Common Human Factors Issues in the Design of Airport Surface Moving Maps

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ABSTRACT

A surface moving map presents a dynamic image of the airport, along with own aircraft's position. It is expected to improve the overall safety of airport surface operations, but could have unintended consequences if not implemented appropriately. The purpose of this effort was to incorporate usability testing to identify potential human factors issues that could limit the anticipated benefits of surface moving maps and propose possible resolutions. We partnered with industry to obtain two surface moving map software applications and conducted usability evaluations of them to determine common human factors issues. The results are classified into six categories: use of color, symbology, information prioritization, controls, speed and reliability, and taxi route display.

Keywords

Surface moving map, airport moving map, usability assessment, usability inspection, heuristic evaluation

INTRODUCTION

An airport surface moving map provides the flight crew with a dynamic image of the airport along with a depiction of their own aircraft (i.e., ownship). Airport surface moving maps are expected to enhance the flight crew's position awareness and improve the overall safety of surface operations, with additional benefits in terms of reduced taxi errors and shorter taxi times [2, 13]. However, as with any new display that is introduced into the flight deck, a surface moving map display could have a negative impact if it is not implemented appropriately. For example, there is evidence to suggest that a surface moving map may alter pilots' attention out-the-window [12]. Additionally, having any new display in the flight deck may increase workload and head-down time, so a display with a poor human interface could be even more problematic.

The purpose of this effort was to develop an understanding of the common human factors issues associated with the design of airport surface moving map displays in support of the Federal Aviation Administration (FAA). The FAA provides guidance for the design and approval of surface moving maps in Technical Standard Order (TSO)-C165, *Electronic Map Display Equipment for Graphical Depiction of Aircraft Position*, issued on September 30, 2003 [7]. TSO-C165 references RTCA DO-257A, *Minimum Operational Performance Standards for the Depiction of Navigational Information on Electronic Maps* [14], which contains human factors guidance and minimum requirements necessary for FAA approval. However, as more advanced functions are proposed, it is important to understand issues faced in the current state of implementation and identify where additional guidance may be needed to support future functionality. In addition, identifying and understanding common human factors issues for surface moving maps can also assist manufacturers in their design and evaluation process.

The simplest airport surface moving map may be a raster chart (e.g., a scanned version of a paper airport chart) that is geo-referenced at the runways, on which ownship position is superimposed. The airport information elements that are shown on the surface moving map will be identical to what is included on a paper chart, and the display may have limited functionality. More complex airport surface moving maps are developed from a database containing positional information describing the location of airport information elements (e.g., runways, taxiways, runway and taxiway markings, buildings). The database information is collected through a detailed airport survey that maps the location of these information elements. As a result, individual information elements may be manipulated on these types of surface moving maps, so more functionality is available than with raster charts. Advanced features such as the presentation of other aircraft information (traffic) and display of a taxi route have also been proposed. Examples of surface moving maps in development by manufacturers and research organizations can be found in Yeh and Eon [17].

Usability assessments are common processes for developing a better understanding of human-computer interaction. A usability assessment can be conducted using any of several techniques, each with their own strengths and weaknesses [5]. For example, Elgin, Raddatz, and Uhlarik [6] assessed the usability of two weather displays for the flight deck using components of different techniques. For example, evaluators incorporated usability inspection techniques as they familiarized themselves with the features and capabilities of each system to create benchmark tasks and to define an optimal series of steps for completing those tasks. Contextual observations and interview technique was then used to assess how well pilots learned and used each system. The results of the evaluation were used to identify and diagnose usability issues and develop potential resolutions.

The design of *in-flight* moving map displays has been studied to understand the tradeoffs in how this technology is implemented, e.g., the impact of track-up versus north-up orientations on navigational awareness [1]. Although airport surface moving maps have much functionality in common with in-flight moving maps (e.g., changing map orientation, zooming), the display elements that are shown vary considerably. Thus, while the results of previous research were somewhat applicable, it was important to identify, understand, and document the unique human factors considerations associated with the design of airport surface moving maps.

We worked with industry to obtain two prototype surface moving map software applications (Software 1 and Software 2). Both software applications obtained their data for depicting the airport surface from a database. Ownship position was drawn on a detailed depiction of the airport surface, including runways, taxiways, runway and taxiway identifiers, hold lines, and buildings. Software 2 provided the additional capability to show traffic aircraft and taxi route information.

Software 1 and Software 2 varied in terms of interactivity and capabilities. Software 1 was an interactive prototype, which used a simulated Global Positioning System (GPS) signal to present a dynamic display of ownship taxiing on the airport surface. Software 2 was computer-based training presentation that provided an overview of the surface moving map software via a series of interactive slides. Each slide displayed a screen shot from the software that allowed the viewer to actively use the functions on that screen. That is, although the presentation was not dynamic (ownship position was shown statically from one slide to another), the presentation provided the ability to interact with all of the functions (e.g., clicking on the zooming controls changed the map range correspondingly).

Because of the different presentation styles of each surface moving map software, we chose to evaluate Software 1 and Software 2 using different assessment techniques. (Note that because the focus was on the usability of the surface moving map software itself, no attempt was made to integrate either application with a flight simulator that could generate an out-the-window view). For Software 1, we used a technique similar to a *usability inspection*. Human factors experts walked through a series of task-based scenarios that represented typical tasks performed by end-users (e.g., changing the map orientation, zooming in/out, panning). While completing the tasks, they considered human factors aspects of the software de sign, such as the understandability of the symbols and the functionality of the controls. Usability inspections are often contrasted with formal usability testing, in which the interface is explored by typical end users while being observed by human factors experts.

For Software 2, we employed a *heuristic evaluation.* Human factors experts viewed and interacted with the training presentation for the surface moving map and considered how well it conformed to known usability standards and principles. Participants were asked to explore the functionality on each presentation slide and to consider the understandability of the symbols and labels and the functionality of the controls.

It is important to note that the purpose of the evaluations was not to compare the software but rather to develop a general understanding of common human factors considerations in the design of surface moving maps. Thus, although we identified usability issues specific to each surface moving map, we were more interested in determining common potential issues across all surface moving maps, given their different capabilities.

METHOD

Software 1 and Software 2 were assessed in two separate evaluations. Each evaluation consisted of three stages: *pre-usability inspection*, *evaluation*, and *data synthesis*.

Pre-usability Inspection

In the pre-usability inspection, we explored both surface moving map interfaces to familiarize ourselves with the software. For Software 1, we used this phase to develop a task list for the usability inspection. For Software 2, we did not develop a task list, but instead used this phase to fully explore the interface to understand the functionality of the software and the details of the presentation style. As part of this pre-usability inspection, we also reviewed the design of the surface moving map software displays to assess its conformance with FAA guidance (see FAA TSO-C165 [7] and RTCA DO-257A [14]).

Usability Evaluation

During the usability evaluations, human factors practitioners and pilots reviewed the surface moving map software. Seven participants evaluated Software 1. Of these, six had a background in human factors, and one of the six was a general aviation pilot. The seventh participant was an air transport pilot who was included for his domain expertise although he did not have a background in human factors. Software 2 was also evaluated by seven participants. Five of the seven had a background in human factors, and three of the seven were general aviation pilots. (Note that four participants evaluated both Software 1 and Software 2.)

It is worthwhile to note that the participants used for these evaluations were not typical end users (line pilots) nor FAA evaluators. Rather, because the focus was on the human-computer interaction, the participants were selected because of their experience and ability to provide insight into potential human factors issues.

Each usability assessment was conducted on a desktop computer in an office setting. Software 1 was evaluated using *task-based exploration*; participants were given a set of tasks that were considered to be common functions that the typical end-user might perform (e.g., change the map range by zooming into the display and report the current map range). The tasks were specifically chosen so that the participants could proceed from one task to another and fully explore each function that the software offered. Digressions from the initial task list were tolerated to allow participants the opportunity to fully explore the software as they were naturally inclined. Any tasks that were skipped during a digression were revisited later in the evaluation. Participants were asked to complete each task without assistance and were only given feedback after the evaluation was completed.

Software 2 was analyzed using a heuristic evaluation because it was better suited to the presentation of the surface moving map. For Software 2, participants viewed a series of interactive screen shots that showcased the functionalities of the surface moving map and interacted with the active controls. Participants reviewed the user interface and evaluated its compliance with known usability principles. Because Software 2 offered the ability to show other aircraft on the airport surface (i.e., traffic), participants were shown the proposed symbol set without context at the start of the evaluation and asked to identify what they thought each symbol meant. Participants then walked through the interactive training presentation and provided feedback on each aspect of the software.

Two researchers observed each session. Participants were asked to think aloud as they completed each task in an effort to better understand both their impressions of the user interface as well as their thought processes while completing the tasks. Researchers noted both the participant's verbal responses as they thought aloud and their performance while navigating the interface attempting to complete tasks. As necessary, the researchers probed the participants or asked for clarifications.

The evaluations for Software 1 and Software 2 each took approximately 1 ½ hours. Participants were intentionally not given time to familiarize themselves with the surface moving map software before the evaluations were conducted so that we could better assess how easily the interface could be learned.

Data Synthesis

In the data synthesis phase, a post-usability inspection of each surface moving map software was conducted to understand participants' actions and thought processes. In some cases, we re-examined the steps taken to complete specific tasks and recreate the issues encountered to better understand the root cause. Researchers' notes from all the usability sessions were organized into potential human factors issues, and these issues were then ranked according to their persistence.

RESULTS

The findings below represent a list of general human factors issues that were noted. An example is presented for each issue along with a discussion of why the issue should be resolved. The specifics of each manufacturer's implementation are not described in detail. More importantly, the issues identified here were judged to be prevalent throughout the surface moving maps evaluated and therefore findings from both Software 1 and Software 2 will be combined. It is expected that the issues may be applicable to other surface moving map displays as well, although the precise implementations will vary from one manufacturer to another.

Use of Color

Colors on surface moving maps are sometimes selected to match the out-the-window view. That is, an information element on the surface moving map is colored the same way it would appear out the window (e.g., hold lines may be drawn in yellow on the surface moving map to match its appearance on the airport surface). One concern with using this color scheme, however, is that it could lead to an excessive use of red on the flight deck; for example, red can be used for runway numbers, holding position signs, and land and hold short signs among many others. FAA TSO-C165 states that the colors red and amber/yellow be reserved for warning and caution situations so that they indicate an immediacy of response Overuse of these colors may reduce the effect these colors have on the flight crew's response and lead to slower responses to critical alerts [15]. Thus, any deviation from FAA guidance should be discussed with the FAA.

Another problematic color is the use of blue. The color blue has been used for taxiway identifiers or as a background color for text labels. However, due to the physical characteristics of the eye it is physically more difficult to see blue than other colors in many settings. Small blue symbols or labels may be especially difficult to read when placed on a dark background, and using a pure blue background for a label will often make the information more difficult to decipher [3].

Overuse of any one color to code airport information elements can also have a negative effect, particularly on visual search [4]. If too many information elements are coded using the same color these elements can become indistinguishable. The color white, for example, may be used to depict many information elements (e.g., runway and taxiway edges, centerlines, and ownship to name a few). In some cases, these information elements have similar properties (e.g., runway and taxiway markings are white lines). Consequently, if the designer is not careful when depicting these information elements, they may not be easy to differentiate.

Finally, the color contrast of information elements must also be examined to ensure that it is sufficient in all expected lighting conditions on the flight deck and particularly in glare. In some cases, the background color used for the surface moving map may be similar in luminance to the text, symbols, or graphics of the information elements that are overlaid. As a result, the information elements may be difficult to read.

Symbols

Surface moving maps provide detailed representations of the airport surface and may depict other aircraft on the airport surface. One issue in designing these symbols is agreeing upon the number of attributes that should be conveyed, e.g., whether the aircraft is in the air or on the ground, the type of surveillance technology used to transmit the aircraft's position, whether the ”traffic” is an aircraft or a ground vehicle. However, if all these attributes are conveyed, the symbol set will be large and may not be easy for the flight crew to learn and remember. Additionally, consistency across manufacturers regarding which attributes to encode and how will be important so that the symbols are not misinterpreted.

As the number of symbols increase, fine details may need to be used to distinguish between two different symbols. However, depending on the display quality and size of the symbol, these attributes may not be easy to see. For example, if a circle and an octagon are used to represent unique traffic vehicles, these symbols may appear indistinguishable on a low-resolution display or when the map is zoomed out. It is also important to consider the display size; the physical size of the symbols may vary depending on the size of the display on which they are presented, so fine details that are visible on one display may not be visible on another. In some cases, a minimum symbol size may need to be specified.

Information Prioritization

The design of symbols and information elements must consider the prioritization of the different information elements with respect to the pilot's task. One agreed-upon prioritization scheme is to present ownship symbol on top, followed by the taxi route, runways identifiers, runways, taxiway identifiers, and taxiways [14]. Such a prioritization scheme can prevent text labels and information elements from overlapping each other in such a way that information elements are not readable.

A decluttering scheme may also be implemented to reduce the amount of information on the surface moving map. Too many information elements presented on the surface moving map at one time may be perceived as clutter and increase the time required for information retrieval. Designers should consider how information elements on a surface moving map can be organized. An information analysis may help identify the value pilots place on different information elements throughout the various phases of surface operations (see Yeh and Chandra [16] for an example).

Controls

Controls for a surface moving map may be identified using virtual labels, but in some cases, designers try to take advantage of the flexibility of a virtual label by using the label as both a control and a mode indication. For example, the button that toggles the surface moving map between North Up mode (a stationary map with moving ownship) and Track Up mode (stationary ownship with moving map) may be labeled using the current mode. The control label is itself ambiguous, because the user may not immediately understand whether the surface moving map is in the mode indicated or if selecting the button will put the surface moving map into the mode indicated. The 14 Code of Federal Regulations (CFR) specifies that "*Each item of installed equipment must be labeled as to its identification, function, or operating limitations, or any applicable combination of these factors.*" ([8, 9, 10, 11]). Additionally, depending on how the control is drawn, users may not recognize the mode indication as being an active control. A consistent appearance may help users to identify buttons within a user interface.

Speed and reliability

The system response time will affect users' perception of the usability of the surface moving map. If the surface moving map does not respond to user input in a timely manner, pilots may enter multiple inputs erroneously. It will be particularly important to compare system response time of the surface moving map to other flight deck systems because the behavior and response time for one system will influence pilot's behaviors and expectations for other systems. For example, pilots make multiple rapid inputs in succession to the Flight Management System (FMS) display, with the understanding that each input will be processed accordingly. If the surface moving map does not respond in a similar way, pilots may perceive the interaction negatively. One way to help alleviate these issues is to present an indication if an input has been received or is being processed.

Taxi Route Display

One advanced function being proposed for surface moving maps is the ability to show the taxi route directly on the surface moving map. This taxi route may be entered manually via text entry and shown in text format only; drawn manually on the surface moving map, for example, with a "highlighting" tool that allows the pilot to trace the taxi route; or uplinked automatically through an on-board system or via datalink. Thus, the display of a taxi route is not without its costs as it introduces new tasks for the flight crew, which may contribute to an increase in workload. Consequently, special attention should be given to the method used to enter or receive taxi route information.

The graphical depiction of the taxi route must also be examined to ensure that it is distinguishable from other information elements. A taxi route that is drawn with a thin line may be indistinguishable from runway and taxiway markings. Alternatively, if the taxi route is drawn with too thick a line, one line may highlight multiple taxiways, hence resulting in confusion about the actual route.

DISCUSSION

There is a need to understand the human factors implications involved with the integration of airport surface moving map displays into the flight deck. In this phase of our research, we worked with industry to view and evaluate prototype surface moving map software applications in an effort to identify and understand common human factors problems. The evaluation process used here may also be useful to manufacturers to uncover human factors considerations or concerns that may not be apparent from the initial design of the surface moving map. Evaluations can be conducted on software at various stages of development and interactivity, as was the case here.

The general process for such an evaluation can be summarized in the following steps:

1. *Pre-usability inspection*: Become familiar with the user interface, identify key research questions, and develop tasks for participants to complete that address those research questions.
2. *Recruit participants*. Participants in the evaluation should be representative of the target end users. Including non-pilots (as was the case in the current effort) may be valuable for some types of evaluations, e.g., to understand software conformance with general human factors principles.
3. *Usability evaluation*: Conduct the evaluation. Observe while participants complete the tasks. Several techniquest may be used to gather information on the participants' thoughts and actions (e.g., think-aloud). It may be necessary to probe participants or ask for clarifications about their comments or actions.
4. *Data Synthesis*: Compile the observations from each participant to identify areas of the software design that led to errors or confusion.

Six common human factors issues associated with the design of surface moving map displays were identified. The current findings can be of use to manufacturers developing surface moving maps to inform the design and evaluation process. As with any new technology, the functions and capabilities for surface moving maps will continue to evolve, and it will be important to stay abreast of this evolution to understand the human factors implications. Addressing these human factors issues early in the design process will not only benefit the manufacturer, but also the regulatory authority and the pilots using the display.

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