2014

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Abstract
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Disciplines
Industrial Engineering | Mechanical Engineering | Systems Engineering | Transportation

Comments

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Characterization of Information Automation on the Flight Deck

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This paper summarizes the results of analyses to identify characteristics of flight deck information automation systems which can lead to potential human factors issues. Information automation systems are responsible for the collection, processing, analysis, and presentation of information to the flightcrew. Information automation systems can pose human factors issues and challenges particular to this type of automation. This paper presents a formal definition of information automation and identifies characteristics and associated human factors issues in the domain of aircraft flight deck systems. A method was developed to identify a set of consistent and independent characteristics of information automation. Characteristics, a set of properties or attributes which describe its operation or behavior, can be used to identify and assess potential human factors issues. This effort lays the groundwork for providing data to support the development of recommendations specific to different characteristics of information automation.

INTRODUCTION

Pilots are currently provided and have access to a large amount of information on the flight deck. Automation is used to not only assist in the control of aircraft, but also to manage information for presentation to pilots. Information automation systems are being used today and are responsible for collecting, processing, analyzing, and presenting information to the flightcrew. Automation has been defined as “...a device or system that accomplishes (partially or fully) a function that was previously, or conceivably could be, carried out (partially or fully) by a human operator” (Parasuraman, Sheridan, & Wickens, 2000, p. 287). Varying levels of automation result from the allocation of functions between the human and automation: at the lower end the human performs all tasks, and at the upper end the automation performs all tasks (Sheridan & Verplank, 1978). Parasuraman et al. (2000) refined the levels of automation framework with the addition of a second dimension corresponding to specific information processing stages: information acquisition, information analysis, decision and action selection, and action implementation. In this model, types of automation (i.e., sharing of tasks between operator and system) can be individually assigned at each of these four stages: acquisition, analysis, decision, and action automation.

Examples of information acquisition automation include organizing, prioritizing, or filtering incoming information based on some criterion (Parasuraman et al., 2000). Examples of information analysis automation include selecting and organizing relevant data, examining the data, analyzing the data, and applying algorithms to the data. Examples of decision automation include selecting from among available options, selecting the appropriate course of action, and selecting the best alternative. Action automation includes carrying out the selected actions, such as issuing commands to the aircraft, activating displays, or sending data to internal systems.
of information analysis automation capabilities include (Bass & Pritchett, 2008): converting raw sensor data into an easier-to-understand form, or comparing current sensor data to stored data or models to assess performance. An example of decision automation includes conditional logic that prescribes specific decision choices for particular conditions. Finally, action automation might, for example, execute a selected response.

Human Factors Impacts of Automation

Billings (1991) and Norman (1993) argued that the design of automation systems should be centered on the human operator, rather than pushing the human operator to the periphery and forcing them to adapt to the automation. Wickens (1994) pointed out that a potential result of poor automation implementation is human operators being “out-of-the-loop” with what the system is doing, which compromises situation awareness, increases complacency, and may lead to degradation of domain-relevant cognitive reasoning skills. Therefore, automation strategies must be carefully designed for the operator, with the goal of keeping operators appropriately engaged in their tasks and goals.

While this philosophy has been widely agreed upon, its implementation has progressed rather slowly. Sheridan (2001) points to the difficulty in creating predictive models of human behavior over those of physical systems as a cause for this slow progression. Additionally, economic factors and rapidly-emerging technology have continued to be the driving forces behind automation systems, resulting in a shift of human roles and responsibilities to essentially that of monitor, error handler, and automation manager, roles for which humans are not well suited (Wiener & Curry, 1980; Parasuraman, 1987). In these new roles, if an operator is not informed of what the system is doing or such indications are missed, then the operator may be surprised and perceive the system as behaving illogically. “Automation surprises” (Sarter, Woods, & Billings, 1997) occur when the system fails to take an expected action, or the automation carries out an action not explicitly commanded nor expected by the operator. This can lead to operators wondering what the system is doing, why, or what it will do next (Wiener, 1989). The end result is typically delayed response or completely missing the opportunity to provide corrective action.

The design of the automation should include how much information should be made available to the operator about the rationale, criteria, uncertainty, and determining factors used in forming its judgments and its actions (Bass & Pritchett, 2008). The uncertainty considered by the automation, and how that uncertainty is communicated to the human, also impact operator decision making (Andre & Cutler, 1998) and performance (Bisantz, Marsiglio, & Munch, 2005). In addition, the human-automation interaction is complicated by a feedback loop between the automation’s judgments and the human's information seeking, cue utilization, and judgment policy (Bass & Pritchett, 2008). The type and level of information about automation reasoning and behavior has a strong effect on the human’s trust, and may result in under or over-reliance on automation (Lee & See, 2004; Seong & Bisantz, 2002).

The type of automation may also lead to differing impacts in terms of human factors issues. For instance, Kaber, et al. (2005) found that for adaptive automation, humans were better able to adapt to changes in information analysis and action automation rather than for more cognitively intense information analysis and information decision automation.

Categories of Automation in the Aviation Domain

Fadden (1990) provided an initial distinction of aviation automation into two main categories: information automation, which involves the management and presentation of context-relevant information to the flightcrew, and control automation, which addresses the automation of those devices that directly impact the aerodynamics of the aircraft. Billings (1997) introduced a third category of automation called management automation, which deals with the efficient completion of a mission. While control automation is clearly distinct from information and management automation, further details to distinguish these latter two are necessary.

In broad terms, information automation is the programming logic that dictates what information is displayed, when it is displayed, and how it is presented to the flightcrew. According to Billings (1997), examples of information automation systems include the following displays: attitude and flight path, navigation, power, and alerting/warning systems. By contrast, management automation corresponds to the strategic, rather than tactical, operation of the aircraft and includes those functions allocated to the Flight Management System for mission optimization, including: aircraft system performance, guidance optimization, and system testing.

Parasuraman et al. (2000) refer to the two stages of acquisition and analysis automation jointly as information automation, where the primary objective in this context is to augment the operator’s perception and cognition.

INFORMATION AUTOMATION FRAMEWORK

The three different categories of aviation automation specified by Billings (1997) and the four information processing stages specified by Parasuraman et al. (2000) led to the framework shown in Figure 1. The horizontal dimension of the framework shows “What is controlled or acted upon?” The column headings represent parameters similar to the automation categories identified by Billings (1997) and reflect what the automation is controlling: the aircraft, the mission, or information. The leftmost column lists the “Information Processing Steps,” and shows what stage of information processing is being performed by the automation. The steps were defined using the terminology from Boyd’s Observe, Orient, Decide, and Act model (the OODA loop; Boyd, 1987). The rows of the table can be further identified as the four types of automation specified by Parasuraman et al. (2000): acquisition automation (Observe), analysis automation (Orient), decision automation (Decide), and action automation (Act). Different human factors issues are possible depending on the stage of information processing being performed.
Human error taxonomies (e.g., Threat & Error Management; with Air Traffic Control and Airline Operation Centers); manage systems); Flightcrew functions (e.g., communication flight deck functions (e.g., aviate, navigate, communicate, and manage systems); High level products (e.g., Electronic Flight Bag functions); High level automation were identified via brainstorming, pilot interviews, and meetings with stakeholders and other human factors experts. Multiple perspectives and research literature were considered (example citations and examples provided):

Products (e.g., Electronic Flight Bag functions); High level flight deck functions (e.g., aviate, navigate, communicate, and manage systems); Flightcrew functions (e.g., communication with Air Traffic Control and Airline Operation Centers); Human error taxonomies (e.g., Threat & Error Management; NextGen; FAA, 2013a); Human information processing model (e.g., observe, orient, decide, act); Automation human factors (e.g., Parasuraman et al., 2000; Billings, 1991; Lee & See 2004); Adaptive Automation (e.g., Kaber et al., 2005; Feigh, Dorneich, & Hayes, 2012); Situation awareness (e.g., Endsley, 2000); User experience level (e.g., Rasmussen, 1983); FAA regulatory and guidance materials; and Flight Deck Automation (e.g., Landry, 2009).

The affinity diagramming process (Beyer & Holtzblatt, 1998) was used to organize the initial list into a hierarchy revealing common issues and themes. The affinity was built bottom up by collaboratively organizing related items, until all items were placed in groups. Categories for the groups were not pre-defined; rather they emerged from the contents of each group. The resulting list of candidate characteristics was:

- complexity
- functionality
- authority
- level of integration
- opacity
- user interaction requirements
- criticality
- adaptiveness
- accuracy
- degradation behavior

One limitation of the approach was that it was not possible to identify whether any characteristics were missed. Creating the initial list by looking at the problem through different perspectives was an attempt to mitigate this issue. A second limitation was the possibility that some of the characteristics were redundant or captured similar human factors aspects of information automation. The analysis method described below was employed to address this limitation.

Figure 1. Framework to distinguish information automation from control and management automation.

In the framework presented here, the definition of information automation is expanded to include not only the first two stages of processing, but also the final two stages if what is being controlled is information itself. For instance, information automation in the Orient/Information cell might provide judgments to a human operator (Bass & Pritchett, 2000), whereas information automation in the Orient/Aircraft cell might provide input into a hazard mitigation system that might affect the control of the automation. Both are considered information automation (specifically information analysis automation). Conversely, decision automation may or may not be classified as information automation. Automation in the Decide/Information cell that evaluates display options to decide the best way to convey information to the pilot would be information automation. Automation in the Decide/Aircraft cell that decides on an evasive maneuver for the pilot would be considered control automation.

More specifically, the framework can be used to define different areas considered to be information automation: 1) early information processing stages (observe, orient) linked to control and management automation; 2) all information processing stages for automation where information is the primary commodity being controlled, processed and presented; and 3) feedback loops which present information on statuses and states for control and systems automation (while these loops might not be considered information automation, many similar human factors issues likely apply).

INFORMATION AUTOMATION CHARACTERISTICS

Generate an Initial List of Candidate Characteristics

An initial list of 130 features and attributes of information automation were identified via brainstorming, pilot interviews, and meetings with stakeholders and other human factors experts. Multiple perspectives and research literature were considered (example citations and examples provided):

- Products (e.g., Electronic Flight Bag functions); High level flight deck functions (e.g., aviate, navigate, communicate, and manage systems); Flightcrew functions (e.g., communication with Air Traffic Control and Airline Operation Centers);
- Human error taxonomies (e.g., Threat & Error Management; NextGen; FAA, 2013a);
- Information automation pertains to the various ways a user and system exchange knowledge of current systems to a new interface. Learnability (Dix, Finlay, Abowd, & Beale, 2004). These usability principles encompass interface attributes of human-system interaction and may therefore be an indicator for how readily an interface will be accepted and utilized by its users.

Usability principles have three main categories: learnability, flexibility, and robustness (Dix et al., 2004). Learnability affects the ease with which users can adapt their knowledge of current systems to a new interface. Learnability principles are predictability, synthesizability, familiarity, generalizability, and consistency. Flexibility pertains to the various ways a user and system exchange...
information. Flexibility usability principles are dialog initiative, multi-threading, task migratability, substitutivity, and customizability. Finally, robustness addresses a system’s ability to support a user in assessing and achieving the user’s goals. Robustness usability principles are observability, recoverability, responsiveness, and task conformance.

Three human factors analysts – two with 7 and 15 years of aviation systems experience, respectively, and a general aviation pilot – individually rated each characteristic vs. usability principle combination on a scale of [0,1,3,9]. A nonlinear scale was used in order to emphasize differences in the ratings. A rating of 9 represented a direct correlation: changes in the characteristic had a direct impact on the corresponding usability principle. A rating of 3 represented a strong relationship, but with at least one other factor also affecting the usability. A rating of 1 represented a weak relationship with several other factors affecting usability. Finally, a rating of 0 represented no relationship.

The ratings by the three analysts were reconciled through a series of meetings to discuss the rationale behind discrepant individual ratings. Discrepant ratings were not averaged; rather, consensus was reached through discussions in which example scenarios or anecdotes were considered.

Linear independence of the characteristics’ ratings along the 14 dimensions of the usability principles was estimated via Pearson’s pairwise correlation analysis on each combination of characteristics. Each characteristic “vector” has 14 usability ratings. If one considers this a 1x14 “vector”, then any two characteristics’ vectors may be linearly related and, therefore, warrants further scrutiny to determine whether characteristics should be modified, combined, or eliminated. Conversely, high correlation does not necessarily mean one of the two characteristics must be eliminated; rather, it signals a need for further discussion from a human factors perspective.

It is important not to overstate the role that quantification (rating) of candidate characteristics played in this process. The ratings allowed a systematic comparison of candidate characteristics from a pilot perspective, and were used to guide the qualitative analysis of any correlations found. After human factors analysis, some correlated characteristics resulted in the characteristics being combined. However, there were also cases in which a quantitatively high correlation, after consideration and discussion, did not lead to a merging of characteristics. The goal of the quantitative (rating) exercise was to identify those combinations of candidate characteristics that warranted closer scrutiny; only the qualitative analysis determined the final disposition of the characteristics.

**RESULTS**

**Inter-rater reliability**

Inter-rater reliability was assessed by comparing each individual rating to the final reconciled rating. The final ratings matched 52.4% of the analysts’ initial ratings. If the final ratings were based on “majority rules” of the three individual ratings, the reliability would have been higher.

Instead, a more conservative method was used. For example, a set of analyst ratings (3, 3, 1) may have been reconciled to a “1,” so two analysts were one step away from the final rating even though two agreed with each other initially. Cumulatively, 93.3% of the analysts’ initial ratings were within 1 step of the final rating, indicating that the reconciliation process to produce the final ratings started with a strong basis of agreement between analysts.

**Correlation of Characteristics**

Each characteristic “vector” has 14 usability ratings (results not shown due to space limitations). Table 1 contains the Pearson’s pairwise correlations for all combinations of characteristic vectors. Correlations over 0.5 (strong) are in bold font; between 0.3 and 0.5 (weak) in normal font; less than 0.3 (uncorrelated) in gray font; and less than 0 (no relation) were blank. An average correlation is calculated by averaging the column above and row to the right of the “x”.

**ANALYSIS**

While the initial characteristics represent quantities that are different from each other, we were looking for a subset of quantities that would identify the most unique human factors risks. As such, the analysis focused on “combining” quantities that, while perhaps different from each other, would result in many of the same risks.

Figure 2 illustrates the correlations between functionality, accuracy, and criticality. After discussion, the relevant contextual aspects were combined and renamed Information Quality (Wang & Strong, 1996), which includes the confidence that information meets intrinsic (including accuracy), contextual (including criticality and functionality), representational, and accessibility quality requirements.

**Table 1. Pearson’s pairwise correlation analysis.**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Criticality (Cr)</th>
<th>Accuracy (Ac)</th>
<th>Degradation Behavior (DB)</th>
<th>Functionality (F)</th>
<th>Complexity (Co)</th>
<th>Opacity (O)</th>
<th>Accessibility (Ad)</th>
<th>Authority (Au)</th>
<th>Integration (LI)</th>
<th>User Interaction Reqmts (UIR)</th>
<th>Ranks</th>
<th>Average Correlation</th>
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</thead>
<tbody>
<tr>
<td>Cr</td>
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<td>.04</td>
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<td>.25</td>
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<td>3</td>
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<td>Ac</td>
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<td>DB</td>
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</table>

**Figure 2. Correlations of accuracy, functionality, and criticality.**

The next analysis considered the correlations between the characteristics of complexity, opacity, and degradation behavior (see Figure 3). Degradation behavior was considered a system characteristic, where opacity was considered a
characteristic related to the interaction between the system and the human. Both were retained, although opacity was renamed *Automation Visibility* (e.g. André & Cutler, 1998; Bisantz, Marsiglio, & Munch, 2005). Complexity included both the functional complexity of information processing, as well as the level complexity of information presentation. Complexity at the functional level was considered a system property, while complexity at the display level was considered more of a human-automation property. Rather than combining complexity with the other characteristics, it was split into two characteristics: *Functional Complexity* and *Display Complexity*. This is a good example of how the correlation method served as a triage function to identify areas where further analysis was needed. In this case, the candidate characteristics were not eliminated or combined.

**Figure 3. Correlations of degradation, opacity, and complexity.**

Authority was somewhat correlated (0.47) with adaptiveness. Authority is an emergent property of the function allocation, while adaptiveness of the system includes the function allocation. Therefore, authority was eliminated.

Table 2 lists the final set of characteristics, grouped by those associated with the automated system itself, and those associated with the human-system interaction.

**Table 2. Final set of information automation characteristics**

<table>
<thead>
<tr>
<th>System Characteristics</th>
<th>Human-System Interaction Characteristics</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Functional Complexity</td>
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<tr>
<td></td>
<td>Information Quality</td>
</tr>
<tr>
<td></td>
<td>Adaptiveness</td>
</tr>
<tr>
<td>Level of integration</td>
<td>Degradation Behavior</td>
</tr>
</tbody>
</table>

**DISCUSSION AND CONCLUSION**

This research consisted of developing a framework to describe information automation on the aviation flight deck. A triage method was used to focus human factors analysis to refine a final set of eight characteristics particular to information automation. A similar process was used to refine a final set of characteristics particular to information automation. The techniques used in this project could be applied to refine definitions of characteristics for different categories of automation. The next steps of this project will be to design a set of experiments in order to gather empirical data for assessing three of the characteristics developed here: *Information Quality, Automation Visibility,* and *Complexity*.

**ACKNOWLEDGEMENTS**

This work was funded by the Federal Aviation Administration Human Factors Research and Engineering Division (contract #13-G-003). The opinions expressed herein are those of the authors and do not necessarily reflect the views of the FAA.

**REFERENCES**


