Case study

Users and Design Review - What Mock-ups Offer

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Abstract

**Background:** Numerous standards advocate user participation in the process of designing work systems. An iterative design process between designers and users is suggested as important to develop a successful human-machine system. The various methods that have been suggested for user input include: task analysis and review; drawing review (including CAD); mock-ups; prototypes; first of class (FoC) validation; and user trials. Mock-ups are typically a full-scale 3D representation of the design. They can range from a small isolated part of a design to a representation of the whole. They can have varying levels of fidelity: ranging from cardboard cut outs through to full representations of operators' areas including workstations coated and finished to provide the same look and feel as the final product. Mock-ups can increase in fidelity as the design process progresses. **Aim:** This paper explores the role of mock-ups as an interactive design mechanism. **Method:** Examples will be provided from rolling stock projects involving operator cabs and interfaces demonstrating how mock-ups have been successful in the design development stages for new and retrofit projects both large and small. Different methods to gather user input and challenges encountered by design teams will be discussed. **Results:** Mock-ups were found to provide effective user input when used at an early enough stage of the design process to allow design improvement. They appeared to overcome limitations of only using drawings, 3D CAD and task analysis which users found difficult to interpret. Prototypes and FoC would have been too late in the process to allow any more than minor design modifications. The opportunities found to be offered by mock-ups were: integrated view of the design, focus on outcome – task and try-outs; concurrent testing of options; real users seeing and feeling the design; procedural development/review; and, focus on particular questions. Mock-ups provided a focus for review for the whole design team. They provided an opportunity for designers/engineers to understand more about the user's role. Additionally, because mock-ups are tangible and easily understood, they appeared to result in users buying into the design project much more, so it becomes 'ours' rather than 'theirs'. **Conclusions:** Mock-ups were an effective mechanism for gaining user input into the design process if utilised early enough in the design process.

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Background

Engineers and designers spend their professional life designing things to be used by others. The items can range from a simple straightforward inexpensive item, like an eating utensil, through to a whole system that involves many interacting parts, such as a rail system. As the system increases in complexity, there is greater opportunity for the design to diverge and a wider variety of possible design solutions become available. The need to ensure the design provides an effective solution becomes more critical as the cost and implications of an unplanned retrofit process rises. Additionally, the longevity and cost of the product can influence the importance of getting the design right.

Getting the design right: what does this mean? In this paper this means the design is optimised for those who need to use it in order to successfully achieve the system objectives. In this context this is more than the operators. For a passenger train this would include the passengers, the station staff and the train maintainers, as well as, the train crew (driver and guard). Less obviously, it could include the track maintainers, the train controllers and signallers. Design consideration should not be limited to the physical equipment but, more holistically, should include the task and system design. In the rail industry, the design product can be seen to include the equipment, processes, procedures, rules, rule books etc. [1, p3].

Good practice suggests that an effective design results when:

- Task and user requirements are well understood
- Users are involved throughout the process

User participation is advocated by many, for example:

- ISO 6385 Section 3.1 [2] states: “Workers shall be involved in and should participate in the design of work systems during the process in an effective and efficient manner. In work system design, a participatory approach is essential in order to avoid sub-optimal solutions, because the experience of workers provides an indispensable knowledge-base. The design process shall therefore, wherever possible, involve workers in all stages.”
- AS 4024.1901 Section 5.1 [3] states: “... Knowledge of ergonomics principles is the basis for a successful implementation of a human-machine system. In particular,
it is important to ensure that systems are designed as an iterative process between the designer and the users.”

- British Rail Safety and Standards Board [1, p25] advocates that: “Involving users in evaluating the design product at an early stage in the design process will help to ensure that the product is best suited to its purpose. It will also minimise the time, effort and costs associated with making subsequent design changes. Once a system is in development, correcting a problem can cost an estimated ten times more than fixing it during design; once a system is being used, it can cost 100 times more.”

Methods that are used for reviewing concept designs and are used with users include:

- Task analysis and review
- Drawing review
- Mock-ups
- Prototypes
- First of Class (FoC) validation
- User trials/ usability testing.

Mock-ups, prototype and FoC differ in fidelity and, much more importantly, the stage within the design process where they can, practically, first appear. Mock-ups are used to stimulate discussion around arrangement, shape and/or appearance. In this paper a prototype is considered to be a functionally working sample representing the end result of the design process. FoC represents the first production of the completed design. In our experience there is widespread agreement from design teams that mock-ups are “a good thing to do”. However they are not always used or used well.

Industrial designers and human computer interaction specialists have long included mock-up and paper prototyping in their repertoire [4-6]. Interestingly, these techniques have mostly been focused on screen interfaces, for example, web pages and LCD panels. Many industrial design students develop sketch models using blue foam (i.e. a rigid fine foam material that is easily sanded, sawed and shaped) and foam core board (i.e. rigid foam and card laminate which is easily cut with a craft knife) as part of their course work. Often these students take these skills into their professional practice. Engineering has not had such a strong tradition of using these methods. In commercial engineering projects the use of mock-ups has not been so prevalent. This paper discusses the practical experience of using mock-ups in a variety of rolling stock projects.

Methods

Mock-ups were used within many projects to review and improve the design. These projects included: (1) small changes to existing designs to include additional controls; (2) a review of old workstations to see if improvements could be made to assist operators working more effectively, with less discomfort and fatigue. Often with a view to increasing the service life of the train; and (3) a review of new passenger train designs that will be in service for 30 years. In all these projects, the design had to fit within an existing system. The fidelity of the mock-ups varied. Some were simply a cardboard box with an available pushbutton mounted (Figure 1), through to mock-ups that had the look and feel of the real product with usable controls (Figure 4). In each project the mock-up was used to gain feedback from users, as well as technical reviewers.

The methods used to gain user feedback took a number of forms depending on the project. For example:

- User specific questionnaires. A separate questionnaire for:
  - train crew (focusing on cab area but with some questions on passenger area).
  - passengers (focusing on passenger areas and access).
  - ancillary staff (cleaners, maintainers, transit officers, …).
- Non-specific generic questionnaires.
- User groups participating in unstructured viewing of mock-up followed by group discussion.
- Specific fit and task reviews with administered questionnaire with ‘naïve’ operators (a naïve operator is not an unskilled or substandard operator, but rather one who has not been previously involved in the design).
- Semi-structured conversations while performing scenarios.
- Combinations of the above.

Review by technical reviewers generally took two forms:

- Taking measurements of size, force etc. generally used to determine compliance to either specifications or applicable standards.
- Group reviews using scenarios. These reviewers used experience and expertise to judge functionality. Items were not only evaluated for use but, often, also for misuse scenarios.

Results

For all projects, the mock-ups resulted in a better understanding of the design and all prompted change to the design. Examples of results from the mock-up process:

1. The colour of the aisle side grab handles on the passenger seats needed to change to the colour of all the poles and handrails elsewhere in the passenger area. It transpired that people were using colour coding to recognise areas that had been designed as handholds.
2. Exploration of the best location for a foot control within a sloping footrest such that drivers could comfortably place their feet on the footrest when not using the control while still easily reaching it when needed (Figure 1).
3. Adjust the position of an existing controller (i.e. the term ‘controller’ is used to refer to a device that allows the driver to adjust the braking or the powering or both of the train) that was originally too far forward to allow a range of drivers to reach it effectively despite the driver’s position between two controllers in a tight cab. The most difficult aspect was determining the optimum lateral separation between the controllers.
4. Adjustment of the desk layout – particularly controls and displays based on observing emergency scenarios (Figure 2). Engineers watched as the driver 'instinctively' went for the horn and the controller to stop the train.
5. Drivers had developed a local practice to compensate for a design issue. The mock-up helped identify this practice and underlying problem which ensured it was not replicated in the new design.
6. Adjustment of handrail height to a better location despite the original proposal being compliant to standards.
7. Adjustment of step and handrail relationship to increase the usability of the steps by a range of users of varying stature, strength and dexterity.
8. Identification of further practical scenarios for using steps resulting in identifying a need for lower handholds.
9. Procedural review that indicated the proposed solution for a system interaction would need operators to interact with two devices that were geographically separated even though one was receiving all the necessary information. The redundant device was removed and the second device updated to display all the relevant data.
10. Re-enforcement of paper review concerns about procedural difficulties.
11. Change of control types as the original controls provided insufficient visual and tactile feedback.
12. Review of control backlighting to determine whether the dimming range was appropriate.
13. Review of a new controller to ensure the musculoskeletal benefits gained were real and did not cause any unforeseen problems.
14. Confirmation that the proposed sweep of the windscreen wiper was too high and needed to be lowered (carried out in a cab mock-up that was on a train bogie that could be wheeled outside and onto tracks).
15. Identification that the relationship between controller, seat and armrest was not optimal. Comments varied as to the problem, but the underlying issue was the relationship between these three important elements. The relationship was improved by adjusting the lateral position of the seat.
16. Trade-off study on controller and seat height to maximise the number of drivers that could use the controller standing without affecting any seated drivers, in order to provide a larger variety of postures to more drivers.
17. Confirming height adjustment range for a footrest given the seat, controller and desk layout (Figure 4).
18. Passengers walking with bags and umbrellas etc. to identify catch points on handrails and grab points.
19. Transit officers indicated a new passenger area configuration was better than other trains because the aisle width and the seat handle design was such that they could walk through the train without catching equipment hanging off their belts.
20. Cleaners identified corners that did not have curved junctions and would collect dirt and finishes that would be hard to clean.
21. Wheelchair users suggested alternative allocated positions and changes to handrail arrangements that would make manoeuvring in a wheelchair easier.
22. Initial assessment of glare and sightlines.
23. On a new train the position of guards within the train was changed from the middle to the end. Assumptions of how guards would change their position in response to their different location on the train were made in the design. The mock-up allowed these assumptions to be checked and guards to test how they would work in the doorway (now at the end of the train), so identifying training needs.
24. Review the proposed relationship between the seat, writing surface and footrest for crew in a refurbished cab (Figure 3).

It was found that all methods used to gather user input were successful. However, a more structured method with responses from many users can result in more quantifiable numbers. These numbers can be useful for contractual discussions. However, designers report [4, 6, 7] it is often better to only use a few users (three to five) for each iteration and have a number of iterations to fully optimise a design. This latter approach can be successfully taken for in-house projects and with easily modified mock-ups. Too limited a sample can result in personal bias being reflected in the final design.

**Figure 1.** Low fidelity mock-up used to assess where drivers would and could place their feet while still easily pressing a foot control intermittently. This mock-up was rough and was made quickly from available materials not samples. Despite this it provided valuable design input.

**Figure 2.** Mock-up made from foam core board, hook and loop fasteners and photocopied controls and displays.
Discussion

The mock-ups allowed real people to use full-sized items to perform tasks in their usual or expected manner. Technical reviewers were able to more fully recognise the interaction issues in the designs.

Mock-ups Provided

From these examples it was found that mock-ups provided:

- Holistic and integrated review of the design.
- Focus on particular questions and scenarios.
- Assistance in procedure development and review (generally earlier and with more opportunity to influence design compared to traditional projects).
- Design and procedural adjustment.
- Identification of training needs.

For some projects 3D CAD drawings, including 3D manikins, as well as mock-ups, were used to review the design. However, the manikins were chunky and did not move like humans. Also, the 3D images were sometimes coloured for engineering review rather than rendered to give the look and feel of a train. The crew and passenger representatives did not get fully involved in reviewing the design. It appeared that the need for a technical person to present the design and the unrealistic colouring caused users to see it as a presentation of the design rather than an opportunity to engage and critique the design. Some information was gleaned but it was tentative and much less than from the mock-up.

Information Gained From Mock-ups

From these examples the unique information the mock-up process provided were:

- Full-size interaction.
- Relationship testing (result examples: 2, 3, 7, 8, 13, 15, 16, 23, 24).
- Realistic procedural review in workspace and with equipment (result examples: 5, 9, 10, 23, 24).
- Review of assumptions about actions etc. (result examples: 1, 4, 11, 12, 16, 21, 23, 24).
- Scenario review with experienced and inexperienced users (result examples: 14, 18, 19, 23, 24).
- Allow different design options to be tested (result examples: 2, 16, 24)

The mock-ups also helped to confirm design elements, for example windscreen wiper sweep (result example 14); footrest adjustment range (result example 17); grab point colour (result example 1). It would be expected that some of these could be identified by drawings and 3D CAD, however, the mock-ups identified them more easily and provided a reality check on how important or not the issue was in practice. In the case of the grab point colour, this was an unexpected result. This issue had not been identified from design images and may not have become apparent during 3D CAD review even if this involved end users.

Mock-up Fidelity Lessons

For some of these projects, the mock-ups were rough and ready (result examples 2 and 3 above). For example 2 the footrest was replicated with a cardboard box cut to the right slope and a push button (Figure 1). It took half an hour to assemble and a further hour to test with a range of people of
different sizes. The data was invaluable and gave the project team confidence that the concept was going to be successful despite the “quick and dirty” nature of the mock-up.

For examples 4 and 5, the mock-up was an initial mock-up made in foam core board and took about half a day to assemble (Figure 2). It replicated the crew desk in a train cab. The engineers were very pleased with the results as they received the information early enough to easily make substantial changes to their proposed design. A second more robust mock-up was developed which allowed confirmation that the changes were effective. It was a complete mock-up of the full cab with finishes and windows as proposed, allowing holistic review and consideration of glare and ambience. (The engineers involved in this project still use it as an example of how to do mock-ups particularly the foam core board desk.)

Figure 3 shows the mock-up used for example 24. It had a trial seat, desk and footrest made from manufactured wood and temporarily attached. It was used to assess the relationship of the writing surface, footrest and seat and the impact of the arrangement on the other tasks the crew member had to carry out. During the process, desks of various depths were tested.

The other mock-ups were of higher fidelity and became available later in the process (Figure 4). From the experience of these, it is clear that the earlier the mock-up is carried out the more latitude there is for design changes; the design group had not committed so many resources and so much money to the design, so were less locked into a design pattern; more elements were open to change. Also, as designers report, a rougher looking mock-up can result in more critique as the reviewers recognise the product is not finished and they are will not be ‘hurting feelings’ if they say it is not good [4].

**Mock-up Challenges**

From a project perspective, the use of mock-ups can be challenging. Some of the reasons are discussed below. The proper use of mock-ups involves not only the development of the mock-up itself, but also the proper planning of the data collection process and gaining access to the right number of subject matter experts.

For suppliers the mock-up stage is seen as a commercial project risk. The suppliers express concern including that the mock-up process will:

- Cause the design to change and incur more cost.
- Result in scope creep (people wanting more than the specification has requested) affecting delivery schedules.
- Involve users being unreasonable.

From the examples in this paper, it should be recognised that the lack of mock-ups could also incur a project risk. Without testing, the design may not be as effective as expected. For a train design, this can mean 30 years of inefficiency or redesign work that can cost 100 times more [1, p25] and even then the fix can be less effective than if the fault had been picked up during design. This should be considered a project risk, although the supplier may not see it as their risk depending on how the contract is framed.

These mock-ups showed the importance of contract linkages. It was found that:

- the mock-up review process needs to be explicitly linked into the design stages within the contract or it may be seen only as a “nice to do” for PR purposes.
- it is best if it is seen as iterative or else it may simply be delivered and ticked off and not seen as part of the design assurance/validation process.
- it can be seen as simply a representation of the supplier’s design rather than a design optimisation tool.

Also, contractually the mock-ups are difficult for engineers and lawyers as they do not provide exact numbers; they are considered soft.

Those managing projects need to recognise the benefits of mock-ups to managing project risk or else, when a project slips in time and/or budget, the mock-ups that were perceived only as “nice to haves” will be removed. Locating the mock-up can also be a challenge. Ideally, the mock-up is placed so all users can easily access the mock-up. When the mock-up was not in the same city, the logistics of getting users to the mock-up became significant.

**Comparison with Other Methods and Additional Benefits**

One of the key benefits gained from each of the mock-ups was the engagement of users in the design process. Users (and others) often find drawings too abstract, CAD better, but still distant, while mock-ups engage them. Prototypes and FoC also engage, but if issues are found it is generally too late to make any changes, other than small tweaks and cosmetic variations. In addition, this engagement with mock-ups generally changed the project from one being delivered by ‘them’ to a project for ‘us’ and provided an opportunity for designers/engineers to understand more about the user’s role.

**Conclusion**

The use of mock-ups in these rolling stock projects provided useful data and valuable information which resulted in better final designs both in retrofitting projects and new products. A key additional benefit was the engagement of the users in the project that resulted in the projects being ‘ours’ rather than ‘theirs’.

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References


