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Tiffany N. Saffell

Amy L. Alexander

Alan S. Carlin

Andy C. Chang

Nathan Schurr

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Tiffany N. Saffell, Amy L. Alexander, Alan S. Carlin, Andy C. Chang, & Nathan Schurr
Aptima, Inc.
Woburn, MA

While NextGen operations are still under development, several key issues have already emerged, including increased information demands on the flight deck. The ALerting And Reasoning Management System (ALARMS) was designed as a strategic, automated system for combining and evaluating alert-related outputs from current and proposed NextGen systems. The model-driven interface integrates the status of the environment, pilot, and system to automatically present the most critical information at the right time, augmenting existing flight deck technologies. The current level of uncertainty in the environment and system as a whole is also evaluated and represented within the display. The four stage model of information processing presented by Parasuraman, Sheridan, & Wickens (2000) was used to guide the development of the underlying ALARMS automation. This document provides a brief overview of the ALARMS development process. Examples of the interface are included, and we discuss its implications.

Introduction

Although the technologies to support Next Generation Air Transportation System (NextGen) operations are still under development, it is clear that the airspace and flight deck of the near future will raise new challenges in how pilots interact both with components of the airspace and with the existing and advanced technologies of the cockpit.. While alerting systems have existed in aircraft cockpits since their instantiation, the changing role of the pilot within NextGen is expected to fundamentally alter the way these systems will need to operate. Current systems and NextGen systems will both provide critical flight information; however the information will need to be presented to the pilot in an accessible manner, so the pilot does not become overwhelmed by data.

We developed a new model-driven interface to address the future needs of pilots in NextGen airspace while using current and NextGen technologies. The **AL**erting and **R**easoning **M**anagement **S**ystem (ALARMS) is an Integrated Alerting Notification (IAN) system which combines environment and aircraft hazard warnings in an intelligent manner to provide the pilot with the right information at the right time, taking into account the state of the environment, the aircraft, and the pilot. ALARMS consists of a user-centered model to drive alerting functions and a dedicated display to portray these recommendations to the pilot. ALARMS was not designed to replace current alerting technologies but instead to augment them by providing information to support strategic planning. This paper gives a brief overview of the interface development process, focusing on the utilization of Parasuraman, Sheridan, and Wickens' (2000) model of information processing and stages of automation. The presentation of uncertainty information is also discussed.

Information Processing and Stages of Automation

Parasuraman and colleagues (2000) outlined four stages of automation to support four stages of information processing. In particular, they focused on the following stages of information processing: sensory processing, perception/working memory, decision making, and response selection. Sensory processing is the act of information gathering and initial processing of information. This stage includes orienting sensory receptors, sensory processing, and selective attention. The next stage, perception/working memory, refers to conscious perception of the sensory information. During this stage, the information is manipulated along with information from long term memory. This stage can also include rehearsal, integration, and inference. These processes lead to the third stage, decision making, or the selection of a possible action. The fourth stage, response selection, is the embodied action of the decision.

Each of the four stages of automation supports a corresponding stage of information processing. Stage 1 automation, Information Acquisition, supports sensory processing. Stage 2 (Information Analysis), Stage 3 (Decision and Action Selection), and Stage 4 (Action Implementation) correspond respectively with perception/working memory, decision making, and response selection. We used these stages of automation to guide the development of the ALARMS automation. All levels can be associated with greater or lesser levels of automation.

Stage 1 automation (supporting Information Acquisition), can have multiple levels of automation. At a low level of automation, the machine can direct the position and action of the sensors. At a greater level, the automation can prioritize the presentation of information. At the highest level of automation, only selected information is presented to the operator. During the lowest level of stage 2 automation (Information Analysis) algorithms can make predictions of future actions, such as future trajectories. Higher levels of stage 2 automation can include data presentation or data summaries that are context relevant. Stage 3 automation (Decision and Action Selection) can be partial or complete replacement of human selection of a decision from decision alternatives. Decision automation can range from presenting intelligent decision alternatives to making an action selection without human intervention. Finally, during stage 4 (action implementation), the machine or system executes the action choice, at different levels of automation. Stage 4 automation can completely replace the person in the system. On the other hand, the person in the system can make a selection that sets off a series of automatic events.

Method

Aptima used a multi-faceted approach to develop the ALARMS interface. First, we consulted documentation covering current and potential NextGen technologies to develop a catalogue of flight deck systems. This information was used as a catalyst during both subject matter expert (SME) interviews as well as model creation for interface information presentation. SME input was specifically used to define interface requirements. Finally, we adapted Parasuraman and colleagues (2000) stages of automation to drive the display of information on the ALARMS interface.

Cataloging Existing and NextGen Technologies

In order to develop an accurate understanding of the types and nature of the alerts pilots may face, we created a catalogue of current and potential NextGen technologies. The Aptima team consulted manuals and FAA documentation to create the catalogue. We focused on the cockpit environment and avionics systems typically associated with FAR Part 121 operations, and also consulted with aviation SMEs. Each current and potential NextGen system was mapped including its input sources and output parameters. Most notably, we mapped the types of alerts (i.e., advisory, caution, warning), their criticality, and the alerting outputs (i.e., aural, verbal, tactile). Therefore, we were able to categorize the importance of potential alerts and what types of information would be presented. For more information on the cataloging efforts, including examples of consulted references, please see Alexander, Alaverdi, Geiselman, Galster, and Schurr (2010).

SME Knowledge Elicitation Sessions

Knowledge elicitation sessions with pilot SMEs were conducted in order to create prototype interface design requirements. Our first subject matter expert was a First Officer on a commercial carrier. Aptima conducted a Work Domain Analysis (Vicente, 1999) in order to capture the objectives, constraints, and information required during nominal and off-nominal situations. We used this information along with our catalogue of current and NextGen technologies to compile an Abstraction/Aggregation hierarchy. The draft Abstraction Hierarchy was reviewed and corrected during interviews with three additional pilots (a retired commercial Boeing pilot, a military cargo pilot, and a business jet pilot). In addition, we conducted a Control Task Analysis (ConTA) with all four SMEs. Two use cases were developed to guide the ConTA, one describing an Optimized Profile Descent and another describing a Trajectory Based Operation. Questions asked during the ConTA assessed what pilots would think, look for, and do during an incident. These use cases were also used to orient the design of ALARMS. For more information on the Abstraction Hierarchy development, please see Alexander, Chang, Saffell, and Schurr (2010).

Model Creation

Aptima developed a model to drive the information presented by the ALARMS interface. The model is primarily composed of a Hazard State Estimator, a Pilot State Estimator, and Planning Module. Finally, information is passed to a Stages of Automation module. The Hazard State Estimation module is actually a Bayesian Network that model's the airplane's environment via the information being passed by the alerting systems. It weighs these inputs and associates them with the certainty of hazards. The Hazard State Estimation module outputs a probability distribution of the "Environment State," that is, an estimate on the probability and severity of the various hazards.

The Pilot State Estimation module receives information about the performance of the pilot as well as the ALARMS interface and outputs the expected performance quality and the expected duration of pilot actions. It predicts the pilot's capability to handle each hazard at each state of automation. The Pilot State Estimator can also accept inputs for measures of mental effort, task demands, and ongoing task performance.

The Planning of Interface Actions module leverages a TMDP (Time-Dependent Markov Decision Processes) (Boyan & Littman, 2000) model that is used to capture both state uncertainty in the environment as well as duration uncertainty in human (pilot) actions (Schurr, Marecki, & Tambe, 2008). Its input is the Hazard and Pilot states, as well as a Markov model of the effectiveness of the pilot and automation in handling the hazards, given various levels of alerts. Its output is a time-dependent plan for addressing the alert.

The plan is passed to the Stages of Automation module, which interprets the level of automation and decides what level of alerts and options to send to the pilot. This decision is then sent to the ALARMS interface, which displays the information to the pilot. More information about the modeling methods can be found in Carlin, Alexander, and Schurr (2010) and Carlin, Schurr, and Marecki (2010).

ALARMS Stages of Automation

We used Parasuraman, et. al's (2000) stages of automation to guide the development of the ALARMS automation. Automation stages 1 through 3 were slightly redefined to better support the interface and the task environment. Stage 1 automation was designed to support Information Acquisition. This stage supports the perception of, and attention to, relevant information in the environment. Within an IAN context, information acquisition automation can support the allocation of operator attention to relevant hazards within the environment. Stage 2 automation supports Information Analysis. The interface displays concepts to assist in the integration and understanding of information. Within an IAN context, information analysis automation can be used to convey the present and predicted future locations of hazards relative to ownship. Finally, we used stage 3 automation to support Decision Selection. The interface displays decision support for identifying feasible actions and/or making optimal decisions. Within an IAN context, decision selection automation can provide recommendations for trajectory changes to avoid impending hazards.

Note that ALARMS does not currently address stage 4 – Action Implementation within our notification methodology. This is intentional because at this stage in aircraft and automation technology adoption, ultimate decisions often remain in the hands, and the heads, of the pilot. However, our current approach can be easily extended to incorporate stage 4. Often advisories appear during stage 1 automation, warnings appear in stage 2, and cautions appear in stage 3, however there is not a direct 1-to-1 mapping between hazard or alert type and stage of automation.

ALARMS Interface

The ALARMS interface is shown in Figure 1. The full functionality of ALARMS will not be discussed in this paper due to space constraints. It is important to note that ALARMS is not just an information display, but a tool to display categorized information at any stage of automation based on the pilot's choosing. An information display would only show the pilot what the automation calculated as important; however we designed an interface so that the pilot can choose which information to display.

ALARMS is composed of three main panels. The left hand panel supplies broad situational awareness information, the middle panel shows the status of different alert categories (traffic, terrain, weather, and aircraft), and the third column displays alert specific information (i.e. traffic information for possible incursion). The model described in the Methods section drives what information is displayed. However, at any time the pilot could touch a radial button and select other information to display. For example, the pilot can choose to view weather information by pressing the Weather button, even if the display defaults to traffic information. There is also a button in the lower right hand corner labeled "model recommended." At any time the pilot can return to the model recommended state display by pushing this button.

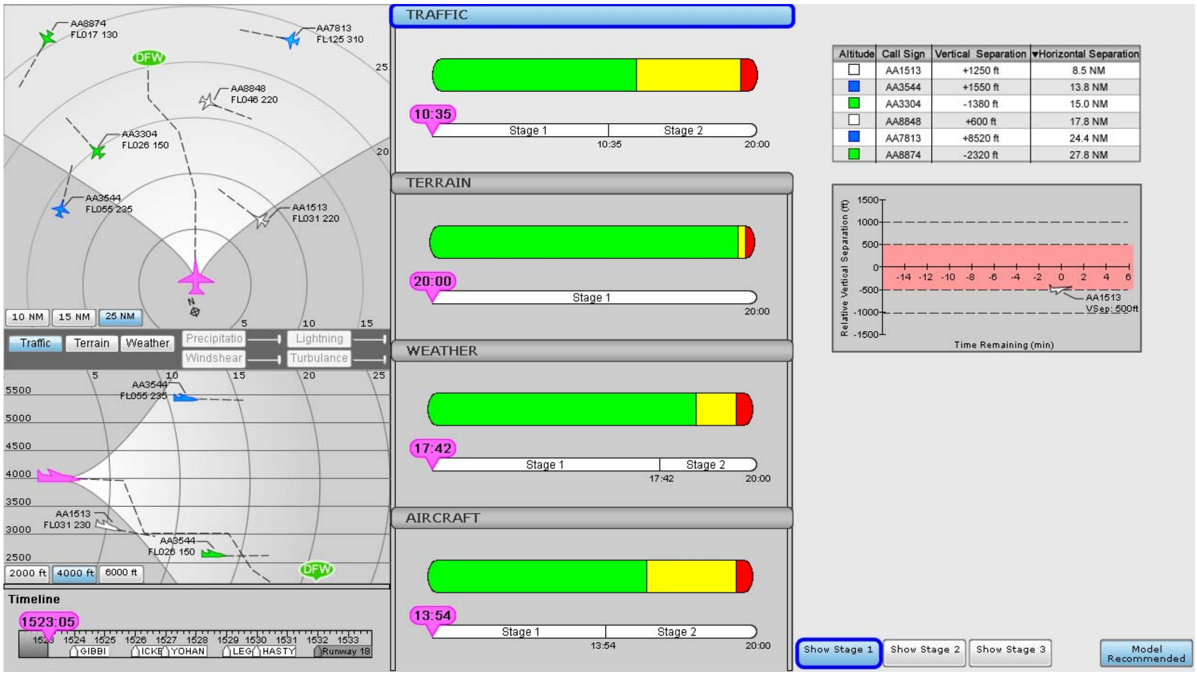

Figure 1. The ALARMS interface in stage 1 automation, supporting Information Acquisition

Left Column: Map of External Elements

The leftmost panel of ALARMS presents the external elements. It contains a vertical and horizontal situation display (VSD and HSD, respectively). The aircraft's possible operation envelope is shown as a white flare emanating from the nose of ownship. The HSD and VSD also graphically represent external entities that may pose potential hazards or provide critical information, such as traffic, terrain, weather, flight path, and airports. This information can be filtered by selecting the associated information button (i.e., traffic, terrain, weather) presented between the HSD and VSD, automatically changing it to "on" or "off." The timeline at the bottom of the panel presents upcoming waypoints in the preprogrammed flight plan.

Middle Column: Hazard State and Stages of Automation

The center column displays information about the hazard state and stage of automation associated with four alert status categories: traffic, terrain, weather, and aircraft. Based on the level of alert, the information displayed in these categories will dynamically change to aid the pilot in maintaining situation awareness about the respective hazard states (discussed in depth in the right column discussion below). The middle column provides a broad overview of the hazard status to the pilot. It shows the pilot how certain a hazard is, the time the hazard might advance to a later stage, and how the hazard relates to other potential hazards. The column also shows what category of information is being displayed in the right hand column. If the "Traffic" button is highlighted or selected (as it is in Figure 1), then traffic information is being displayed in the right column.

Under each of the hazard state categories is a stage planner timeline presenting the current stage of automation as well as a countdown to any anticipated future stages. To ensure that the proposed interface serves as an effective tool for the pilot, the ALARMS interface was designed to reflect the output of the integrated model in order to display each of the first three stages of automation as well as their level of uncertainty.

Hazard State Uncertainty Display. The Hazard State Estimator information is presented as large horizontal bars in each of the four categories. Each bar consists of up to three colored subsections (green for hazard stage 1, yellow for hazard stage 2, and red for hazard stage 3), and was designed to have a total fixed width so that the subsections combine to fill the entire bar. The more certain a stage, the larger its color block. As hazards appear and priority changes, the three colored bars will vary in width to indicate the uncertainty associated with each hazard state. Therefore, even though an alert can consist primarily of a certain hazard state, there is a possibility for the other two hazard states to simultaneously exist. Using this convention, the current hazard state is represented by the bar with the largest width, while bars with equal widths may indicate equal uncertainty of two hazard states, such as during a transition period. This design allows the pilot to quickly and visually make a qualitative assessment of the current hazard state and the uncertainties associated with the other two.

Right Column: Detailed Contextual Information

The right column of the ALARMS interface provides additional information to the pilot by displaying only relevant information about the most critical hazard based on the stage of automation determined by the models. The pilot can chose to display the information about any hazard by selecting the radial button, however ALARMS defaults to display the most critical hazard at any given time.

Figure 2. Two right hand columns of the ALARMS interface in stage 2 (left image) and stage 3 (right image) automation.

Stage 1 Automation. Stage 1 automation is used to support information acquisition, in this case to provide information about the presence of potential hazards (see Figure 1). At this stage, the interface simply indicates possible types of hazards and allows the pilot to assess the situation without further assistance. Hazard type indication takes the form of a status display that provides computational offloading and contextual information to enhance the pilot’s ability to acquire information.

Stage 2 Automation. During stage 2 automation (Figure 2, left image), the interface supports the pilot’s ability to integrate information by highlighting that aircraft AA1514 is about to breach vertical separation. This is displayed in a number of ways: (1) in the right hand column, top table - tabulated information about ownship’s protected airspace is highlighted in red; (2) in the right hand column, the middle graph - a graphical representation of ownship’s vertical separation zone is shown with the encroaching aircraft’s past and projected trajectory and an estimate of time of impact shown in red; (3) the middle column - a large yellow bar in the Hazard State Estimator for Traffic and stage 2 automation in the stage planner; (4) in the left hand column - the symbol for the encroaching aircraft turns to red in both the HSD and the VSD in the very left hand column (the left panel can be seen in Figure 1, however no planes are currently displayed in red); and (5) in the left hand column - a red marker is added to the main timeline to indicate the projected time of collision (the main timeline is shown in Figure 1 without the red marker). These projections are based on the assumption that both aircraft continue on their respective trajectories. In effect, the pilot is sufficiently alerted to the problem while simultaneously being shown the same information in different contexts. Therefore, instead of having to mentally integrate one piece of information into different contexts, the pilot is shown the integrated information to support their decision making process, reducing their cognitive load.

Stage 3 Automation. If a hazard is not addressed in sufficient time, the model invokes stage 3 automation (Figure 3). This stage of automation provides the same information as stage 2 automation but also offers decision support. This may manifest as one (or multiple) suggested courses of action which the pilot can follow to avoid the hazard. In the example shown in Figure 2 (right image), the suggested mitigation strategy is for ownship to alter its horizontal trajectory and decrease its speed. On the HSD and VSD, the result of such a change is shown graphically so that the pilot can immediately visualize the outcome with no added cognitive workload. Time-stamped location markers are also supplied to give the pilot additional contextual information about the 4D trajectory. Note that in this case, the right hand column has only had the "Suggested Trajectory Change" added.

Conclusions

The ALARMS interface is a significant step forward in intentionally applying a variation of Parasuraman et. al's (2000) stages of automation when developing an interface. By designing the automation to support various stages of information processing, the pilot is provided with the right information at the right time given the dynamic nature of the flight environment.

The current instantiation of the ALARMS prototype is limited in its functionality such that it is driven by simulated data as opposed to real-time sensor/system inputs. In addition, the underlying models are limited to a small set of particular situations, such as weather hazards, traffic incursions, engine fire alerts, and landing gear indicators. However, the system was designed for extensibility and further development could focus on modifying the models as needed. Finally, while the interface has been reviewed by subject matter experts, the interface itself and the models driving the information display have not been rigorously tested. The models should be tested for situation appropriateness and the interface should be tested in simulated flight scenarios prior to transitioning the alerting logic and/or representations to actual systems.

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