KEEPING HUMAN FACTORS ON TRACK – THE DESIGN OF THE NEXT GENERATION INTERCITY EXPRESS TRAIN

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This case-study discusses the design and development of the UK's new Intercity Express train, to be introduced to the East Coast and Great Western mainlines in 2017. The paper describes the iterative development approach adopted to ensure stakeholder engagement and regulatory compliance throughout the design process. This includes the use of prototype evaluation, from very low to very high fidelity, and the application of human factors tools such as Hierarchical Task Analysis and an innovative approach to glare assessment. The paper highlights how the described multi-method approach considers both the cognitive and physical requirements of the user population, ensuring successful delivery.

Introduction

The approach described in this paper was developed to support the design of the Intercity Express Programme (IEP) Driver's Cab (see Figure 1). As described in Jenkins et al. (in press), the project involves the design and manufacture of 122 new trains for the UK's East Coast and Great Western mainlines, increasing capacity and reducing journey times. The first trains are planned to go into service in 2017. While the project involved the design of all the interior areas of the train, the scope of this paper has been limited to the design of the cab.

The link between cab design and driver performance is clear and well established. A well designed train cab provides reach to all equipment, good visibility of well organised controls and instruments, and a suitable view of the external environment. Historically, guidance on appropriate driving postures and control layouts have been dominated by the anthropometry of the drivers (e.g. Dreyfuss, 1955; Diffrient et al. 1973). On a physical level, controls should be arranged so that they are clearly visible and readable by the target population. Likewise, they should also be arranged to ensure that driving tasks do not require

poor postures that may result in driver discomfort or musculoskeletal injuries. Additionally, from a cognitive perspective, cab layouts should ensure that controls are easily identifiable, and that the mode of actuation is highly intuitive, with minimal risk of confusion or inadvertent operation. Controls can be assessed individually based on simple heuristics. However it is also important to assess the cab in its entirety against its anticipated scenarios of use.



Figure 1: Internal view of the final cab mock up

Many different people will interact with a passenger train across its lifespan on a physical and a cognitive level. As such, there are many stakeholders that have a vested interest in the final design. These include the representatives for the train drivers, train crew, maintenance staff, cleaners, passengers, cyclists, and persons with reduced mobility. They also include representatives from the train operating companies and the UK Department for Transport. Alongside stakeholder engagement, there is also a need to demonstrate compliance with a number of contractually specified standards and mandatory regulations.

To ensure that the physical and cognitive needs of the stakeholders are considered throughout the design process, it is very useful to create a human factors integration plan to highlight the activities that are required at different stages of the design process. This process is explained at a high-level in the following section.

Approach

Development of product requirements

Contractual and regulatory requirements formed the basis of the human factors requirements. For example, for passenger areas, guidance exists on the location of buttons above floor height, their maximum actuation force and arrangement. The relevant requirements were presented in tabular form in order to capture the description and their origin, along with a column allowing compliance to be recorded at each stage of the development process. Anthropometric datasets of the user population (e.g. Adultdata, 1998) were also used to create additional requirements where appropriate. The requirements list remained a living document throughout the project and was updated as new requirements were identified.

Desk based evaluation of concept

The initial layout of the cab was constructed and evaluated using Computer Aided Design (CAD) models. In the initial stages, 2D projections provide an efficient way of considering the design. Reach envelopes and mannequins based on anthropometric data can be used to optimise the layout for reach and visibility of controls. Likewise, in terms of external visibility, standards exist (GM/RT2161, 1995) that describe largely unambiguous test criteria for assessing forward visibility using sightlines. 3D CAD models are also used to optimise the cab layout as the design matures.

The initial cab control layout was also informed by the guidance provided in GM/RT2161. This standard also classifies each of the commonly used controls within the cab as either primary or secondary in terms of reach and visibility. By arranging the controls based on this guidance and the familiar layout of legacy trains (such as the Class 395 train), a basic design was derived. The initial control layout for the cab was also heavily influenced by the requirement to operate the combined power brake controller (the 'T' shaped handle to the left of the driver; see Figure 1). As the actuation of this control requires the use of the driver's left hand, the majority of controls and screens with touch screen functionality were moved to the right side of the cab, while indicator lamps and displays without controls (CCTV screens) that do not require actuation, were located on the left side of the cab. Functional grouping was also employed to cluster similar controls to aid the task of identification (e.g. grouping all controls to do with the control of diesel engines in one place). Likewise consideration was made of the consistency with current rolling stock and the need for future upgrades.

Physical evaluation and refinement of initial layouts using part prototypes

Once a basic cab arrangement had been formulated, this was then assessed with representative train drivers from each of the train operators (three from each). To support this, a low-fidelity prototype was constructed (see Figure 2). This 1:1

scale mock up provided a low-cost representation of the cab panels along with controls printed on paper, allowing them to be easily repositioned. Each of the drivers performing the assessment was encouraged to rearrange the controls to best represent their ideal control layout. As expected, different drivers favoured different layouts, partly due to individual preferences and experiences and partly due to different working procedures between the two Train Operating Companies. However, through a process of rapid iteration, the group was quickly able to achieve a consensus of opinion that closely matched the original proposition.

The early engagement of stakeholders provided an extremely useful method for validating the design and accommodating changes before significant design work had been undertaken. It is, however, important to draw the distinction between stakeholder-informed design and user-led design. The low fidelity mock up allowed the physical space constraints of the cab to be communicated. In addition, a human factors specialist was involved throughout the process to communicate the importance of control grouping and spacing.



Figure 2: Validation of early control layout

Evaluation and refinement of full-sized spatial mock ups

Once an agreed design had been established, the design was revised in CAD and represented in a full-size spatial ergonomic mock up (see Figure 3). A second phase of assessment with train drivers was conducted to further refine the design. The addition of a fully functional production chair allowed a more accurate assessment to be made. As such, further refinements were made based on reach and visibility and the comfort of the posture required to actuate each of the controls.



Figure 3: Validation of control layout in ergonomic mock up

Evaluation and refinement of full-sized visually representative mock up Following the ergonomic mock up, a 1:1 scale visually representative mock up of the cab was constructed (see Figure 1 and Figure 4 for exterior view). This mock up adds an additional level of fidelity by using production versions of the driver's seat and controls, as well as providing representative colours and surface finishes.

Alongside fitting trials assessing comfort and reach, the full mock up was used to conduct a glare study (see Jenkins et al, 2015). Unlike assessment of other factors, such as forward visibility, there are no standardised approaches for performing assessments of glare. While it is unrealistic to evaluate every possible lighting condition that may potentially occur in the vehicle cab in service, a pragmatic and practical approach was taken to provide a good level of indicative information about the cab design's likely glare performance against internal and external light sources. The assessment of internal light sources involved blacking out the cab windows and assessing the impact of glare from internal lights and illuminated controls. The impact of external lights was assessed by simulating external light sources (e.g. the sun, other trains' headlights) by illuminating the cab mock up windscreen, side and door windows with a single light source manually located in a sequence of discrete positions and orientations and assessing the resulting glare impacts (see Figure 4). As a result of the glare study, modifications were made to the cowling along the top of the cab control console, internal lights were recessed, control panel angles were adjusted, and a patterned film was added to the side windows. The glare study was repeated following



these modifications to the cab and found to confirm the effectiveness in terms of reduced instances of instances of direct and indirect glare..

Figure 4: Arrilite light source on a Hague CamCrane K16DV aligned to one of the positions on the train side window

Formal assessments of the train operating tasks were also conducted in the full mock up. A structured approach for assessing a train cab against task requirements was developed. The assessment is divided into two stages; (1) the first assessed the location of each of the cab controls in turn against their frequency of use, functional grouping, and risk of inadvertent operation. (2) The second assessed the cab against routine tasks based on a Hierarchical Task Analysis (HTA) model. For the initial static assessment, a list of all the controls within the cab was compiled in tabular form (87 controls). Columns were added to the table to capture the control type, location, frequency of use, and whether the control was used while driving or stationary (e.g. door controls). Three train drivers (recruited to represent both Train Operating Companies, both genders and a range of statures) were asked to actuate and assess each of the controls in the cab in turn, observed by a human factors expert. For each control, the driver was asked to report any concerns or issues with visibility, reach, risk of inadvertent operation and suitability of posture while actuating. The driver's comments were recorded in the table along with any additional observations from the human factors expert.

In order to assess a cab against common tasks, or sequences of operation, some form of task description is required. Ostensibly, task analysis involves breaking down a task into smaller sub-tasks or operations. Arguably, the most commonly used and well-known task analysis technique is Hierarchical Task Analysis (HTA; Annett et al 2007). HTA involves breaking down the task under analysis into a nested hierarchy of goals, operations and plans. The end result is an exhaustive description of task activity, which, importantly for the train driving task, can be distilled down to modelling the actuation of individual controls. Despite HTA being one of the most commonly used human factors approaches, as reported by Rose & Bearman (2012) there are few examples of HTAs that cover train driving in the public domain. As such, the option of adopting an existing HTA model for the purpose of this analysis was not available. Rose & Bearman (2012) present a task analysis model of train driving for the purposes of identifying human factors issues in new rail technology. However, the model they discuss is based on goal-directed task analysis, a variant of HTA that places a focus on situation awareness. As a result of this focus on situation awareness, the model is primarily concerned with the cognitive aspects of the task, and does not contain the detail of the physical control manipulations required for this analysis. Accordingly, the first stage of the process was to create a task model that included individual manipulations of controls. Initially, an HTA model was built based upon a Class 395 operating manual and cross-referenced against the model created by Rose & Bearman (2012) and a report by Haworth et al. (2005; Based on the Australian railway) to ensure its completeness. The overall goal of the train driving specified at the top of the hierarchy is broken down into subgoals (for example, start-up, drive train, manage communications). In turn, these goals were decomposed further until an appropriate operation was reached (e.g. place foot on DSD pedal, depress plunger, check for alarm, and check CCTV). The first draft of the HTA model was validated with two train driver experts on two occasions to ensure its suitability and completeness. The validation process involved stepping through the model task-by-task (in a tree view format), adding additional detail and validating the plans. Once an agreed task model was finalised, the task steps (nodes) were coded to indicate which of the tasks would be explicitly assessed in the cab. Omitted tasks included elements that were not supported by the mock up (for example, data entry on the train management system, or using the key to unlock the door). In addition, sub-routines that had been previously assessed a number of times were also omitted. The resultant model contains a total of 513 nodes (360 base level operations) of which 187 tasks were explicitly tested.

The task model was taken into the cab in list form and the drivers were asked to perform each of the tasks in the order dictated by the HTA (read aloud by the human factors specialist). After each task step, the driver was asked to report any concerns or comments about the current layout. These were recorded in an additional column in the HTA table along with additional observations from the human factors specialist. Detailed assessments included an assessment of ingress and egress, an assessment of emergency evacuation of the driver's seat and the second person's seat, assessments of standard driving tasks, and an assessment of emergency procedures. The adopted approach proved to be an effective mechanism for validating the cab control layout. Specifically, the system design and the associated number and location of controls were challenged and in some cases simplified as a result of the process. The static assessment ensured that each control was considered and evaluated in turn. In addition, the sequenced assessment identified a number of issues that are unlikely to have been detected from a static assessment alone. Moreover, the clear structure of both assessments has allowed them to be readily communicated to the wide range of stakeholders involved in the project, thus supporting prompt and well considered decision making.

Conclusions

The outcome of the project is a stakeholder-informed cab design that is compliant with the identified project requirements. The two more innovative assessment approaches discussed in this paper, (1) the glare assessment and (2) the task-based assessment, were found to be very useful additions to the wider development process – producing new insights and allowing the cab to be further optimised. The glare assessment was found to be an efficient means of optimising the cab design to minimise the impact of glare – yielding practical recommendations for improvement. With regards to the task assessment, the sequenced task-based assessment was found to reveal additional insights which were not detected in the static assessment of the controls. This sequenced assessment is, however, considered to be a complimentary approach, rather than a replacement for the static assessment. There are, of course ,clear benefits to assessing each of the controls in turn, since this ensures that each control is operable regardless of the way the cab is to be used.

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