Developing a Decision Support Interface for Surface Domain Air Traffic Controllers

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The effects of advanced automation tools on the air traffic control tower environment were assessed through a real-time simulation study. One focus of the study was the impact that advanced tools would have on controllers’ roles and work patterns. Participants controlled simulated traffic during 45-minute scenarios, and reported their perceived workload and experience of using a prototype automation tool. Perceived workload was significantly reduced in the advanced automation conditions, more so as the automation assumed more functions. Participants interacted a great deal with the automation in these conditions, a notable proportion of which was interface management. Despite generally liking the tool, controllers reported the automation had assumed all of their role’s decision-making responsibilities and left them with mechanical tasks. It is concluded that a more artful allocation of functions is required if controllers are to be engaged in their task when using advanced automation tools.

In the air traffic control (ATC) domain, the airport surface (tower) environment has been among the least automated and supported. Tower controllers rely on their out-the-window view for aircraft position information, and printed flight strips for flight details. Several developments in the technology supporting Air Traffic Management (ATM), in particular improved surface sensing capabilities, are enabling consideration of tools that provide integrated information and decision support. As air traffic is predicted to continue to increase, the benefits of advanced support tools may be that the same-size controller team will be able to manage twice as much traffic when assisted by appropriate tools. This is a key factor that will allow airports to increase their capacity in the future.

As part of a larger project looking at the future US airspace and future ATM tools (see VAMS, 2006), a real-time simulation was developed that integrated a representative future surface automation concept into a high-fidelity airport tower research environment. The aim of this integration was to explore the utility and design of a prototype controller tool, assessing the value of the information presented to controllers and recording their interaction. The prototype tool chosen was GoSAFE (the Ground-Operation Situation Awareness and Flow Efficiency tool), which is part of the example concept (SOAR – Surface Operation Automation Research) (Cheng, 2004).

The SOAR concept envisages that future surface operations will involve taxi clearances containing precisely timed taxi routes. This will be achieved through collaboration among tower control tools (e.g., GoSAFE) and additional advanced automation (future) flight deck tools. GoSAFE is intended to plan efficient taxi operations (Cheng, 2004), with the assumption that flight decks of the future can execute very precise taxi commands. Due to timing information embedded in the clearances, it will be impractical for these clearances to be given by voice, and thus data link (electronic down/up-loading of information) is required for the procedure.

The GoSAFE system will provide a comprehensive set of tools to assist tower controllers; chief among these are automated route planning and clearance processing functions. Information is displayed to the controller through a graphical user interface (GUI) and a keypad provides the user interface for input. At the time of testing, the GoSAFE GUI had three display areas with an optional fourth display: a map of the surface, a table showing arrivals, and a status bar showing clearances issued and pending. A timeline referenced to taxiways was optional.

PROCEDURE FOR TESTING THE FUTURE ATM TOOL

An initial prototype of the GoSAFE tool and the simulation facility were tested in a two-week study. Eight retired tower controllers participated, as two crews, to control simulated airport traffic, using GoSAFE as the representation of a future support tool. All participants had over 21 years of experience, and all had worked at large US airports. The first day was reserved for training each set of controllers –introducing GoSAFE and familiarizing controllers with airport procedures at the test airport.
The east side of Dallas/Fort Worth (DFW) airport from the vantage point of the East Tower was simulated. Participants manned four positions – Local East #1 (LE1), who controlled parallel runways 17L and 17C; Local East #2 (LE2) who controlled runways 17L and 13L; Ground East #1 (GE1) who controlled the three terminal ramp exits and the northern taxiways; and, Ground East #2 (GE2), who controlled the southern taxiways and bridges.

Participants controlled traffic through three scenarios, built to have different traffic flow patterns (e.g., arrival rush). All scenarios had approximately 1.5 times the current-day DFW traffic (avg. 173 aircraft/45 min). Arriving aircraft were simulated from approximately 12 nmi out, to landing and taxing to their ramp. Departing aircraft were simulated from their ramp, through taxi-out and take-off, to about 5 nmi from the runway. GoSAFE was operated under two conditions—in a fully automated mode, where data link was used for all communication with the cockpit, and in a mixed mode, where data link was used to issue the pre-clearance information and radio communication was used to issue the clearance. As a study baseline, a ‘similar to current day’ condition was also run where participants relayed all clearance information by voice, and did not have access to any advanced tools. Twenty-one data collection runs were completed during the two weeks, nine in the full GoSAFE condition, eight in the mixed, and four in the baseline. The three scenarios were balanced across the two GoSAFE conditions.

A real-time ATM simulation environment (VAST) was used to run the study. VAST is designed to integrate various high-fidelity, human-in-the-loop, real-time simulators with low to medium-fidelity target generation tools and ATM/ATC decision support tools (Northrop Grumman, 2005). The VAST Federation forms the core of the simulation environment, integrating all of the required simulation components, including target generators, research tools, high-fidelity facilities, data collection and other modules that support distributed real-time simulation. For this study, high-fidelity tower and cockpit simulators and the GoSAFE automation tool were linked with the VAST Federation. This configuration is discussed in more detail in VAST (2004).

Experimental data including simulated aircraft state data, controller inputs, controller communications, and participant videos were recorded. These data were used to generate airport efficiency and other statistics. Details of how data are filtered and processed for analysis are included in Northrop Grumman (2005). In addition, subjective workload, situation awareness and user opinion data were collected through questionnaires and scales, including ATWIT (Air Traffic Workload Input Technique, Stein, 1985) and the NASA TLX (Task Load Index, Hart & Staveland, 1988).

Although much other data were collected, the discussion below focuses on three key areas. These are the way controllers worked with automated tools to control traffic, how future tools should support surface automation, and what effect automation is likely to have on workload and the controllers’ role.

**ADVANCED TOOL IMPACT ON CONTROLLER WORKLOAD**

Participants were asked to rate their workload every five minutes during runs, using a workload assessment keypad, and then again after the end of the run using the NASA TLX. Both sets of workload ratings were compared across the study conditions. For the fully automated condition, workload ratings were fairly steady from all positions, with the Local East #1 controllers rating themselves as having higher workload than the ground controllers and LE2. LE1’s average rating varied around 3 (out of 7, which is a medium/low rating) while other positions’ average ratings varied around 1.5 to 2 (low). Ground-East controllers #1 reported being busiest at the beginning of the runs, while all the other positions reported themselves getting busier during the first five or ten minutes of the simulation. Ground East controllers #2 rated their workload as very low—always close to 1.

In the mixed condition, shown in Figure 1, controllers’ workload reports had the same ranking, with GE2 reporting the lowest workload. LE1, again, reported the highest workload, although, at around 4, this was still only at the midpoint of the scale. LE2 reported workload that was higher than the ground.

![Figure 1: Composite ATWIT ratings for the mixed GoSAFE condition](image-url)
positions’ but not quite as high as LE1. While estimates of workload around 7 would imply controllers were overloaded, ratings of 1 indicate the opposite. Controllers in the GE2 position commented that they felt under-utilized in this position, indicating that the higher ratings around the midpoint of the scale showed preferable levels of workload.

The overall average ATWIT rating was compared across the study conditions using a oneway ANOVA. There was a significant difference in the average workload reported between the three conditions (F=3.83, df=2, p=0.04). A post hoc Tukey’s test indicated that the workload difference was between the baseline and fully automated condition (SE=0.42, p=0.04), which is consistent with the NASA TLX results (see below). Controllers felt they were busier in the baseline condition than in the fully automated condition, which indicated automation tools had an effect on participants’ perception of their workload.

Participants answered the NASA TLX rating scales (Hart & Staveland, 1988) after each simulation run but did not complete the pairwise scale comparison that is part of the measure, so the six scales must be treated separately.

As Figure 2 shows, participants rated four of the six TLX elements as higher under the baseline condition. The differences in participants’ TLX ratings under the three study conditions were tested using oneway ANOVAs. Four of the six scales showed significant differences between the conditions. Mental demand was rated significantly higher in the baseline condition versus the GoSAFE conditions (F=8.55, df=2, p<0.01). Temporal demand followed the same pattern (F=9.42, df=2, p<0.01). Physical demand was rated differently in the three conditions (F=8.24, df=2, p<0.01), i.e., physical demand was higher in the baseline than in the GoSAFE conditions, but also significantly higher in the mixed than the fully automated condition. These differences show the extra load the controllers incurred by having to issue clearances by voice in the mixed condition. Radio operation had an impact on controllers’ workload level in both the physical work they had to do (pushing to talk) and also in terms of the time pressure they felt with the additional task.

As would be expected, as higher demands were perceived, effort was rated significantly differently under the three conditions (F=9.96, df=2, p<0.01). Again, controllers reported having to expend more effort in the baseline condition than the others, but they also had to expend more effort in the mixed condition than in the fully automated condition. Despite the greater workload demands, controllers did not report significantly different performance and frustration levels between the conditions.

Controllers Use of the Automation

One measure of controllers’ activity during the simulation was the degree to which they interacted with the advanced tool. Digital videos of the GoSAFE GUI for the LE1 and GE1 positions were captured for each run. These videos show the display, in real time, with moving traffic and controllers’ mouse movements. Half of the videos were coded to assess the amount the controllers used the GUI, which features they used most, and how they used them.

On average, the LE1 controller interacted with the GUI 641 times over a 45-minute study run, i.e., just over 14 times per minute. Primarily, these actions were moving the mouse to a location and clicking on a screen object, but some mouse movement-only actions were also counted if the new location highlighted or revealed information on the mouse-over action. The GUI usage covered a

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1 Note: performance is a reversed scale, a lower rating indicates greater satisfaction with your own performance.
separately, performed more actions on each aircraft. Despite the number of interactions with GoSAFE, the TLX ratings indicated that controllers did not perceive them as increasing physical workload.

Of the four GUI windows, the map was used by far the most often, on average for 75.2% of actions. Again, the usage range was large—from 63% to 84%. Following this, the arrival table, timelines and clearance bar were used in this order of frequency. Other features that were occasionally used were the scroll and zoom, to move around the map, the ‘deselect routes’ button, and the crossing times function.

Controllers seemed to spend a large amount of time performing housekeeping tasks; not only did they reduce the size of the data blocks to clear the screen (at an estimate a quarter of their map actions) but they also de-cluttered areas by extending the tag leader lines and deselecting routes. Counting only the specific de-cluttering tasks, controllers spent over 7% of their time in interface management.

Ground controllers used the GUI in a similar way to the local controllers; differences are due to the differences in their tasks. The GE1 controller used the GoSAFE GUI 309 times on average over a 45-minute study run—just under 7 times per minute. Again, GE1 GUI usage had a reasonably broad range, from 228 actions in one run to 500 actions in another, showing both different strategies for using the GUI, and different usage of the tool. As for the LE1 position, the map window was used by far the most often, on average for 84.5% of actions. Again, the usage range was large—from 72% to 95%. In part, the map was used a greater percentage of the time by ground than local positions because they did not have the arrival table to monitor and clear aircraft. GE1 did use the timelines and clearance bar, but less than LE1. GE1 also used the scroll and zoom, deselect routes button, and crossing times functions. Occasionally, GE1 also used the future time bar—a scale where the controller could advance time and see where GoSAFE predicted the selected aircraft to be at that time. For those controllers who used this function, it was on average 3% of their actions. The GE1 position also spent a large amount of their time performing housekeeping tasks with, again, just over 7% of their actions being to de-clutter the map.

With so many GUI interactions, what did controllers think of using an advanced automation tool? In their questionnaire responses, controllers rated all of the GoSAFE tools and functions as usable (mean=3.2 out of 5), rating the taxi route display function and the clearance status line as “very easy to use” (M=4.5). They felt they used most of the functions “frequently” (M=4), with the exception of the last clearance record display, which they “hardly ever” used (M=1.2). Controllers acknowledged the information presented on the GoSAFE GUI did create some clutter because data blocks laid on top of each other, especially when aircraft were in queues, making the data blocks unreadable.

In debriefs, controllers discussed that they spent a lot of their time during simulation runs trying to manage the clutter on the GUI, specifically moving data blocks so that they did not overlap. This indicates that time spent on screen management was an issue. Controllers gave numerous suggestions for additional GoSAFE functions that would assist them with managing clutter, e.g., having automatic reduction of data tags after a clearance has been given.

Controllers liked GoSAFE because it was easy to learn, easy to interpret, and used color and equipment they were familiar with. They had many suggestions for improvements including adding a map scrolling function; being able to configure the GUI before the traffic was running; being able to bring up the route for one taxi segment only; and, combining the mouse and data entry keys to reduce the number of input devices that they had to use. (The mouse and data entry pad, in addition to the headset push-to-talk meant that controllers had to operate more controls than they had hands for.) A function that controllers wanted to add to the GUI was an indicator for the departure path that a flight is going to take—a piece of information that would have been available on a flight strip but was not on the GUI’s data tag. The only item controllers wanted to be removed was a procedure—having a button push and a voice acknowledgement in the mixed-mode condition—as one or the other should suffice.

**CHANGE IN CONTROLLERS’ ROLE**

The workload measures and usage analysis indicated that using an automated tool had a marked effect on what controllers were doing. In debriefs, controllers were asked how they saw the changes in their role. Controllers felt that GoSAFE had taken away all of the decision-making aspects of their role. They felt their remaining responsibilities were at a mechanical level and not at a decision-making level. In large part, this was due to the immaturity of the tool—unplanned software constraints in GoSAFE severely limited the degree to which controllers could interact with traffic. For example, they could not easily alter the taxi route set by GoSAFE, which means controllers’ feelings that they could not
positively control aircraft were accurate. (The existing route editing function in GoSAFE was considered too time-consuming to use, and hence was not included in the study.) These observations emphasized that defining the controllers’ role is not sufficient; it must be supported in, and defined by, the tools as well.

However, other concerns that controllers mentioned were not due to tool development limitations. For example, in today’s environment, aircraft generally immediately comply with control instructions issued by controllers. In the GoSAFE environment, however, clearances have an associated crossing time that incurs a wait of several minutes (to meet the crossing time) before the controllers see an action from the aircraft. This delay in compliance may require a paradigm shift for the controllers.

Improving GoSAFE to foster a partnership between the controller and his/her automation will, in large part, occur as functions in the tool become more flexible and open to user input. In addition, removing dull and frustrating tasks, like de-cluttering data tags, will also rebalance the controller-tool relationship.

**DISCUSSION AND CONCLUSIONS**

The aim of the real-time simulation to explore controller use of, and reaction to, advanced automation tools with 1.5 times traffic was met. Using advanced automation tools, controllers’ activities changed, and much of their time was spent interacting with the tool and monitoring traffic on the GUI. The workload data from different sources all trend toward the same suggestions: that local controllers were busier than ground controllers, but none reported having unmanageable workload at any time. Participants rarely used the ‘busiest’ end of the scales they responded to. ‘Current day baseline’ workload was rated higher than in the automated conditions. Between the two tool conditions, the fully automated mode was rated as less busy, and indeed, controllers did have fewer tasks because they did not have to give voice commands.

However, these findings are deceptive when taken alone. While controllers did not dislike, or express significant issues with using an automated tool to give clearances, the impact they felt of such a tool on their decision making role and strategic input was marked. Controllers felt the decision-making aspects of their job, where they made the greatest contribution (and which were the most interesting), had been removed. This reduced their role to an executor of instructions, rather than being the planner and creator of surface operations. Possibly, providing the controllers ability to change routes or crossing times might empower them.

Future development of this prototype automation tool has to consider the importance of preserving a meaningful role for the controller at the same time as removing the burden of numerous repetitive commands. The present study, as intended, shed much light on the requirements for an advanced automation tool and the impact of inserting a tool into the surface ATC environment. The goal of preserving controllers’ strategic (decision making/traffic management) role while reducing workload and enabling tighter tolerances between aircraft on the surface requires a more careful balance. Functions allocated to the controller and those allocated to the automation should be carefully determined through research and analyses to support the most appropriate function for each.

**REFERENCES**


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