effective human factors integration programmes for railways. In J. R. Wilson, B. Norris, T. Clarke, and A. Mills (eds), *'People and Rail Systems: Human Factors at the Heart of the Railway'.* Ashgate, Aldershot, pp 511 – 516.

EUROCONTROL 2007. The Human Factors Case: Guidance for Human Factors Integration. Edition 2, 29.06.2007. Ref.nr. 07/06/22-35. Brussels: EUROCONTROL.

Kelly, T. P., and Weaver, R. A., 2004, The goal structuring notation – a safety argument notation. *Proceedings of the Dependable Systems and Networks Workshop on Assurance Cases*, July 2004.

Lowe, C., Lock, D., Annan, B., Thompson, P., and Raistrick, P. 2007, Human factors integration for the computerized track access control system. In J. R. Wilson, B. Norris, T. Clarke, and A. Mills (eds), *'People and Rail Systems: Human Factors at the Heart of the Railway'.* Ashgate, Aldershot, pp 343 – 351.

London Underground Limited 2007, *Integration of human factors into systems development.* 1-217.