Addressing the Catch 22: No User, No Train

Fiona BIRD, Christopher PATRICK
Bombardier Transportation, UK

Abstract. Integrating Human Factors (HF) into new rolling stock is complicated by end user availability, absence of an integrated train, commercial constraints and concurrent engineering processes. Using broader definitions of ’end user’ and progressive HF de-risking allows Bombardier to ensure timely HF integration. This paper describes the approach including the assessment of HF risks, use of ‘virtual’ end users and subject matter experts, and progressive HF assurance and operability testing of finished trains to validate HF work streams and identify unforeseen issues.

Keywords. Assurance, Train, Testing, User,

1 Introduction

Traditional models of User Centred Design often focus on involving users early in the design process and iteratively testing designs until an optimal design solution is achieved. In complex manufacturing projects, such as the delivery of new rolling stock, this process is often impractical as the usability of a product often emerges through the integration of multiple zones and subsystems. In practice, this means that user testing only becomes viable when the costs of change become prohibitively high, limiting the opportunity for ergonomic optimisation.

To overcome this problem, Bombardier’s HF team has developed a structured process of procedural de-risking for rolling stock projects. This process decomposes the vehicle by zones and subsystems and then identifies areas of novelty or change which present HF risks. Programmes of targeted early design contribution can then be put in place based on the results of this assessment followed by HF assessments of increasing ecological validity appropriate to the design maturity of the subsystem. The aim of the process is that the first train level tests validate the design having minimised HF risks throughout the design lifecycle and preceding work streams.

This paper describes the process of procedural de-risking employed by Bombardier and the associated challenges imposed by this process including the identification of appropriate carryover, operating with limited availability of end users, and demonstrating the value of optimised ergonomic design. The paper utilises case studies from the development of the AVENTRA™ product platform, Class (CL) 345 (Elizabeth Line) and CL710 (West Anglia) to demonstrate how this process has been utilised successfully whilst acknowledging lessons learned and the need for continuous improvement.
2 No Users

2.1 The challenge
The process of involving end users in the engineering process is complicated by the number of stakeholders involved in the process. Before the CL345 contract was awarded, the basic AVENTRA platform product was already at concept phase, existing in the form of requirements and CAD (computer aided design) models. There were no historical customers for that specific product from whom feedback could be obtained and no supply contract in place to enable specific users from the operational railway to be involved. However, user input was considered critical to the long-term success of AVENTRA.

Even when an AVENTRA product is being developed for a customer, design activities often commence with no end users (e.g. drivers) available, for the following reasons:

- At bid phase, the design is confidential so the involvement of external end users would be inappropriate.
- At contract award, end users may not be available, e.g. for CL345 and CL710 the franchise was awarded after the rolling stock design had begun, so the Train Operating Company (TOC) was unknown.
- During the project, making end users available for design reviews and testing is challenging because of:
  - Costs associated with releasing end users from duty; paying for travel, etc.
  - Operational circumstances can mean end users must return to their front-line role despite planned engagement with the design teams.

During projects, the interface between the end users and the Unions is managed by the customer and often the customer is not the TOC, e.g. Rail for London was the customer for both CL345 and CL710; meaning end users can be another step removed from Bombardier.

When end user engagement is successful, it is not a simple process of eliciting end user feedback and changing the design. Where end users (as with all stakeholders) identify changes from the “as-bid” product, a robust change control process must be followed and the change is not guaranteed to be accepted. So, whilst end user’s engagement is valued, it is not guaranteed - the Engineering process will continue apace and Human Factors (HF) need to keep up, with or without the presence of the end users. By taking a wider view of the definition of “end user” and the methods by which end user requirements and needs can be elicited, it is possible to implement a user-centred approach without the users being physically present.

2.2 Finding users when there is no customer
During the early development of the AVENTRA product platform, Bombardier’s Engineering and Sales teams engaged with industry seeking operational feedback on existing rolling stock and aspirations for future rolling stock. The feedback focused on energy efficiency, reliability, maintainability and reducing overall lifecycle costs, as well as improving items that generate operational issues, e.g. toilets. These were captured as requirements for integration with the design.

From an end user perspective, Bombardier’s HF team captured lessons learned from the previous projects and HF good practice in the form of the requirements which were allocated to
other disciplines, zones and subsystem owners. The HF team also elicited feedback from East Midlands Trains’ drivers on the AVENTRA concept driving cab using a wooden mock-up.

2.3 Theoretical users

Where physical people are not available, theoretical or ‘virtual’ users can be created based on defensible data. For CL345, this process started during the earlier AVENTRA platform development. The HF team had data and proven processes available from the development of Bombardier’s ELECTROSTAR™, TURBOSTAR™, S-Stock and 2009 Tube Stock for London Underground. This was supplemented by available industry data, standards and requirements.

2.3.1 Physical and Competent Theoretical Users: Target Audience Description

The Target Audience Description (TAD) provides a set of anthropometric data with corrections such as allowances for clothing, slump, maximum joint movements, etc. and user competencies based on existing legislation and standards. Using this data, mannequins are created in ALIAS™ to aid CAD-based physical ergonomics assessments of the cab, saloon and exterior design as they develop, providing progressive assurance of their compliance. This process of design and assessment is conducted jointly by HF and the Industrial Design team. Both data and mannequins are backed up by sufficient assurance demonstrating the validity of the method by which they are developed. The findings of the final assessments against the compliant design are recorded in physical ergonomics reports.

2.3.2 Working Theoretical Users: DITLOTT and Task Analysis

DITLOTT (Day in the Life of the Train) is a multi-stakeholder workshop that reviews train operation including interactions between users and the train and its subsystems from train preparation through to stabling. The workshops are typically attended by various stakeholder engineers who understand the required functionality of the train and operations specialists who understand how the train will be used. This multi-faceted approach provides a sanity check that the train concept as-bid against existing requirements will deliver what is needed by the customer. The output includes the elicitation of candidate requirements for inclusion in the design and an operational concept. Candidate requirements are new requirements which need to be assessed in terms of their technical and commercial impact before they are accepted and incorporated into the design.

The DITLOTT session provides a valuable input to the driver’s task analysis. The purpose of task analysis is to study an operator’s actions and/or cognitive processes required to achieve a goal (Salvendy, 2006). Task analysis data has various applications in the design process that define its scope and stopping rules. The scope of Bombardier’s driver’s task analysis is limited to driver interactions with the train as opposed to competency-based decision-making tasks and interactions with the external infrastructure because:

- the customer’s Train Technical Specification (TTS) specifies the systems to be fitted to the Unit and the requirements to be met to make the train operable on routes foreseen in the life of the train; so infrastructure based analysis is not necessary.
- assurance documents are created that detail the requirements and user interactions for all controls, indicators, alarms, human machine interfaces (HMI); so there is no need to duplicate this information.
the Functional Integration and Vehicle Engineers allocate functions to the appropriate subsystem or end user as appropriate; so there is no need to conduct functional allocation.

training needs and associated training manuals are managed by the Product Integration team; so the Task Analysis is not needed for training needs analysis.

The primary uses of the Task Analysis are:

- to check that all controls, indicators, alarms and interfaces have been assessed in terms of human error and workload
- to define operational scenarios for scenario-based Operability Testing on static and dynamic Units.

2.4 User Representatives

Whilst end users, e.g. drivers, passengers, have valuable input and are critical to certain HF activities, e.g. testing, valuable input is available from other sources where end users are not available. As discussed previously, users can be represented by operational specialists and other industry stakeholders in processes such as DITLOTT and Hazard and Operability Assessment (HAZOP). Umbrella organizations have the “bigger picture” view and can represent a range of end users based on their research but can also engage other organizations to which they are related, e.g. passenger reviews were undertaken by Transport Focus on CL720 with additional input from persons with reduced mobility. The customer will liaise with Unions and provide feedback to Bombardier through agreed communication channels.

Aside from verbal input, industry standards and guidance often aim to standardize user design and communicate human factors or operational good practice; sources include British Standards Institute, International Union of Railways (UIC) and RSSB (Rail Safety and Standards Board).

It is also worth bearing in mind that the design of trains and their subsystems is well established and as such there are few elements of a train or its operation that are completely novel. Where novelty often occurs is new combinations of subsystems to deliver functionality or performance. Recent examples include signalling and the incorporation of Driver Awareness Systems (DAS). CL345 for instance interfaces with three signalling systems during its journey from Reading in the West to Shenfield in the East. Wherever appropriate, carryover design is used which is accompanied by HF design assurance, evidence from verification and validation activities and, ideally, where proven in service.

End users are required, however, for testing where operational knowledge and experience is critical, e.g. operability testing on static and dynamic Units where new or novel concepts are being proposed for use in service.

3 No Train

3.1 The challenge

The second aspect of the Catch-22 facing rolling stock developers is that by the time there is a prototype, mock-up or end-product of any subsystem, zone or train which can be tested, it is often too late in the project to make significant changes to the design based simply on user
feedback. Costs and timescales are fixed at contract sign-off so change must be carefully managed, particularly where it impacts long lead-time items, which need to be ordered early in the design phase if the final delivery date is to be achieved.

The management of all engineering and design activities is defined by the Bombardier Engineering Process and, recognising the number of disciplines involved in a project, this process will not change to accommodate the whims of HF Specialists. As a result, the HF team has had to develop a progressive de-risking approach that fits with this wider engineering process. The result is an evolving set of HF activities, which develop through each design phase; from the systematic identification of risk and requirements in the bid/concept phase which subsequently define the targeted HF activities that need to be performed to address those risks through the design and realization phases of the programme. The result is a train that complies with the necessary requirements and manages critical HF risks in a timescale acceptable to Bombardier and the customer.

### 3.2 De-risking the theoretical train

The HF team at Bombardier has developed a de-risking approach to HF integration for AVENTRA vehicles. This utilizes previous project experience and lessons learnt from the development of ELECTROSTAR and TURBOSTAR multiple units, S Stock and 2009 Tube Stock. This process, used in the design of CL345, is discussed in the following sections and summarised in Figure 1.

![Figure 1 Bombardier approach to de-risking the integration of HF into rolling stock](image)

#### 3.2.1 HF Risk Matrix (no train, no user)

The foundation of the process is the HF Risk Matrix. The purpose of the risk matrix is to identify areas of novelty, carryover and modification for a given class of train and highlight and categorise potential risks in terms of HF as early as possible in the project lifecycle. The risk matrix breaks the train down into its various zones and subsystems based on a generic AVENTRA vehicle architecture. Potential risks are identified and classified in terms of the history (proven in service and/or previous HF assurance) and the consequences of the risks identified (safety such as injuries; or operational such as delays to service).
This results in a prioritised set of potential risks which forms the basis of the plan of activities for the HF team: the Human Factors Integration Plan for that project.

3.2.2 *Theoretical Assessments (theoretical train, theoretical user)*
Where a risk is identified through the HF risk matrix, the first step in addressing this risk in the design is to work with the system owners in the early development of that system to guide the design towards a form and function which is appropriate for the needs of the end user. At this point in the design process, there are no users and no train so risks need to be identified and mitigated through theoretical methods that are based on sound commercial knowledge and HF good practice. This is achieved through activities described in the following sections.

**Assessments against guidance and standards**
The HF team become involved in the early design phases defining requirements using experience from previous projects, standards, industry conventions, etc. and evaluating proposed design solutions. At this stage, it is possible to use data that is available on the theoretical user, as described above, to make design decisions that can be assured. The layout of controls and indicators can be determined and agreed by considering the user tasks and frequency of use as well as expectations regarding functional grouping and expectations from other national rolling stock. The impact of control / indicator colour, type or shape mandated in standards can also be captured at this stage. The size and position of doors, steps and external door controls can be assessed using simple anthropometric data and access to equipment in accordance with theoretical maintenance guidance can be reviewed. These can be discussed with available users and subject matter experts using paper-based layouts during the early concept phase.

**CAD assessments**
Once a physical zone e.g. cab, or subsystem e.g. doors, is in the process of being designed, the HF team perform assessments of the design models to ensure that design compliance can be achieved. Here the theoretical users in the form of mannequins, discussed above, are employed and placed in the CAD models of the train. The mannequins are moved and manipulated in a wide range of assessments of the cab, saloon and exterior zones. Assessments include but are not limited to external sightlines, internal cones of vision, reach to controls and equipment, access / egress and throughways. The results of these assessments are recorded and form the basis of the HF design assurance for the physical ergonomics of the train. A typical assessment of the minimum percentile driver’s fingertip reach in the cab is shown in Figure 2.
3.2.3  **Mock-Up Assessments (theoretical train and users)**
As the design matures the CAD assessments are verified through mock-ups. During the development of the AVENTRA platform, full-scale wooden mock-ups were created of the cab and cab exterior doors to conduct assessments and aid reviews with stakeholders. The mock-ups included paper control panels, as opposed to physical controls, and this was sufficient to enable further assessments of internal cones of vision, reach to controls, access and egress, throughways, accommodating the user in the seated position, etc. The user, in this case, was initially represented by the customer’s engineer and operations specialists who reviewed and modified control and indicators positions considering operational experience as well as discussing and challenging HF theory used to underpin decision making where compromises between HF and engineering constraints were necessary. This was followed up with a review by the end user representative body, the Unions. The mock-ups also enabled the development of specific subsystems that were more difficult to assess in CAD models, such as the side windows to allow stop boards to be seen and the second person seat which was purpose built to comply with HF requirements and accommodate the constraints imposed by the door system.

3.2.4  **Physical Ergonomics Assessment (train, no user)**
The physical ergonomics assessment is a dimensional check conducted without users to ensure that the dimensions cited in the CAD/mannequin-based assurance document are accurate on the train once it is built (within design tolerances).

3.2.5  **Operability Assessments (train and user)**
There are three possible operability assessments: static, dynamic and on-network. These tests are conducted with end users on the train, interacting with and using a zone and/or subsystem(s) as per the scenarios defined in the task analysis. This enables the HF team to determine if the HF
design assurance is valid (i.e. can it be used as expected), determine that no further HF risks are present in the design when used in context and conduct assessments that could not be assessed using theoretical trains and users, e.g. stopping the train using the traction brake controller (TBC).

The operability test is split into three to enable testing to be done as early as possible, e.g. it is possible to do the static operability assessment before the train is in a state to move, and it is possible to do dynamic testing on the Bombardier test track or at Old Dalby test track before it has sufficient permissions to operate on the customer’s network. This enables progressive de-risking to continue seamlessly from the design phase into realization as and when a zone or subsystem reaches an appropriate state of readiness.

4 Discussion

The challenge that Bombardier’s HF team faced in the development of the AVENTRA platform was producing a train design that was compliant with HF requirements when there was no train to assess and no end users available with whom to review the train. Bombardier had the advantage of having utilised HF in-house for over 20 years and had a strong baseline of data, tools and methods from which to further develop their approach.

The resultant HF process takes a flexible approach to the use of HF tools and methods to enable them to fit in with the Bombardier Engineering Process. The progressive de-risking means that there is no need to rely on the presence of a design or end users; it enables the HF team to provide appropriate HF input to subsystem and zone owners at critical points in the design process. This can be captured in the design with HF assessments occurring iteratively as the design develops using information that is available.

“User” input can take various forms and is used flexibly in a manner that is cost-effective, supports compliance with requirements, is appropriate to the state of the design of the train and considers the availability of end users. So, when the end users and the train are available together for final testing, any issues identified should have a low consequence (if any at all).

The lessons learned process is on-going; what works well and what could work better is constantly being reviewed allowing the costs-benefits of alternative approaches and enhancements to be discussed and improvements implemented. This has led to significant cost-benefits associated with the Risk Matrix, Human Error and Workload Assessment and Task Analysis. Going forward, the Risk Matrix is identified as needing further development to support a closer working relationship with Bombardier’s Product Safety Team.

One recent development has been the creation of a global Centre of Competency for HF within the business. This means that the HF process used on the AVENTRA platform and CL345 is likely to be developed into a standardized approach which can be used by Bombardier worldwide.

5 Conclusion

This paper describes some of the challenges associated with integrating human factors into new rolling stock designs including the availability of end users, the absence of an integrated product until the last minute, commercial constraints and concurrent engineering processes. To address these challenges and ensure the timely integration of human factors Bombardier has developed a risk-based approach of progressive design assurance using a variety of inputs and definitions of end user characteristics which culminates in operability testing to validate preceding HF work.
and capture unforeseen issues. This approach has been used on Bombardier’s AVENTRA trains. The first example of this rolling stock family, the CL345, is now in service on the Elizabeth Line running through London.
The HF process is continually being refined to maintain its fit with wider business objectives and, with the creation of a global Centre of Competence for HF within the business, likely to be developed as standardized approach for use by Bombardier on any project.

References