DENMARK RAIL UPGRADE HUMAN FACTORS: A SUPPLIER CASE STUDY

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In 2009, Banedanmark (BDK) embarked upon an ambitious €3.2 billion project to upgrade Denmark’s entire national rail signalling infrastructure (Fjernbane or ‘F-bane’) before 2021, and the Copenhagen mass transit system (S-bane) by 2020. Two supplier organisations were employed to deliver the rail infrastructure for the Fjernbane (one for the East and one for the West of the country). Quintec conducted the Human Factors (HF) activities for the West as part of the Thales-Strukton consortium. The main HF interfaces are a new signalling control centre and workstations; signalling equipment and software; and hand-held devices for use trackside. HF activities included task analyses; mock-up trials; Human-Computer Interface (HCI) design and user testing; maintenance support; and safety case input. This paper will describe the HF activities and highlight the benefits of HF involvement, such as reduced operating expenditure, as well as lessons learnt for future programmes of this nature.

Introduction

An ambitious €3.2 billion infrastructure upgrade programme was agreed by the Danish parliament in January 2009. The modal ratio of rail usage compared to other forms of transport is approximately 10% in Denmark, the second highest in Europe. The existing infrastructure is nearing the end of its service life, necessitating major investment. An intention of the project was to avoid obstacles that traditional rail upgrade projects encounter such as the need to integrate new technology with legacy equipment long-term, and provide opportunities for complete redesign of equipment and processes. The signalling
upgrade is expected to significantly reduce delays throughout the network and increase Journey Time Capability (JTC) on selected lines.

The programme was divided into four main work-packages. Two work-packages pertain to the provision of signalling infrastructure to meet European Railway Traffic Management System (ERTMS) standards for the national Danish network (Fjembane). To complement this, a further work-package provides the on-board equipment. Together these programmes should remove the need for line-side signalling. The fourth work-package addresses the replacement of the S-bane urban mass-transit system with a radio-based Communication Based Train Control (CBTC) system by 2020.

All of the work-packages are being delivered by different supplier groups. The Fjembane upgrade is supported by two main suppliers; one for the East and one for West of Denmark. The Thales-Strukton consortium is responsible for the West and Quintec have been conducting the Human Factors (HF) activities on behalf of this consortium.

HF involvement in the Denmark rail infrastructure project began at the Concept Design (CD) Phase of the programme, in 2012. An Early Human Factors Analysis (EHFA) was produced and a Human Factors Integration Plan (HFIP) addressed HF requirements and activities throughout the project lifecycle. This was updated as HF involvement continued throughout the Preliminary Design (PD) Phase and the Early Deployment (ED) Phase, which included the Final Design (FD) phase. A Human Factors Issues Log (HFIL) was also produced and maintained throughout the programme.

The main HF interfaces addressed in the HFIP were a new signalling control centre and workstations; signalling equipment and software; and hand-held devices for use trackside. Proposed HF activities included task analyses, mock-up trials; Human-Computer Interface (HCI) design and user testing; maintenance support and safety case input. These activities are described in the following section.

**HF management activities**

Typical HF management activities, HFIP (with iterations), EHFA and HFIL were employed during the design phases of the Fjembane (West) infrastructure upgrade project. The remainder of the paper will focus on the HF technical activities relating to the signalling control room; signalling software; hand-held terminal; maintenance and the project safety case.

**Signalling control room design**

A new Traffic Control Centre (TCC) was designed for managing the signalling and rail infrastructure for the West of Denmark. It will reside in a cylindrical building, occupying approximately half of a floor, in a semi-circle shape.
Several task analyses were conducted to support the project activities. These addressed signalling and information-critical roles that were defined in the Traffic Management System (TMS) such as: signaller (operator and dispatcher); passenger information operator; network manager; bridge guard and shift leader. The task analysis work also covered supporting and planning roles such as infrastructure and maintenance coordinators; short term and long term planners. A large operational specification was also produced, which was subsequently used by the project to record changes that had operational impact. An environmental assessment was recommended to minimise the impact of the curved walls on noise.

A signalling workload analysis, conducted in conjunction with the HF specialists from BDK and Fjernbane East, assessed current and predicted task demand. The main aim was to determine the required number of signalling workstations in the control room. Signaller (operator; not dispatcher) workload was determined by assessing areas of control in relation to the number of stations, the complexity of each of those stations and the number of trains per hour. Railway task demand data was provided by BDK. The HF specialists determined how to best to relate it to signaler workload in the context of fully operational ERTMS with advanced TMS functionality. The implementation of TMS for Fjernbane will include Conflict Detection (CD) and Decision Support Systems (DSS) with strict adherence to a plan. That is to say; even making changes two minutes before they happen should be implemented by a plan, not individual signaller control. The reliance on Automatic Route Setting (ARS) for the majority of train control should necessitate very few signaller (operator) actions. However, the signaller (dispatcher) and infrastructure co-ordinator workload is expected to increase. Overload failure in these roles would impact the signaller (operator) task so the HF activities addressed these issues. The results for the number of signallers (operators) varied according to different traffic demands and also in relation to whether the full TMS functionality would be available.

The figures were used to help identify the number of desks in the control room and whether these should be ‘double-manned’ at any time. The workload analysis identified that double-manning would be unnecessary. Together with the workstation development work described below, it was agreed that enough single-manned desks could be installed to manage the railway under the expected conditions, including fall-back and degraded modes. This HF work positively impacted the long-term reduction in manpower and the ability to provide a workstation for a single operator. The double-manning workstation would have been a compromise and had a considerable number of associated technical difficulties. Therefore, the workload study provided savings to both the railway operator and the supplier.

Workstations were ergonomically designed to facilitate operations, enhance the user experience and ease of maintenance. Stakeholder design brainstorming sessions were held. Equipment lists were then generated in conjunction with HF specialists from BDK and the Fjernbane East project team. This helped ensure
consistency and avoid duplication of effort. After early workstation design options were analysed, mock-up exercises were conducted (see Figure 1).

A curved desk solution was adopted. An HF specialist was involved throughout the entire workstation design and development process. This included specification and selection of suppliers, Computer Aided Design (CAD) work and end user consultation. The HF involvement generated cost-savings by reduced iterations, knowledge-flow from user approval and supplier communications.

HF activities demonstrated that the original requirement for twelve monitors on each control room workstation could be reduced to eight. This was partly attributable to the change to single-manned workstations. Technical teams provided evidence that the largest area allowable (according to the workload analysis) could be presented on track diagrams which occupied no more than four overview screens. This left four screens for other content such as detailed station views, third-party windows, and scheduling information. Human information-processing capacity was also an important HF consideration. This reduction in number resulted in cost-savings in equipment procurement, installation and maintenance. The desks were designed to accommodate a modular concept and allow an increase of two monitors per desk with minimal workstation changes. The control room layout was designed to facilitate teamwork. Priority layout drivers were identified in a stakeholder plot board workshop using wooden cut-outs to represent desks and other furniture in a 1:40 scale (see Figure 2). Key layout drivers were identified as:
• Geography of the railway (linked to verbal communications and neighbouring signalling areas);
• The need for the Shift Leader to have an overview of operations;
• Flexibility (to address varying workload and associated staffing level changes).

Figure 2: Stakeholder control room layout consultation

The building footprint was initially concealed from workshop attendees, to prevent them being influenced by the shape. Boards representing the footprint were then introduced and stakeholders tested different layouts using the cut-outs.

The workload analysis was used to influence the control room layout. Nine signalling control areas (shown on the railway map to right hand side of Figure 3) were used to identify the best location and relative position of each workstation in the control room (shown in the diagram to the left of Figure 3).

Figure 3: Control room layout and the corresponding signalling control areas on the workload map for Fjernbane West

Signalling software assessment

The Fjernbane West project is implementing a number of important user interfaces. Specifically, the Centralised Traffic Control (CTC) and European Train Control System (ETCS) control views are provided by the Thales software
product known as the ‘HMI for Integrated Solutions’ (HIS); the passenger Traffic Information System (TrIS) is provided by a Thales Portugal software product; and the Hand Held Terminal (HHT), which uses Windows-based software, was chosen by collaboration between BDK and the East and West products. The HIS incorporates multiple screens that provide an integrated set of interfaces for track layouts; messages, alerts/alarms; maintenance/fault views; permission and user management; and ETCS information/interaction. An initial style review was conducted to identify HF compliance and an HF specification for usability was produced. HF considerations included zooming and content display; operator command nomenclature and menu structure. Detailed HF/usability expert evaluation using a simulator was then conducted and compliance reports produced. Recommendations were identified to enhance aspects of the design such as the use of colour; menu structure (including the use of English and Danish words); the Catalogue of Commands (CoC); and alarm list management.

The HF team introduced the project to EEMUA 191 alarms guidance. The HIS and the alarm management documentation were reviewed to determine compliance, and recommendations were identified. The recommendations addressed allocation of roles and responsibilities for the alarm system; design of required responses to alarms; consequences of failing to respond to alarms; definition and allocation of alarm priority; and integration of audible warnings in the control room. The resultant alarm design will be tested during the ED Phase.

The TrIS will be supplied by Thales Portugal for both the East and West Fjernbane projects. Big data for signalling is expected to produce better passenger information in the longer term.

**Hand-held terminal design and assessment**

The HHT is designed to be used by a Person In Charge Of Possessions (PICOP) or Shunting Area Manager, who work trackside, to manage possessions and shunting. Its main functions are to:

- Confirm the location of the PICOP to the signaller (operator);
- Receive tasks;
- Operate points within a possession or shunting area;
- Allow feedback on task progress, to help update railway plans and improve train scheduling.

Operators do not currently use a HHT. Instead, the location task uses physical short-circuit devices, which are presented on the track-circuits in the signal operator’s track diagram. On-the-ground activities and communications use paper-based reports and a radio or telephone. A task analysis, operational specification and personas were produced in conjunction with HF specialists from Fjernbane East. An important HF input was the development of an HF-lead
Style Guide. This was used to consolidate the design of the HHT and to direct all HMI implementations.

During the preliminary design, a series of evaluation exercises were conducted in conjunction with the HF specialists from BDK and Fjernbane East. Expert evaluations and low fidelity prototyping were used. These processes included a variety of people and expertise from BDK and Fjernbane East and West, such as ‘Super-Users’; TMS client team; HF specialists; and technical experts. The Independent Safety Assessor (ISA) was also invited to attend and observe.

User trials were conducted using the expected hardware device with prototype software. Six rail employees were guided through a set of trial scenarios using a script. Scenarios included possession planning; handover; requesting a Temporary Speed Restriction; and handing back a Temporary Shunt Area. Each participant started the session with either bare fingers or gloves. A second run was performed using a touch-screen stylus, for comparative purposes. Gloved operation is illustrated in Figure 4. Data collected included:

- HF expert observations of task performance and usability (e.g. errors made, learnability; weight of HHT);
- Time taken on each (sub) task;
- HF expert observations of physical hardware characteristics;
- HF expert observations of user interactions with the HHT software.

**Figure 4: HHT user testing with gloved hands**

Users were observed to attempt gestures which were not available on the device for safety and maintainability reasons, such as swiping and press-and-hold. Gloved operation of the touch-screen was found to be problematic because of the type and thickness of the gloves and lack of dexterity they afford. The HHT was also perceived to be too heavy for prolonged use. However, all users could
complete the prescribed tasks in the required timescales and were quick to learn how to navigate around the device. The user experience varied depending on aspects of the target audience such as age, role and reported dyslexia. The results were used to generate specific recommendations for future iterations of the design.

**Design for maintenance**

Thales-Strukton are responsible for installing trackside signalling equipment in the TCC building equipment rooms and control room; satellite locations; trackside Technical Object Buildings (climate shelters and protection against unauthorized access for the signalling equipment); external equipment cabinets; and track equipment (such as marker boards, point machines, axle counters and level crossings). A set of detailed maintenance task analyses identified maintainer requirements which will be re-used by the training teams.

A number of different comprehensive HF maintenance checklists were developed. The tools comprised HF project requirements; personal safety and access requirements (UK Railway Group standards); UK and USA defence industry HF requirements (DEFSTAN 00-250 and MILSTD 1427G); Thales ‘in-house’ maintainability information and HF best practice. The checklists were designed so initial HF assessments could be conducted without the need for an HF specialist, and followed up by focused HF support. The aim was to expand the reach of HF influence.

**Safety case support**

The project Hazard Log was reviewed to identify HF-related hazards. HF input to the Hazard Log is ongoing at the time of writing and should continue throughout the programme. The largest proportion of human causes of hazards at a project level pertained to manufacture, installation and maintenance. Design and development hazards were also captured. These human causes are being addressed by best practice in the maintenance process; manuals; and documentation quality control. Where hazards have been identified as linked to operators, appropriate mitigations were sought through design of the equipment and software. Where the hazards could not be managed through design, they were exported to those who could best manage them, such as those responsible for the railway company processes, rules and training. Evidence from the safety integration HF analysis will be used to support supplier Safety Case submissions.

**HF Benefits and Lessons Learnt**

This paper described the HF activities involved in the Denmark rail (West) infrastructure upgrade. An important lesson was that focused HF work-packages in the HFIP helped ensure timely delivery of HF input. Scoping the HFIP correctly in the first place, aligning the deliverables and content with the project
deliverables and stages of development, is critical for HF to be beneficial and not just about ‘box-ticking’. Earlier involvement of HF would have been preferred.

The task analyses conducted for this project have been reused for a number of practical benefits. Often, a task analysis is useful only to those who produce it. However, on this project, task analysis material will be re-used by the project’s training and maintenance teams. Additionally, the client organisation has used the task analysis to review user interactions with the systems and interfaces.

The workstation development and control room layout involved a considerable amount of resource effort. The work completed by the HF team was fundamental in gaining client trust for the most obvious user-facing products. However, a key lesson learnt was that strong guidance is required for workstation and room layout design. The users were not always correct in the placement of items. Indeed, they often sought the assistance of HF professionals and did not want to give an opinion that may be judged by their peers in the future. It is therefore advisable to provide simple options, all of which are compliant; or show options that are not compliant and help users realise why. It is inadvisable to assume that users should lead the discussions and decision-making because a single, strong voice can inappropriately direct the outcome.

The HF workload analysis and workstation ergonomics provided valuable content to the supplier and client organisations to guide decision-making with respect to product selection and manpower requirements. The reduction in both should save future operating expenditure, and generate installation and maintenance savings. The control room layout was designed to facilitate teamwork and enhance the user experience.

The HCI Style Guide produced by the HF team was used to consolidate the design of the hand-held device. The software development process for the signalling system and the HHT further profited from systematic HF reviews. Software engineers’ ideas were in conflict with user needs. The users wanted and needed simple interactions that were quick, straight-forward and self-evident. The HF-lead user trials demonstrated speed of learning through the simplistic layout of controls. The benefits of the HF activities, as well as lessons learnt, are provided to inform future programmes of this nature.

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