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Display Concepts For En Route Air Traffic Control

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16. Abstract

Previous research in the domain of air traffic control (ATC) has explored factors that describe the complexity facing a controller. Based on this research, new technologies and procedures have been developed that may aid the controller and reduce the complexity in ATC. Most of these technologies were designed to reduce ATC complexity associated with air traffic density, identification and resolution of conflict situations, and the operational efficiency of the human-machine interface. The purpose of the present study was to explore and prototype new display enhancements that may reduce complexity in ATC. A team of researchers from the Human Factors Branch (ACT-530) of the Federal Aviation Administration William J. Hughes Technical Center and the Human Resources Research Division (AAM-500) of the Civil Aeromedical Institute (CAMI) identified four complexity factors as being suitable for a graphical enhancement. These factors were the effects of weather on airspace structure, the effects of active Special Use Airspace (SUA), the effects of the number of transitioning aircraft, and the effects of the reliability of radio and radar coverage. We conducted a user evaluation of the display enhancements and their possible impact on ATC complexity. Two supervisors and 13 Full Performance Level controllers from the Jacksonville Air Route Traffic Control Center participated as observers in this evaluation. The results of the user evaluation showed that the controllers supported earlier research that identified weather, SUA, transitioning aircraft, and reliability of radio and radar coverage as factors that increase ATC complexity. The controllers favored the proposed display enhancements. More importantly, the controllers predicted a substantial reduction in their job complexity from the enhancements. Based on these findings, we recommend a formal test simulation of the proposed enhancements to determine their efficacy for reducing task complexity in ATC operations. We also recommend further studies to determine the optimal colors for each display enhancement for use in operational systems.

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Executive Summary

Previous research in the domain of air traffic control (ATC) has explored factors that describe the complexity facing a controller. Based on this research, new technologies and procedures have been developed that may aid the controller and reduce complexity in ATC. Most of these technologies were designed to reduce ATC complexity associated with air traffic density, identification and resolution of conflict situations, and the operational efficiency of the human-machine interface. The purpose of the present study was to explore and prototype new display enhancements that may reduce complexity in ATC.

A team of researchers from the National Airspace System Human Factors Branch (ACT-530) of the Federal Aviation Administration William J. Hughes Technical Center and the Human Resources Research Division (AAM-500) of the Civil Aeromedical Institute (CAMI) reviewed earlier research by Mogford, Murphy, Roske-Hofstrand, Yastrop, & Guttman (1994) and Wyndemere, Inc. (1996) to identify complexity factors that could be addressed by a display enhancement. Four complexity factors were identified in a pilot study as suitable for a graphical enhancement: weather effects on airspace structure, the effects of active Special Use Airspace (SUA), the amount of transitioning aircraft, and the reliability of radio and radar coverage.

To evaluate the usability of our display enhancements and their possible impact on ATC complexity, the team conducted a user evaluation at the Jacksonville Air Route Traffic Control Center. Two supervisors and 13 Full Performance Level controllers participated as observers in this evaluation. We showed the prototype to the controllers during structured interviews and collected user ratings on the acceptability of the display enhancements together with ratings on the degree by which the enhancements would reduce ATC complexity. For each of the four complexity factors, the controllers also explained what actions they have to take when confronted with the factor, how frequently each factor adds difficulty to controlling traffic, and to what extent the complexity factor impacts on their job.

The results of the user evaluation showed that the controllers supported earlier research that identified weather, SUA, transitioning aircraft, and reliability of radio and radar coverage as factors that increase ATC complexity. The controllers were very much in favor of the proposed display enhancements. Most importantly, the controllers predicted a substantial reduction in their job complexity from the enhancements.

Based on these findings, we recommend a formal test simulation of the proposed enhancements to determine their efficacy for reducing task complexity in ATC operations. We also recommend further studies to determine the optimal colors for each display enhancement for use in operational systems.

1. Introduction

The purpose of the Air Traffic Control (ATC) system is to provide a safe, efficient flow of air traffic from origin to destination. Therefore, it is important to identify and reduce the factors that increase the complexity of ATC operations. Mogford, Guttman, Morrow, and Kopardekar (1995) described ATC complexity as having both physical aspects (e.g., sector size and airway configuration) and dynamic aspects relating to the movement of aircraft through the airspace (e.g., the number of climbing and descending aircraft). Factors such as equipment, environment, and controller ability and experience further influence the degree of complexity. Increases in complexity have been reported to result in increases in controller workload and, consequently, more operational errors (Mogford et al.; Rodgers, Mogford, & Mogford, 1998; Stein, 1985). This research examines methods of reducing ATC complexity and thus reducing controllers' workload and errors.

1.1 Background

Several studies have explored factors that describe the complexity facing a controller. For example, Mogford, Murphy, Roske-Hofstrand, Yastrop, and Guttman (1994) proposed 15 factors that seem to be of significant importance (see Appendix A). Wyndemere, Inc. (1996) proposed 19 factors believed to contribute to complexity (see Appendix B).

New technologies and procedures have been developed to reduce job complexity by aiding the controller in ATC. For instance, new Traffic Management Unit (TMU) technologies allow TMU specialists to predict when aircraft will arrive at a particular sector and reroute aircraft from overly dense sectors. These technologies attempt to reduce ATC complexity associated with air traffic density. Conflict probes, such as the User Preferred Routing Tool of the Center-TRACON Automation System (CTAS) and the User Request Evaluation Tool (URET), allow controllers to predict and resolve many conflicts in a short time and test possible resolutions (Carrigan, Dieudonne, & MacDonald, 1997). These tools attempt to reduce complexity associated with identifying and resolving conflict situations.

Attempts have also been made to reduce complexity by enhancing the human-machine interface in the ATC environment. The Operational Display and Input Development (ODID) system, with a windows-based graphical user interface, demonstrated promising ATC concepts (Skiles, Graham, Marsden, & Krois, 1997). A controller operational review showed that the ODID dialogue design simplified information retrieval and data entry with simple mouse operations and available pop-up menus. Along similar lines, systematic studies of the use of color in ATC displays have developed guidelines for implementations that will reduce the controller's information processing by enhancing display information (Reynolds, 1994). Using seven visual layers with different color palettes, Reynolds created displays that emphasized the most important data without increasing the overall complexity. As a promising system for future display enhancements, the Three-Dimensional Volumetric Display could ease the controller's workload even further than what is possible with current 2-D display technology (Hanson, 1997). For example, the Three-Dimensional Volumetric Display can integrate all of the components of a complicated airspace onto a single display.

1.2 Purpose

This study explored and prototyped new display enhancements that may reduce complexity in ATC. It consisted of five project phases: identification of complexity factors, prototype development of display enhancements, a pilot study to implement and evaluate the enhancements, refinement of the display concepts, and the primary study in which the refined enhancements were finalized and evaluated.

2. Method

Research psychologists from the National Airspace System Human Factors Branch (ACT-530) of the Federal Aviation Administration William J. Hughes Technical Center (WJHTC) and the Human Resources Research Division (AAM-500) of the Civil Aeromedical Institute (CAMI) identified complexity factors that could be addressed by a graphical enhancement. We reviewed earlier research by Mogford et al. (1994) and Wyndemere, Inc. (1996) to identify complexity factors that could be addressed by a display enhancement. The team explored and prototyped new display enhancements that may reduce complexity in ATC.

2.1 Participants

Twenty controllers and supervisors were involved in evaluating the display enhancements discussed in this report. Five Full Performance Level (FPL) en route controllers participated in the pilot study. Two were from Minneapolis Air Route Traffic Control Center (ARTCC) (ZMP), one was from Jacksonville ARTCC (ZJX), and two were from Houston ARTCC (ZHU). Two supervisors and 13 FPL controllers (mean experience = 17 years, SD = 7.2) from ZJX participated in the primary study.

2.2 Apparatus

The research team developed the prototypes in Macromedia Director™ 6.5 (Macromedia, 1997) using a Gateway 300 MHz Pentium II computer and a 21 in. color monitor. The pilot study was conducted using this equipment. For the development of actual ATC scenarios for the primary study, we recorded a System Analysis Report (SAR) tape from the Host computer at ZJX. After Data Analyses and Reduction Tool (DART) and National Track Analysis Program processing of the SAR tape, we loaded the resulting files into the Systematic Air Traffic Operations Research Initiative (SATORI) System, captured an ATC scenario, and imported it into Director. The primary study used two portable Gateway notebooks and an external 15-in. color monitor.

2.3 Procedure

2.3.1 Identification of Complexity Factors

The research team identified five complexity factors that might be ameliorated by display enhancements: weather effects on airspace structure, the effects of Special Use Airspace (SUA), transitioning aircraft, the reliability of radio and radar coverage, and the workload associated with the number of required procedures that the controller must perform. Discussions with two

subject matter experts and informal interviews with Air Traffic Control Specialists (ATCSs) indicated the importance of these five factors regarding air traffic complexity. Furthermore, we chose these five factors because they presented an attainable combination for this first prototyping effort.

2.3.2 Initial Display Enhancements

To develop the initial display enhancements, we visited Jacksonville (ZJX) and Boston (ZBW) ARTCCs to gather information about the different weather display systems used by controllers, TMU personnel, supervisors, and meteorologists. We also examined the procedures used for activating SUA. Using a generic air traffic scenario (Guttman, Stein, & Gromelski, 1995), we developed display concepts for a six-level weather display, color coding of active SUA, color coding of climbing and descending aircraft, graphical representations of radio and radar outages, and an on-screen representation of standard and temporary procedures.

2.3.3 Pilot Study

To receive feedback on our initial display enhancements, five en route controllers participated in a pilot study at the WJHTC Research Development and Human Factors Laboratory. The purpose of the study was to receive feedback on our initial display enhancements so that we could optimize each separate prototype. The controllers participated in two groups during the study. One group consisted of the two controllers from Minneapolis (ZMP) ARTCC and the controller from Jacksonville (ZJX) ARTCC; a second group consisted of the two controllers from Houston (ZHU) ARTCC. Prior to showing the prototypes to the controllers, we discussed the purpose of the study. We asked them to explain what actions they normally take when confronted with each complexity factor, how frequently each factor adds difficulty to controlling traffic, and whether the display enhancements would reduce the complexity associated with the factor. After these instructions, we presented the five separate prototypes to the controllers and recorded their feedback. The controllers' responses are summarized as follows.

a. All controllers complained about their current weather system, its lack of accuracy, and their inability to pass on any weather information to the pilots. Usually, the pilots tell the controller where the weather is located. All of the controllers could see the benefit of a weather display as shown in the prototype. They also thought that all the information that would be needed (i.e., the level of precipitation, upper-level winds, cloud tops, and animated weather prediction) when controlling traffic was displayed in the prototype.

b. Controllers were very much in favor of the color coding of SUAs and the text-based information about altitudes and activation times.

c. The display concept of having climbing and descending (i.e., transitioning) aircraft coded in different colors yielded mixed reactions from the controllers. Three of the five controllers saw a benefit of having descending and climbing aircraft in different colors, whereas, the other two controllers saw a greater benefit in having overflight color coded. It seemed that color coding would be useful to the controllers, but several factors (e.g., sector characteristics and traffic flow) determine what would be useful to color code.

d. All five controllers were strongly in favor of a graphical representation of a navigational aid (navaid) outage directly on the situation display. However, only two of the controllers liked the graphical representation of an area that has minimal radio coverage. The other three argued that such a representation would be unnecessary because controllers learn where these areas are as they work their sector.

e. The controllers liked the concept of having standard and temporary procedures available in a pop-up window. However, they all agreed that this is not a problem in their daily work and, therefore, would contribute very little compared to how these procedures are stored currently. These controllers reported that this enhancement would not reduce the complexity of their task.

2.3.4   Refined Display Enhancements

The revised prototype contains an enhanced weather display (Figure 1). As a basis for the weather display, we incorporated some display information that is similar to that found in the Integrated Terminal Weather System. The weather display depicted six independent levels of precipitation with an animated prediction of weather cell movements. We used Next Generation Weather Radar data from the National Weather Service to produce the six levels of precipitation. The animated weather prediction consisted of 17 frames of weather and was intended to give information about the weather cell movements during a 30-minute period. In addition to the graphical representation, the display presented text-based information about the intensity of precipitation, thunderstorms, turbulence, radar echo tops, and upper level winds in an information message window. The weather intensity ranged from level 1 to level 6. When levels 4-6 are encountered, the majority of aircraft will request alternate routings. Levels 1-3, on the other hand, are generally navigable and associated with minor turbulence. They also can be used to predict the build up of increasingly severe weather. Thunderstorm information is critical to flight safety and is associated with severe weather phenomena including hail, lightning, and moderate to severe turbulence. Echo tops are directly related to thunderstorm intensity and are defined in the prototype by their highest altitude level. Upper level winds are identified by altitude, direction, and speed. For example, FL290 310 25G35 indicates the winds at flight level (FL)290 are from the northwest (310) at 25 knots gusting to 35 knots. This wind information is useful to the pilot because it indicates the possibility of turbulence and can be used to calculate fuel consumption.

Figure 1. An illustration of the weather display enhancement (a color version of this picture can be accessed from http://www.tc.faa.gov/act-500/hfl/complexity/CAMI_wx.JPG

The proposed display enhancement for active SUAs consisted of color coding of all active areas on the situation display. Figure 2 shows this implementation for the Cedar Key Sector where areas W-470, Nova 1, Nova 2, Zephyrhills Jump Zone, and R-2938 are color coded. As soon as an SUA becomes active, text-based information about altitudes and activation times was displayed in a system message window. The current prototype used solid color infills for active SUA areas. A solid color infill is easy to perceive against the background and the sector map lines, and an appropriate brightness control would make it possible to adjust the setting to a level where the area is visible but not distracting. It would also be possible to use dotted lines or solid outlines instead of solid infills, depending on the specific sector configuration and sector map complexity. In the current implementation, we used examples in which we activated the SUA from the surface up to a specific FL (i.e., surface to FL500 and surface to

Figure 2. An illustration of the color coding of active SUAs (a color version of this picture can be found at http://www.tc.faa.gov/act-500/hfl/complexity/CAMI_sua.JPG).

FL150). Sometimes, however, only a specific section of the total airspace volume over an SUA was activated at a given time. Thus, aircraft would then be allowed into this area below or above the activated airspace volume. Investigators need more research, however, to implement possible display solutions for these more complex situations.

Figures 3A and 3B demonstrate the use of color coding data block text to denote specific aircraft transitions. For the Cedar Key Sector, the demonstration included two types of color coding that seem to be useful for this specific sector: overflights (3A) and airport destination (3B). The data block for each en route aircraft consisted of three lines of data text. The first line in the data block showed the callsign (i.e., DAL705 is Delta Airlines 705). The second line contained altitude information. The third line contained ground speed, destination airport identification, and the computer identification number. In the prototype, a yellow coding of the second line in the data block indicated that the aircraft was an overflight. An overflight is any aircraft that will transition the sector without landing. An orange letter (T) as the destination airport identification in the third line indicated that the aircraft was on a route to Tampa, and a blue letter (Q) indicated that the aircraft was on a route to Sarasota. Although several other airport destinations are possible within the sector, the idea is to use color coding to highlight important target groups in the traffic flow that affect controller actions. The prototype demonstrated how the user can select either one or a combination of the two color schemes, all depending on whether the traffic situation at hand makes it useful to display this information. An important issue concerning the use of color coding in data blocks has to do with the amount of text being colored and the specific way it is implemented. Currently, no data are available on the optimal implementation for operational use; more research is needed to investigate this issue.
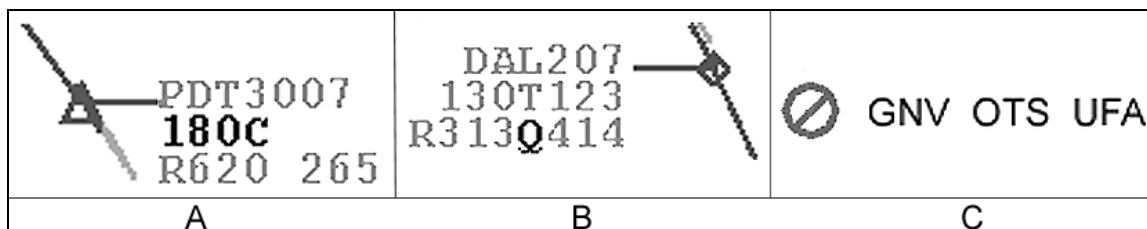

Figure 3. An illustration of the color coding of (a) overflights, (b) airport destination, and (c) a graphical representation of a navaid outage (color versions of these pictures can be found at http://www.tc.faa.gov/act-500/hfl/complexity/CAMI_color_coding.JPG).

Because the ARTCC radar system is mosaic in its design, the system provides redundancy and target integrity even if one radar site fails. Only in the case where multiple, remotely located radar sites fail will the potential for reduced or total loss of radar coverage occur. However, failure of a single radar site can result in reduced radar coverage at lower altitudes. A more common problem than loss of radar coverage is the failure of navaids. When a navaid outage occurs at a location that is commonly used for aircraft navigation, the controller must take action by either vectoring or having the aircraft use alternate navaids. These situations will increase controller workload and might also increase the complexity in controlling traffic. Area Navigation (RNAV) equipped aircraft, however, are unaffected by a navaid outage and do not need help from the controller for navigation. Figure 3C demonstrates a graphical depiction of a navaid outage on the sector map. In addition to the graphics, specific text-based information is displayed in a system message window. When the navaid is back in service again, the graphic disappears from the sector map and information about the status change is displayed in the

system message window. In this way, a constant reminder of a navaid outage is displayed on the sector map, and, when there is a change of the navaid status, the new information is conveyed to the controller directly.

The pilot data were from a relatively small number of controllers (5), and we presented the display modifications in separate prototypes. To assess these enhancements further, we conducted a second, larger (primary) study in which we integrated all the display modifications together. In this way, we more accurately simulated how controllers would view the display concepts on the job. In response to the controllers' feedback in the pilot study, the prototype constructed for the primary study did not include graphical representations of areas that have minimal radio coverage or the on-screen representation of standard and temporary procedures.

The refined prototype contained a 15-minute ZJX ATC scenario from the Cedar Key Sector. Cedar Key Sector 14 suited the needs of the study because it regularly experiences weather effects, has large areas of SUA, and contains many complex traffic routes with heavy traffic. The demonstration contained the Cedar Key traffic scenario, a weather display, color coding of active SUA, examples of color coding of transitioning aircraft, and a graphical representation of a navaid outage.

Although the use of color in ATC displays is far from resolved (Cardosi, 1998; Galushka, 1997), the pilot study demonstrated a potentially successful application. Graphics and colors can be used to emphasize important data and possibly to reduce complexity in ATC operations. However, we do not suggest a particular color palette for display enhancements or visual layers. The display concepts used colors that do not interfere with one another when viewed on a black background in normal office lighting conditions. For example, as the data blocks moved over weather cells or color-coded warning areas, there was sufficient chromatic contrast so as to ensure information legibility. (For a description of the colors used in the prototype, see Appendix C.) Further studies are necessary to evaluate specific color palettes for our display enhancements in operational systems and what consequences they might have on information retrieval and overall display complexity.

2.3.5 Primary Study

During the primary evaluation, the controllers participated one at a time sitting in front of the computer monitor as the research team instructed them on how to interact with the prototype. We demonstrated each menu function in the prototype to the controller: how to toggle weather levels on and off; how to control the animated weather prediction; how to use the three options for data-block color coding; and how to stop, forward, and rewind the traffic scenario. After the controller had interacted with all display enhancements in the prototype, he or she gave feedback regarding the acceptability of the enhancements during structured interviews and using rating scales. For each of the four complexity factors, the controllers explained what actions they normally take when confronted with the factor, how frequently each factor adds difficulty to controlling traffic, and to what extent it impacts their job. The third question used a 5-point rating scale in which a rating of 1 implied no impact and a rating of 5 implied a very high impact. Likewise, for each of the four display enhancements, controllers evaluated to what extent it

would reduce their job complexity. A rating of 1 implied no complexity reduction and a rating of 5 implied a very large complexity reduction. Finally, the controllers commented on the new display as to whether it was the best way to reduce complexity and why.

3. Results

In the following sections, we evaluate the display enhancements for each of the four complexity factors.

3.1 Weather Display

The controller questionnaire responses supported the assertions that increased weather activity adds to ATC task complexity. The controllers reported that weather factors add to the difficulty of controlling aircraft as little as once a week to as often as 6 times a day during the summer. They reported that it is routine to reroute affected aircraft around weather and to decrease traffic volume to account for a constrained acceptance rate. In addition, it is often necessary to slow the input from other sectors when weather activity increases. Increases in altitude changes were reported to keep aircraft vertically separated. Substantial coordination between different sector controllers and with ATC facilities is required to facilitate the changing, slowing, and closing of flight paths. To accomplish this, controllers reported that they need to know trends, directions of movement, and intensity patterns of sector weather activity. According to controller feedback, the presentation of this information is inadequate on the current system. Figure 4 shows that controllers believe that weather factors have a high or very high impact on their job.

The controller responses shown in Figure 5 indicate that the weather display enhancements would moderately reduce ATC complexity. Most controllers responded that the new display would produce a moderate-to-large task-complexity reduction. One controller reported that "it would facilitate the ability to differentiate the heavy weather areas and adjust the traffic flow accordingly." Several controllers commented that the easily understandable weather display and projected weather directions would aid in vector planning and allow clearer directions to the pilots. Although an optimal display might reduce the complexity associated with controller actions and planning, the weather activity would remain a basic control problem.
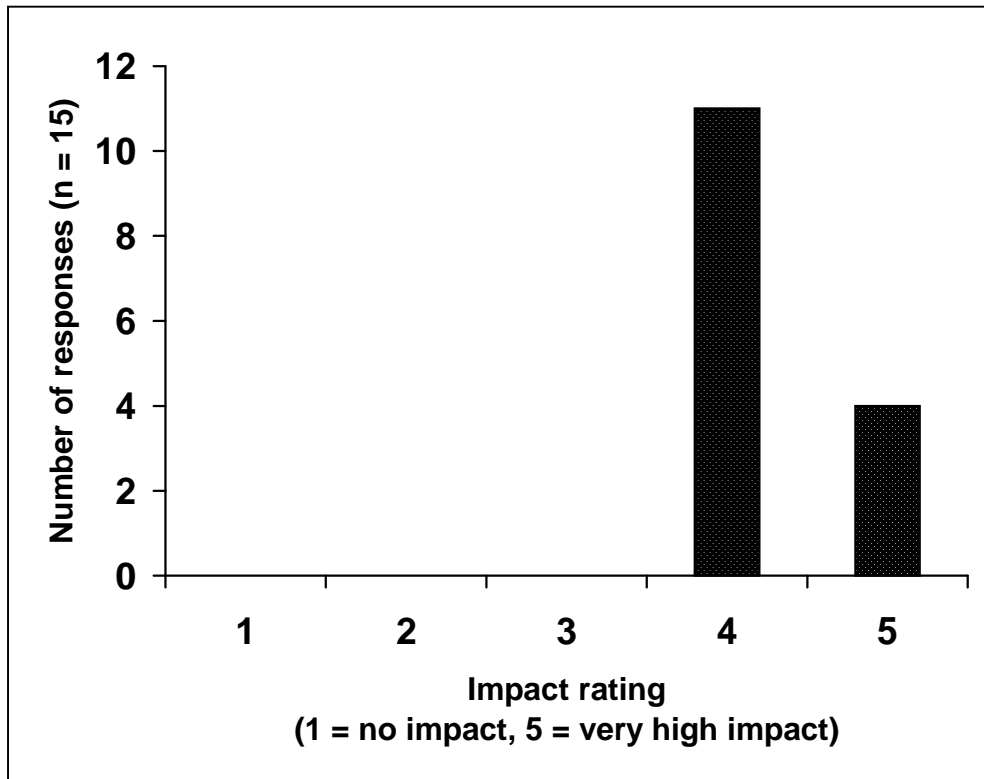
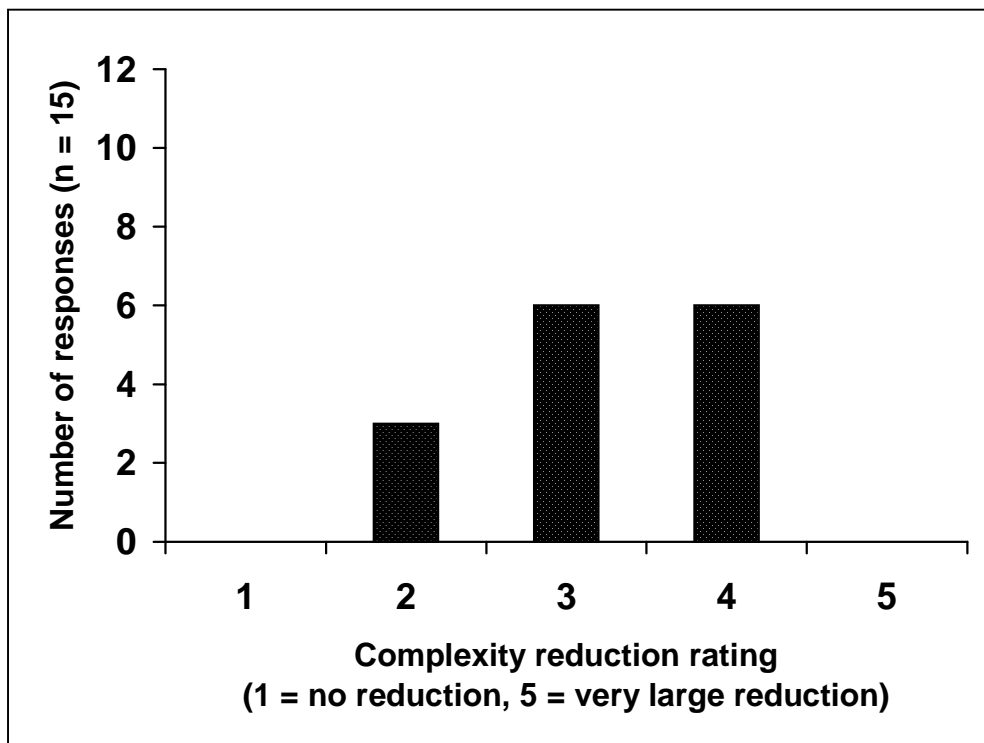Figure 4. Controller ratings of the impact caused by weather factors.

Figure 5. Controller ratings of complexity reduction resulting from the weather display.

The controllers reported that SUAs require them to confine traffic to less airspace, reroute aircraft, and maintain a heightened awareness of all aircraft locations and headings. For most controllers, the reported frequency during which restricted areas add difficulty to controlling traffic ranged from once a day to 50 times a day. Only one controller reported that these restricted areas add to the difficulty of controlling traffic (i.e., "several times-per-year, depending on the sector").   In the old Plan View Display (PVD) system, SUA information was transmitted verbally as general information memos or written on an information board. Restricted areas were indicated on radar displays manually using a grease pencil. This method resulted in a greater potential for communication errors, attentional focus diverted from the radar display, additional actions required by the controller, and grease pencil smudges on the scope. In the current Display System Replacement (DSR), no restricted area information is indicated on the display. SUA status information is presented on an Enhanced Status Information System (ESIS).

Figure 6 shows that controllers believe that active restricted areas have a high impact on their job.
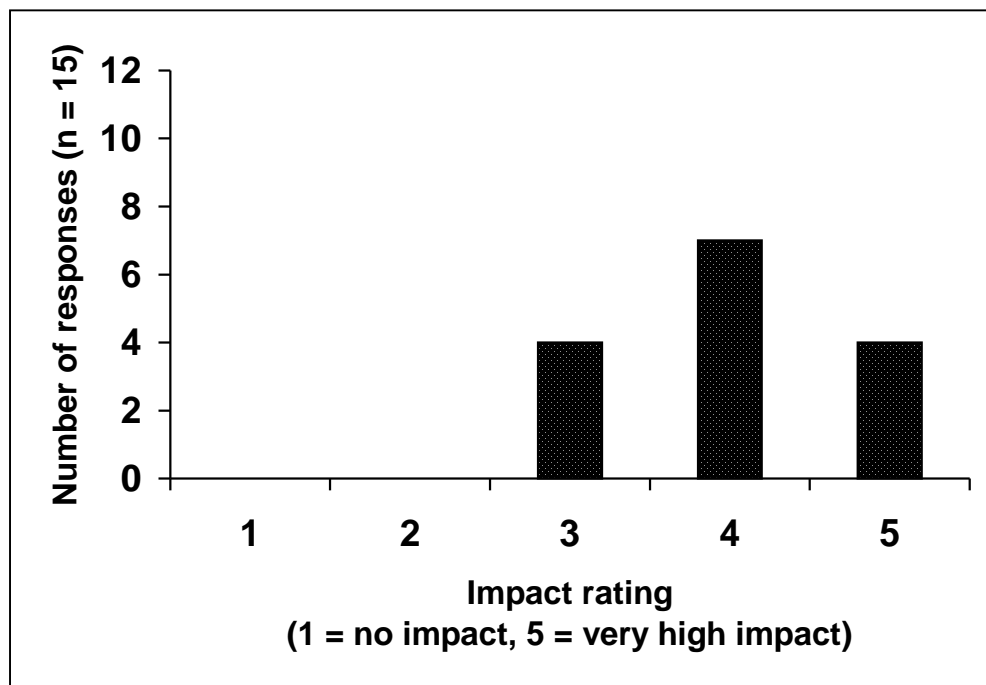

Figure 6. Controller ratings of the impact caused by active SUAs.

The responses to the SUA display enhancement indicated that the controllers thought the display enhancement was useful. Several controllers indicated that the SUA enhancement would serve as a continual reminder of the SUA status and would reduce errors due to a failure to remember.

Figure 7 shows controller responses indicate this display enhancement would have a moderate to large reduction on complexity. When the research team discussed possible ways to display this information, four controllers commented that bright colors and flashing (when the SUA becomes active) might be too distracting. Some suggested using only a colored outline of the restricted area. Nonetheless, most controllers thought that the enhancement would reduce vectoring errors, help keep attention on the display screen, reduce task complexity, or all of the above.
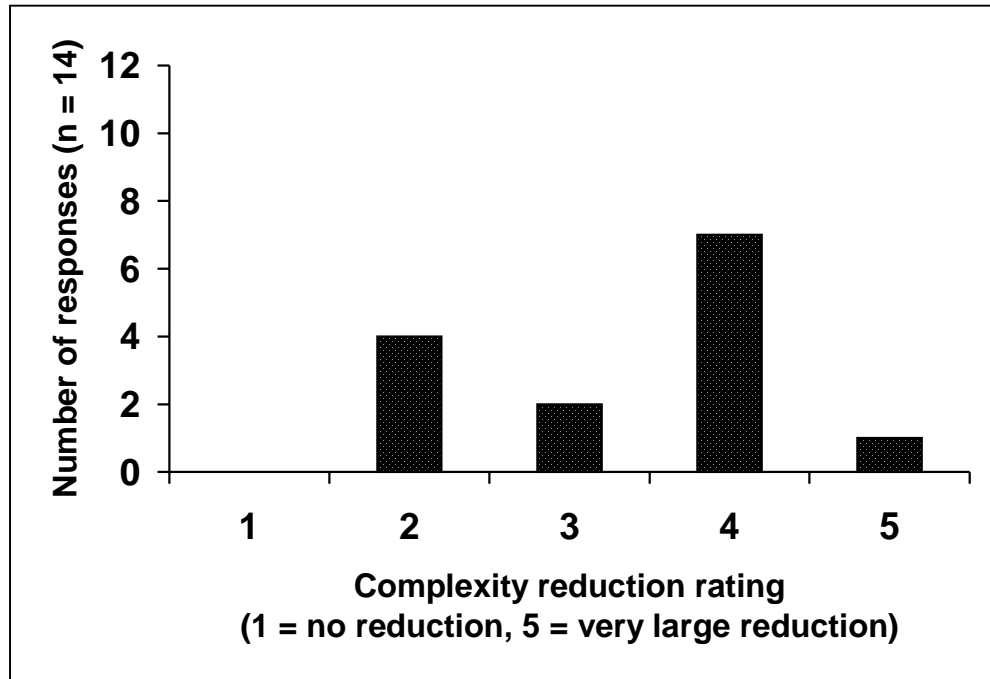

Figure 7. Controller ratings of complexity reduction resulting from the color coding of active SUAs.

3.3 Transitioning Aircraft

To maintain aircraft separation when there are transitioning aircraft, controllers reported that they must closely monitor and redirect aircraft vectors, speeds, routings, and delays of climbs and descents. The controllers estimated that these factors add to the difficulty of controlling traffic every day, ranging from twice a day to 60 times a day. Maintaining vertical and lateral separation requires increased controller coordination between sectors and increased controller awareness. Overflights need to be closely monitored to place them appropriately above or below ascending or descending aircraft. In the current system, controllers need to look at the destination in the data block if aircraft is landing nearby or retrieve and read flight strips to ascertain important transitioning aircraft information. This process requires additional processing time and necessitates that attentional focus be diverted from the radar display. Figure 8 shows that controllers believe that transitioning aircraft have a high impact on their job.
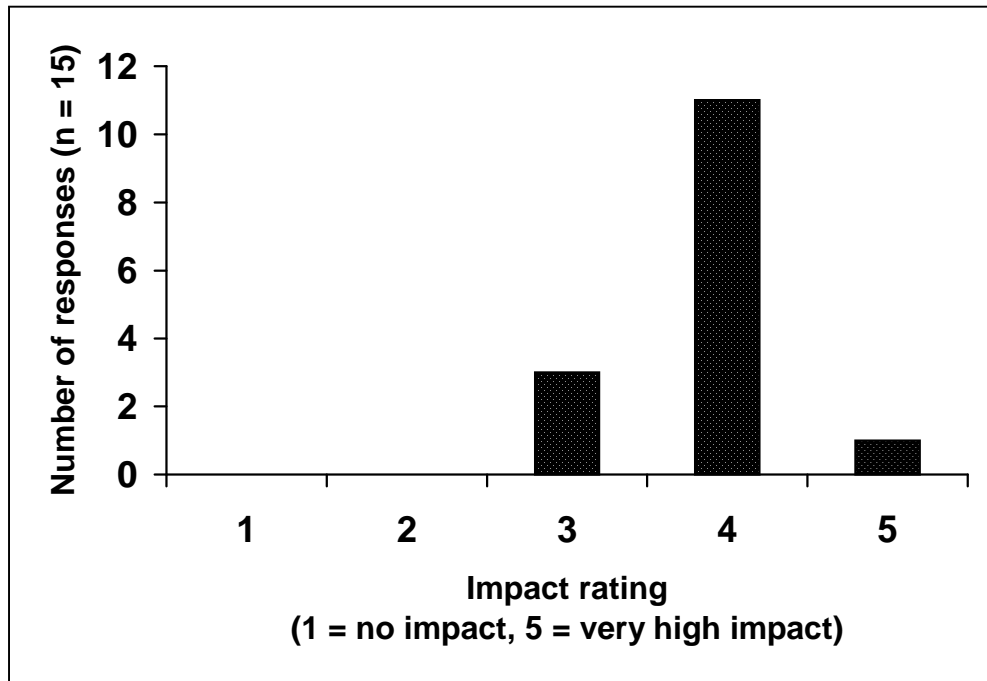
Figure 8. Controller ratings of the impact caused by transitioning aircraft.

As Figure 9 indicates, the controllers thought that the transitioning aircraft display enhancement would produce a moderate reduction in complexity. Two controllers commented that this enhancement would not be especially helpful. In one case, the controller thought that highlighting transitioning aircraft was not helpful because 90% of his traffic was either climbing or descending. In the majority of the other cases, however, the controllers believed that the display enhancements would result in several advantages including reducing scanning time and the time controllers must look at flight strips.
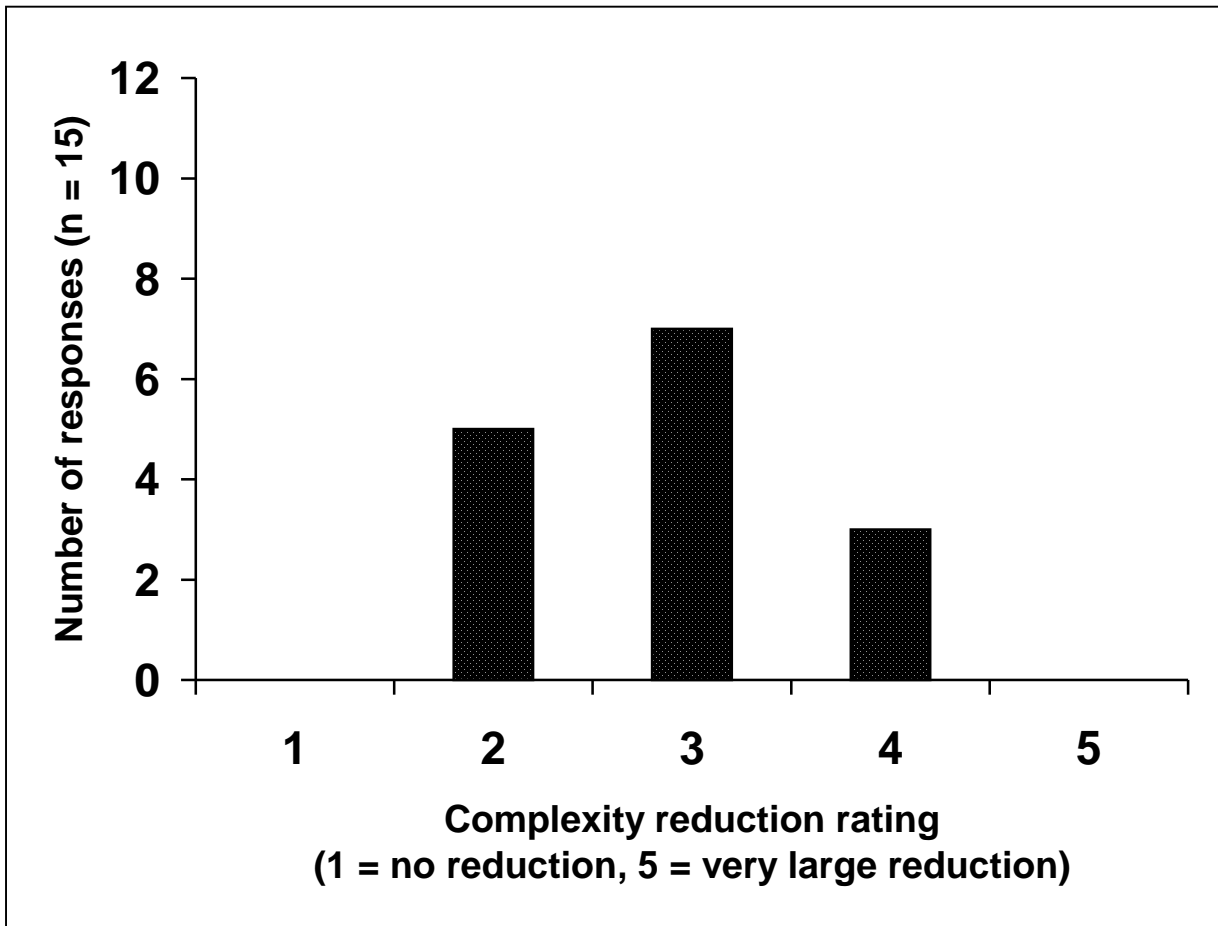
Figure 9. Controller ratings of complexity reduction resulting from the color coding of over flights and airport destinations.

3.4 Navigational Aid Outages

The ATCSs reported that when navaids are not operational, increased workload occurs due to frequency congestion, increased vectoring, and alternative route instructions. Two controllers report that this adds to the complexity of controlling traffic only once a month. The remaining controllers reported a much more frequent effect, ranging from once a day to 5 times an hour. In the current system, navaid failures are communicated manually and verbally from supervisors to controllers. Outage areas are posted on an outage status board. Reading these postings diverts attention from the scope. Furthermore, increases in sector traffic can result in the controller forgetting about the current navaid outage. Several controllers suggested that some form of reminder would be useful. Figure 10 shows that controllers believe that navaid outages have a moderate-to-high impact on their job.
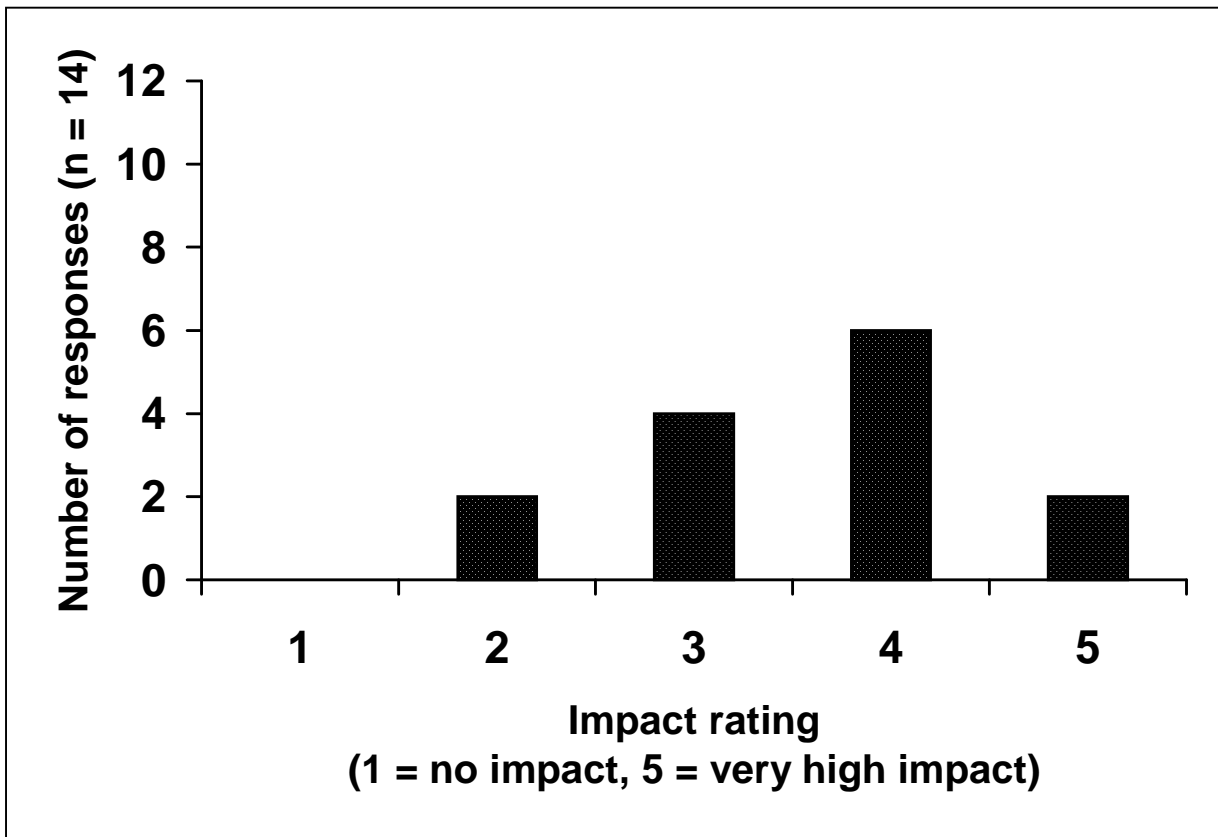
Figure 10. Controller ratings of the impact caused by navaid outages.

As in the previous enhancements, most controllers believed that this change would reduce task complexity. Most of the comments indicated that this enhancement would reduce the time that attention is taken away from the radar screen. There would be no need to look at the status board allowing controllers to remain focused on the traffic. Other controllers commented that this enhancement would help planning and reduce errors. Figure 11 indicates that most controllers thought this display enhancement would produce an average value reduction in task complexity.
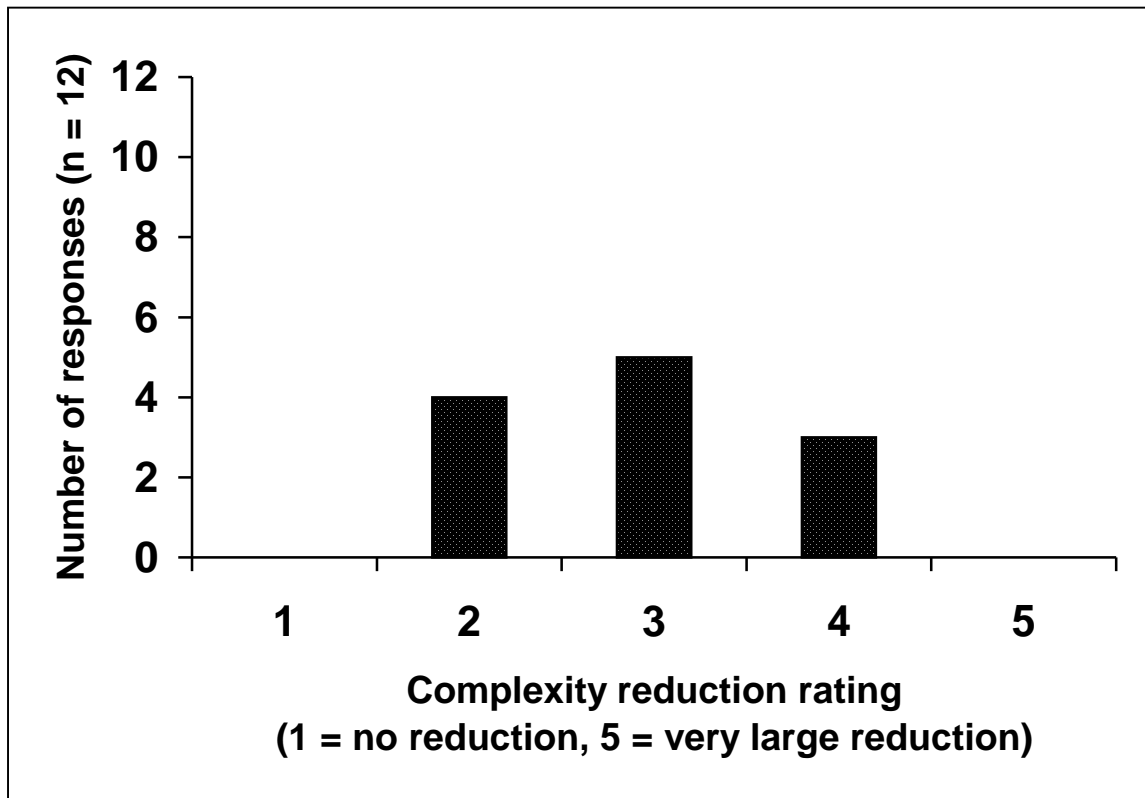
Figure 11. Controller ratings of complexity reduction resulting from graphical representations of navaid outages.

4. Conclusions

The objective of the present study was to develop display concepts designed to reduce en route ATC complexity. By applying graphical and color-coding techniques, the research team demonstrated how important ATC information can be presented more directly on the radar display, thereby facilitating controller action and planning. We identified four factors previously reported to add to ATC complexity: a) the effects of weather, b) active SUA, c) transitioning aircraft, and d) navaid outages. The responses to questionnaires by ZJX controllers supported the assertion that these factors increase ATC complexity. Furthermore, our results showed that controllers predicted a substantial reduction of their job complexity from the proposed display enhancements. These results suggest that the specific display enhancements developed in this study are workable solutions for reducing ATC complexity. They also indicate that a future ATC system using high-resolution graphics and colors can be favorably received by ATCSs.

The controllers reported that the amount of time that attention is diverted from the radar screen is a major source of complexity. The enhancements for transitioning aircraft, active SUA, and navaid outages were all cited by the controllers as potentially useful for maintaining attention on the radarscope. The addition of memory aids for important information was reported as a crucial complexity-reducing factor because it would attenuate memory failures and reduce cognitive workload. Both enhancements for active SUA and navaid outages were described by the controllers as useful for providing reminders of important ATC information. Finally, most controllers reported that the weather enhancement would provide a much more useful means to

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present important weather-related information than the current ATC system. The increased amount of weather-related information included in the weather enhancement would give controllers a greater ability to advise pilots, supervisors, and other controllers.

The display enhancements described and evaluated in this paper could serve to reduce ATC task complexity for controllers and simplify information flow for supervisors. Whereas the present study outlines the conceptual framework for these display enhancements, additional research is needed to determine the precise efficacy of these display enhancements in operational systems and to specify optimal color and other implementation choices.

5. Recommendations

Based on the above findings, we recommend the following activities:

a. A formal test simulation of the proposed enhancements for future en route ATC display systems should be conducted to determine their efficacy for the reduction of task complexity.

b. Specific studies should be conducted to determine the optimal colors for each display enhancement.

c. Emphasis should be placed on maintaining readability of all important display information, reducing visual interference, and reducing extraneous visual distractions.

We recommend four display enhancements for implementation pending further study.

a. color coded weather activity in a graphical presentation plus supplemental text-based information,

b. color coded SUA in a graphical presentation plus supplemental text-based information,

c. color coded text in data blocks representing information for transitioning aircraft (including overflights), and

d. color coded graphical representations indicating navaid outages plus supplemental text-based information.

References

Cardosi, K. M. (1998). *Use of Color in ATC Displays*. Unpublished manuscript.

Carrigan, E. P., Dieudonne, J. E., & MacDonald, B. C. (1997). Field evaluations move ATM system toward free flight. *Journal of Air Traffic Control, 39*(2), 12-21.

Galushka, J. (1997). *European HMI design philosophy and the application of color in ATC displays: Recommendations for the next generation of ATC displays in the U.S.* Unpublished manuscript.

Guttman, J. A., Stein, E., & Gromelski, S. (1995). *The influence of generic airspace on air traffic controller performance* (DOT/FAA/CT-TN95/38). Atlantic City, NJ: DOT/FAA Technical Center.

Hanson, E. R., Jr. (1997). Travel through the next dimension: 3-D volumetric display. *Journal of Air Traffic Control, 39*(1), 24-27.

Macromedia Director (Version 6.5) [Computer Software]. (1997). San Francisco, CA: Macromedia Inc.

Mogford, R. H., Guttman, J. A., Morrow, S. L., & Kopardekar, P. (1995). *The complexity construct in air traffic control: A review and synthesis of the literature* (DOT/FAA/CT-TN95/22). Atlantic City International Airport, NJ: Federal Aviation Administration Technical Center.

Rodgers, M. D., Mogford, R. H., & Mogford, L. S. (1998). *The relationship of sector characteristics to operational errors* (DOT/FAA/AM-98/14). Washington, DC: Office of Aviation Medicine.

Mogford, R. H., Murphy, E. D., Roske-Hofstrand, R. J., Yastrop, G., & Guttman, J. A. (1994). *Research techniques for documenting cognitive processes in air traffic control: Sector complexity and decision making* (DOT/FAA/CT-TN94/3). Atlantic City International Airport, NJ: Federal Aviation Administration Technical Center

Reynolds, L. (1994). Colour for air traffic control displays. *Displays, 15*(4), 215-225.

Skiles, T., Graham, R., Marsden, A., & Krois, P. (1997). En route ODID-PVD baseline comparisons. *Journal of Air Traffic Control, 39*(1), 38-41.

Stein, E. (1985). *Air traffic controller workload: An examination of workload probe* (DOT/FAA/CT-TN84/24). Atlantic City International Airport, NJ: Federal Aviation Administration Technical Center.

Wyndemere, Inc. (1996). *An evaluation of air traffic control complexity* (Contract number NAS2-14284). Boulder, CO: Author.

Appendix A
Factors Contributing to ATC Complexity (from Mogford et al., 1994).

1. The amount of climbing or descending traffic

2. The degree of aircraft mix (Visual Flight Rules, Instrument Flight Rules, props, turboprops, and jets)

3. The number of intersecting flight paths

4. The number of multiple functions the controller must perform (e.g., approach control, terminal feeder, en route, and in-trail spacing)

5. The number of required procedures that must be performed (e.g., all Raleigh arrivals must cross TENNI at FL210)

6. The number of military flights

7. Amount of coordination or interfacing with other entities (adjacent sectors, approach controls, center, military units, etc.)

8. The extent to which the controller is affected by airline hubbing or major terminal/airport traffic

9. The extent to which weather-related factors affect ATC operations

10. Number of complex aircraft routings

11. The extent to which the controller's work is affected by restricted areas, warning areas, and Military Operations Areas and their associated activities

12. The size of sector airspace

13. The requirements for longitudinal sequencing and spacing

14. Adequacy and reliability of radio and radar coverage

15. Amount of radio frequency congestion

Appendix B
Factors Contributing to ATC Complexity (from Wyndemere, Inc., 1996)

1. Airspace structure

2. Weather effects on airspace structure

3. Aircraft density

4. Number of aircraft climbing or descending

5. Weather effects on aircraft density

6. Variance in directions of flight

7. Winds

8. Angle of convergence in conflict situation

9. Level of knowledge of intent of aircraft

10. Coordination

11. Special use airspace

12. Proximity of potential conflicts to sector boundary

13. Number of facilities

14. Number of crossing altitude profiles

15. Variance in aircraft speed

16. Performance mix of traffic

17. Distributions of closest points of approach

18. Neighbors

19. Separation requirements

Appendix C
Color Specification of Display Features

The following table defines the colors that were used for different display features in the
prototype. The colors are defined in terms of the L*a*b color model which is a refined version
of the original color model proposed by the Commission Internationale d'Eclairage (CIE). The
CIE L*a*b color model defines a color by three components; a lightness component (L) and two
chromatic components, a and b. The L component can range from 0 to 100, and the a and b
components can range from +120 to –120.

Display feature	L	a	b
Sector lines	63	-54	40
Data block green	76	-70	54
Data block yellow	97	-20	88
Data block blue	90	-52	-16
Data block orange	69	47	73
Navaid outage	58	27	3
Active SUA	8	26	13
Weather level 1	12	0	0
Weather level 2	26	0	0
Weather level 3	41	0	0
Weather level 4	20	-6	26
Weather level 5	36	-9	40
Weather level 6	53	-13	54