DOT/FAA/TC-10/14, III

Federal Aviation Administration
William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

Future En Route Workstation Study (FEWS III): Human-in-the-Loop Simulation of Air Traffic Controller Management of Advanced Aircraft Concepts

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March 2010

Technical Report

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U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No. DOT/FAA/TC-10/14, III	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Future En Route Workstation Study (FEWS III): Human-in-the-Loop Simulation of Air Traffic Controller Management of Advanced Aircraft Concepts		**5. Report Date** March 2010 **6. Performing Organization Code** AJP-6110
7. Author(s) Carolina M. Zingale, Ph.D., Human Factors Team – Atlantic City, ATO-P Ben Willems, Human Factors Team – Atlantic City, ATO-P Jennifer M. Ross, Ph.D., Hi-Tec Systems, Inc.		**8. Performing Organization Report No.** DOT/FAA/TC-10/14, III
9. Performing Organization Name and Address Federal Aviation Administration Human Factors Team – Atlantic City, ATO-P William J. Hughes Technical Center Atlantic City International Airport, NJ 08405		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.**
12. Sponsoring Agency Name and Address Federal Aviation Administration Human Factors Research and Engineering Group 800 Independence Avenue, S.W. Washington, DC 20591		**13. Type of Report and Period Covered** Technical Report **14. Sponsoring Agency Code** ATO-P
15. Supplementary Notes		

16. Abstract

The Federal Aviation Administration (FAA) and the Joint Planning and Development Office have developed the Next Generation Air Transportation System, NextGen, in an effort to transform the existing air traffic system to manage anticipated increases of up to three times current traffic levels by 2025 (FAA, 2008b). In this third volume of the Future En Route Workstation Study (FEWS) series, we conducted a simulation with eleven en route air traffic controllers to provide an initial evaluation of three NextGen-related concepts: the increased use of Area Navigation (RNAV) routes, aircraft self-spacing (one aircraft follows a lead), and aircraft grouping (two or more aircraft fly as in military formation flight). We conducted the simulation under very high traffic conditions (two to three times current levels) using a Baseline system that simulated the En Route Automation Modernization, ERAM, system and using the FEWS system that added features and capabilities to support controller tasks. We found many benefits for the FEWS system. The participants managed more aircraft, held traffic less, and reported lower workload and higher performance when they used the FEWS system. We also found benefits for the use of RNAVs that implemented both lateral and vertical conformance constraints. The participants managed more aircraft and issued fewer voice clearances to aircraft. We found few objective benefits of self-spacing and grouping. The participants commented favorably on self-spacing, but they commented negatively on grouping.

17. Key Words Area Navigation Routes Automatic Dependent Surveillance – Broadcast Next Generation Air Transportation System Self-Spacing	**18. Distribution Statement** This document is available to the public through the National Technical Information Service, Springfield, Virginia, 22161. A copy is retained for reference at the William J. Hughes Technical Center Library.

19. Security Classification (of this report)	**20. Security Classification (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified	Unclassified	123	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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Acknowledgments

The authors thank the many individuals who contributed to the preparation and conduct of this simulation. We thank Dave Chappuies, Front Line Manager from Los Angeles Air Route Traffic Control Center (ZLA), who was on detail at the Federal Aviation Administration (FAA) Research Development and Human Factors Laboratory (RDHFL) as a Subject Matter Expert (SME) during the development and execution of this simulation. He supported concept integration and scenario development as well as provided participant training, Data (D)-side support, and observer ratings. We thank Kelly Stephenson, Hi-Tec Systems, Inc., and retired air traffic controller from Kansas City Air Route Traffic Control Center (ZKC), who served as a SME during the simulation and provided training, D-side support, observer ratings, and assisted with data analysis.

We thank Gary Mueller of the Human Factors Team – Atlantic City and members of the programming, simulation, and engineering team at the RDHFL for their outstanding efforts in integrating the new simulator and workstation functionality and design elements into the simulator, ensuring optimal functionality of the equipment, communication system, and data collection tools as well as providing data analysis support: They are Joel Grochowski and Albert Macias from the FAA; and Matt Zeits, Yevgeny Tabekman, Ed Jaggard, Ed Little, John Dilks, Wallace Daczkowski, and Otto Smith from Engility Corporation.

We thank members of the Target Generation Facility (TGF) staff, especially Dana Whicker and Samantha Fullerton, who developed and integrated the new aircraft capabilities necessary for this simulation and who provided assistance with data analysis. We also thank Rhoma Gordillo for monitoring and troubleshooting the TGF system during shakedown and testing. We thank Al Rehmann (FAA) and George Chachis (Engility) for their support in scheduling and providing the simulation pilots required to prepare and run the simulation, and we thank the simulation pilots who supported this effort: Bill Hickman, Tru Hall, Audrey Wilmer, Lee Dixon, Tom Vispisiano, George Bigge, J. C. Lester, Ross Spath, Steve Allen, and Tom Callahan.

We thank the research assistants who helped organize, collate, and code test materials and who supported data recording, data entry, and data analysis: Scott Terrace, Kate McDevitt, and Mark Hale (Hi-Tec Systems, Inc.) and Kevin Hallman and Henry Dorsey (Northrop Grumman). We also thank Jim McGhee and Rich Ridgway (Northrop Grumman), retired controllers and current SMEs at the RDHFL, who assisted with scenario development and troubleshooting.

Executive Summary

The Federal Aviation Administration (FAA) projects that the number of flights in the National Airspace System (NAS) will double (FAA, 2009a) or even triple by 2025 (FAA, 2008b). The FAA (2009b) and the Joint Planning and Development Office (JPDO, 2007) developed the Next Generation Air Transportation System (NextGen) to transform current surveillance, navigation, and communication systems and to implement new concepts to manage the expected increase in air traffic. Concepts such as performance-based navigation and the delegation of some responsibilities to the flight deck will greatly alter the roles of the pilot and air traffic controller. The FAA needs to determine the feasibility and benefits of these concepts before implementing them in the NAS.

This Future En Route Workstation Study (FEWS) is the third volume in the series. This simulation provided an initial evaluation of three concepts that are designed to increase airspace capacity. We evaluated an emerging concept – the increased use of Area Navigation Routes (RNAVs) – and two advanced concepts: (a) the delegation of self-spacing responsibility to the flight deck and (b) a grouping procedure that enabled the controller to manage two or more aircraft as a single unit, similar to the way military aircraft are managed in formation flight. We evaluated the concepts' effects on system and controller performance using very high traffic level scenarios.

We conducted the simulation at the FAA William J. Hughes Technical Center (WJHTC) Research Development and Human Factors Laboratory (RDHFL), using two simulated en route air traffic control systems. We used a simulated system similar to the En Route Automation Modernization (ERAM) system as the Baseline system because in 2010 the FAA plans to use ERAM to replace the current system: Display System Replacement (DSR). We also used the FEWS system. FEWS adds display features to the controller workstation to support controller management of high traffic volumes. Two previous FEWS simulations identified features to support existing air traffic procedures. In this third FEWS simulation, we added other features to specifically support controller use of the new concepts.

We evaluated each system under four test conditions. Two of the test conditions included weather. In the first condition, we included the use of RNAV routes that used only lateral conformance criteria that we termed, *Limited RNAVs*. In the second condition, we included RNAV routes that used both lateral and vertical conformance criteria that we termed, *Full RNAVs*. Weather was not a factor in either of the first two conditions. In the third condition, we included Full RNAVs and weather. In the fourth condition, we included Full RNAVs, the advanced concepts (self-spacing and grouping), and weather.

In all scenarios, we used 3 nm (5.56 km) lateral separation standards under the assumption that advanced surveillance capabilities (Automatic Dependent Surveillance–Broadcast, ADS-B) would be in use by the time the procedures are enabled. We designated 70% of the aircraft in each scenario as Data Communications (Data Comm) equipped. Data Comm is expected to begin use in the field during the NextGen mid term (through 2018).

Eleven currently Certified Professional Controllers (CPCs) from five en route facilities participated in the simulation. We recorded and analyzed system and controller performance, capacity, and efficiency data. We also obtained subjective measures of workload, situation awareness, and ratings of system features and concepts.

Overall, we found strong benefits for the FEWS system and the use of Full RNAVs. When the participants used FEWS, they managed more aircraft, held or redirected traffic outside their sector less, and reported lower workload and higher performance ratings than when they used the Baseline system. They reported that the FEWS system supported their control efficiency, sector operations, and control strategies better, and provided better display designations, than the Baseline system. With Full RNAVs, the participants managed more aircraft, issued fewer altitude clearances, and made fewer voice transmissions than when they worked with Limited RNAVs. The aircraft also spent more time and traveled a greater distance through the sector, indicating that the participants did not need to intervene much when aircraft adhered to the more constrained route structures.

With respect to the advanced concepts, self-spacing appears promising, but grouping does not. The participants rarely activated either concept and had more difficulty working with them when using the Baseline system. In their subjective responses, the participants commented favorably on the self-spacing concept, but reacted negatively towards grouping – describing it as unsafe and too complex. The participants found many of the FEWS display enhancements useful, including the addition of a highlighted frequency field in the data block that signaled that the frequency needed to be transferred. They also found the expanded FEWS D-side capabilities highly beneficial, but they had concerns about how to distribute responsibilities between the Radar- and D-side controllers.

We recommend that future system designs incorporate many of the FEWS display features and functions to improve system and controller performance. Our results support those of the earlier FEWS simulations in that the use of a mouse, instead of a trackball, provided more advanced display interaction capabilities that the participants found highly useful. The mouse enabled them to perform actions more quickly and effectively, including the ability to move data blocks to preferred locations and to initiate reroutes by dragging aircraft routes to desired locations. We also recommend that future systems include display features (a) that clearly designate aircraft status and procedure use and (b) that are automatically displayed by the system, not entered by the controller.

Finally, we recommend that subsequent research efforts focus on further assessment of the RNAV and self-spacing concepts, particularly to determine whether feasibility and benefits are achieved in off-nominal (i.e., equipment outage) situations.

1. INTRODUCTION

The Federal Aviation Administration (FAA) projects that the number of flights in the National Airspace System (NAS) may double (FAA, 2009a) or even triple by 2025 (FAA, 2008b). The FAA (2009b) and the Joint Planning and Development Office (JPDO, 2007) developed the Next Generation Air Transportation System (NextGen) to address the management of increasing air traffic levels. NextGen is a comprehensive, multiagency initiative designed to transform the existing air traffic management system. The plan calls for sweeping changes to surveillance, navigation, and communication systems that will enable new concepts and procedures. The new concepts and procedures are expected to greatly alter the role of the pilot and the air traffic controller. The flight crew will be expected to take responsibility for some procedures (e.g., self-spacing) that were once managed exclusively by air traffic control, and the controller will be expected to work more as an airspace manager. As a result, the FAA (2008b) has identified human factors as a cross-cutting research and development area for NextGen.

The FAA (2009b) and JPDO (2007) describe the phases of NextGen research and development. The mid term phase (through 2018) focuses on the increased use of Area Navigation (RNAV) routes and Required Navigation Performance (RNP). These capabilities are already in use in the NAS to some extent. Using RNAV and RNP, aircraft are able to fly more direct, point-to-point routes, thus improving traffic flow and fuel efficiency and allowing for more predictable and precise route navigation. RNAV and RNP are central to two basic NextGen concepts, Performance-Based Navigation (PBN) and Trajectory-Based Operations (TBO), that require aircraft adherence to defined routes and specific operational performance criteria.

The mid term phase also focuses on the development and implementation of the core technologies necessary for enabling more advanced concepts, such as the delegation of some procedures to the flight deck, that are anticipated for use in the far term (2018 and beyond). One of the enabling technologies is Data Communications (Data Comm) that will allow the nonverbal transmission of information between the air and ground. Data Comm is expected to reduce voice channel occupancy and the chance for miscommunications; it also enables the transmission of more complex air-ground exchanges (e.g., routes). Another key technology is Automatic Dependent Surveillance – Broadcast (ADS-B). ADS-B provides satellite-based surveillance capabilities. ADS-B *Out* allows aircraft to transmit highly accurate aircraft positioning information that would allow the potential to reduce separation standards in en route airspace from 5 to 3 (9.26 to 5.56 km). ADS-B *In* allows aircraft to access identity and location information and, depending on level of service, intent data of other aircraft.

This simulation evaluated the benefits and feasibility of three concepts. One is an emerging concept, the increased use of RNAV routes. The other two are advanced concepts that involve the delegation of some responsibilities to the flight deck. The first advanced concept involves the delegation of self-spacing responsibility. The second advanced concept involves a grouping procedure that enables the controller to manage two or more aircraft as a single unit, similar to military aircraft in formation flight.

We evaluated the concepts using two simulated controller workstation systems. We used a simulated system similar to the En Route Automation Modernization (ERAM) system as our Baseline. The FAA plans to replace the current Display System Replacement (DSR) with

ERAM in 2010 (FAA, 2008a). We also used the Future En Route Workstation Study (FEWS) system. Researchers at the RDHFL developed FEWS to assist the controller in managing high traffic levels efficiently and without negatively affecting safety or adding to workload (Willems, Hah, & Phillips, 2008; Willems & Hah, 2008). The researchers designed FEWS to provide aircraft and airspace data to the controller, when and where it is needed, in a format that is easily accessible and interpretable. The FEWS enhancements are based on core human factors design principles (e.g., Mejdal, McCauley, & Beringer, 2001) that strive to

- provide access to information through the fewest number of steps possible,
- prevent time sharing of information,
- maintain consistency across display windows,
- provide clear links between related information,
- place related information in close proximity, and
- reduce or eliminate the number of windows and lists, or make them optional.

Two earlier simulations evaluated the FEWS system's support of existing air traffic procedures (Willems, Hah, & Phillips, 2008; Willems & Hah, 2008). The results of those simulations found benefits for FEWS that included fewer controller data entries. For the current simulation, we added other features to support controller use of the RNAV, self-spacing, and grouping concepts. The results of the current simulation help determine how these concepts affect system capacity, safety, controller workload, and the utility of the FEWS display enhancements in supporting concept use.

1.1 Purpose

We designed the FEWS III simulation to assess the feasibility and benefits of (a) the increased use of RNAV routes, (b) aircraft self-spacing, and (c) aircraft grouping. We evaluated the concepts using the Baseline system and the FEWS system. We also included weather in half of the scenarios. We assessed system efficiency and Certified Professional Controller (CPC) performance, communications, and workload in a high-fidelity, human-in-the-loop (HITL) simulation.

1.2 Background

The FAA must conduct research to determine the benefits and feasibility of the NextGen concepts that propose to transform the air traffic system. Delegating procedures to the flight deck is anticipated to reduce controller workload, enabling more aircraft to be accommodated in the airspace. PBN and TBO are expected to allow more predictable routes and promote more efficient use of the airspace. However, these concepts also change the way controllers interact with the aircraft. Their role shifts from one that primarily involves active, tactical control to one that involves more passive airspace management. The FAA needs to understand the implications of this shift to fully evaluate whether these concepts will achieve the anticipated goals.

Previous research identified that the use of predictable route structures and pilot-delegated spacing procedures enhanced airspace efficiency. However, most of the research focused on concept use from the pilot perspective. Zingale and Willems (2009) and McAnulty and Zingale (2005) summarized research that had been conducted on aircraft self-spacing concepts. The research showed that self-spacing aircraft maintained more precise spacing intervals than aircraft that were controlled using existing procedures. However, some research also found that new controller tools improved spacing precision for aircraft that were not self-spacing, suggesting that other methods may promote the same benefit (e.g., Prevôt et al., 2007). Prior research also indicated that self-spacing aircraft required less vectoring and fewer air-ground communications, although the ability of aircraft to adhere to predictable route structures such as RNAV routes also produced similar benefits (e.g., Boursier, Hoffman, Rognin, Vergne, & Zeghal, 2006).

Although some researchers examined delegated procedures under degraded situations (e.g., aircraft terminated use of a procedure), they did so using structured scenarios in which the controllers knew what to expect. Most of the prior work did not systematically investigate the effects of weather on these procedures. Therefore, questions remain as to how beneficial the different procedures are relative to one another and how much benefit would be derived in off-nominal conditions.

NextGen anticipates the increased use of RNAV routes and RNP through the mid term (2018). NextGen also anticipates that the enabling technologies will be developed during the mid term that will make possible the use of more advanced concepts such as aircraft self-spacing in the far term (after 2018). However, not all of the aircraft will be equipped with the necessary technologies at the same time. As a result, not all aircraft will be capable of conducting the procedures, and the controller will be managing aircraft in a mixed-equipage environment. For example, the FAA is currently planning to deploy Data Comm to the field during the mid term, but there is no mandate for equipage. Although the FAA has proposed a mandate for ADS-B Out equipage by 2020, the agency has no proposed mandate for ADS-B In (FAA, 2007). The FAA anticipates that many aircraft carriers will equip with ADS-B In voluntarily when installing ADS-B Out. However, aircraft without ADS-B In will not be able to perform delegated procedures.

We conducted this simulation to determine the extent to which increased airspace efficiency and capacity benefits could be realized through the use of the RNAV, self-spacing, and grouping concepts and to evaluate the effects on controller performance. We evaluated the concepts using two different controller workstations. We used a simulated ERAM system as our Baseline system because ERAM will be in use at least into the mid term; therefore, it provides a valid point of comparison. We also used the FEWS system that added display enhancements to the Baseline system to support the use of the concepts. We added display elements to FEWS to indicate which aircraft were equipped with the necessary technologies and to designate which aircraft were conducting specific procedures. We also made other enhancements to the display to minimize clutter. We modified the data blocks of the aircraft that were performing certain procedures under the assumption that aircraft that are engaging in more predictable maneuvers require less controller intervention than other aircraft. We made these modifications to support the effective distribution of controller cognitive resources to help them manage more aircraft in the airspace without increasing their workload to unacceptable levels.

1.2.1 Baseline System

We used a simulated ERAM system as our Baseline because DSR will no longer be in use in the field in the mid term (FAA, 2008a). However, the Baseline system shares many features in common with DSR. Both systems provide a radar display, trackball, and keyboard at the Radar

(R)-side controller workstation position. Both systems also provide the Display Control (DC) View that enables the controller to access system features and the Computer Readout Display (CRD) that allows the controller to enter commands and receive system feedback. Both systems provide the CRD on the Data (D)-side display as well as the User Request Evaluation Tool (URET) that displays electronic flight progress strips and provides conflict probe capabilities.

The Baseline and DSR radar displays present position symbols to indicate aircraft location and data blocks that provide information about each aircraft. Both systems display Full Data Blocks (FDBs) for aircraft that are under the controllers' responsibility. The basic components of the 3-line FDB are the aircraft call sign (line 1), altitude (line 2), and computer identification (CID) and speed (line 3). The systems also provide the capability for the controller to enter text in the fourth line if desired (e.g., destination). Both systems display 2-line Limited Data Blocks (LDBs) for aircraft that are not currently under the controller's responsibility. The LDBs display only the call sign and altitude.

The Baseline system interface differs from DSR in several ways. The Baseline system provides controllers with data for aircraft in the airspace of adjacent facilities and incorporates other data blocks in addition to the FDB and LDB. The additional data blocks include (a) the Paired LDB that displays the call sign and Mode C altitude; (b) the Enhanced LDB that displays the call sign, Mode C altitude, assigned or interim altitude, and altitude nonconformance indicators; and (c) the Alternate Data Block that displays the call sign, Mode C altitude, assigned or interim altitude, altitude nonconformance indicators, position symbol, leader line, and the vector line and the Range Data Block (if selected).

The Baseline system also provides controllers with a different means of accessing features and functions via toolbars rather than through the DC View and the CRD. The toolbar consists of different buttons that allow the controller to store and access preference settings, adjust the display range, and so forth. The controller can also "tear off" individual toolbar buttons and place them in different locations on the display. Different types of buttons perform different actions. The Toggle buttons turn views or functions on and off, the Increment/Decrement buttons change values for a feature, and the Parent buttons provide access to other underlying toolbars. The controller can create and store macros on buttons. The macros can then be used to initiate actions in a single step that would otherwise require a series of keystroke entries to initiate. For example, the controller can store the procedure to display a J-ring (i.e., a circle placed around the aircraft position symbol to show minimum separation distance) onto a macro button. He can subsequently select that button to put a J-ring around a specified aircraft.

The Baseline system displays the Data Comm indication, as planned by ERAM. Data Comm allows the nonverbal transmission of information between the air and ground. However, the controller is still able to communicate with the aircraft by voice (as needed). Data Comm is expected to reduce voice channel occupancy and the chance for miscommunications; it also enables the transmission of more complex air-ground exchanges (e.g., routes). The specific interface and messages for the Data Comm system are still in the development phase. The Baseline system displays a filled triangle to the left of the call sign to indicate that an aircraft is Data Comm equipped but not yet on the frequency. When an aircraft is on the frequency, the system displays the filled triangle to the right of the call sign (see Figure 1).

Figure 1. Data Comm symbology in the Baseline system for an aircraft that is equipped but is not on the frequency (left) and for an aircraft that is on the frequency (right).

The Baseline system also incorporates a flyout window that allows the controller to select and submit changes to the system. For example, if the controller selects the speed field in a data block, the system displays a window adjacent to the data block from which the controller can select a different speed from the listed options (see Figure 2). We provide a summary of the basic commands and shortcuts for the Baseline system in Appendix A.

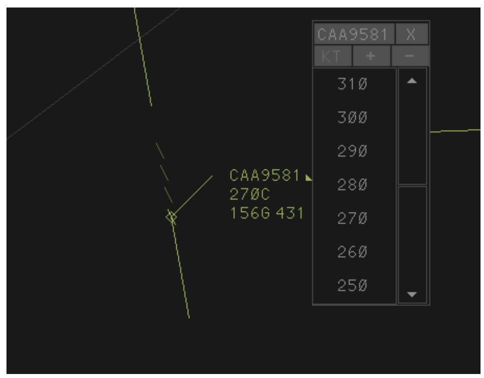

Figure 2. Baseline system flyout window.

1.2.2 Future En Route Workstation

The FEWS system includes additional display elements and automation functions beyond those planned for use in the Baseline system. Researchers at the RDHFL designed FEWS to support the controller in managing high levels of traffic (Willems, Hah, & Phillips, 2008; Willems & Hah, 2008). Willems et al. (2008) and Willems and Hah (2008) provide a comprehensive description of the features and functions used in the first two FEWS simulations. In this section, we provide an overview of the main components of the interface. We also provide a summary of the basic system commands and shortcuts for the FEWS system in Appendix A.

An essential feature of FEWS is that it uses an optical wheel mouse, rather than a trackball, to provide faster access to features. The buttons on the mouse map to the buttons on the trackball. The left button allows the controller to select an object. The center button allows the controller to select an object, modify its value, and submit that update to the system. The right button allows the controller to remove selected data or to cancel a function. For example, if the controller uses the right button to select an interim altitude in a data block, the system removes the interim altitude and displays the assigned altitude. The right button, when selected over an unoccupied area of the map, causes the cursor to jump to the vector line button in the tool bar.

FEWS includes a 29″ radar display for the D-side position, allowing the D-side to provide a much more comprehensive level of support. When the D-side interacts with a data block, the data block on the R-side display is highlighted with a green background to indicate that an action is being taken.

FEWS includes a three-tiered data block that allows the controller to access more detailed levels of information in each tier (as necessary). The researchers developed this capability to reduce display clutter and to allow the controller to access data, when and where it is needed. The first tier displays the same information currently displayed in the data block in DSR and planned for ERAM, but also provides information on aircraft status for aircraft that are entering or exiting the sector. This information includes sector ownership, handoff status, and voice communication status. The system displays these data to the left of the second and third lines of the data block. The system also highlights the frequency field of an aircraft that requires a voice frequency transfer (see Figure 3).

Figure 3. FEWS first tier data block.

The controller accesses the second tier data block by selecting the call sign on the first tier.[1] This action expands the data block and displays additional information including aircraft type, beacon code, and indicated airspeed (see Figure 4). FEWS also replaces the Baseline system flyout window with a scroll function that the controller accesses upon selection of a field (e.g., speed). The system changes the color of the field to indicate that the list is accessible and the controller uses the mouse wheel to scroll to a desired option and then submits the selected option to the system. The researchers integrated this feature to reduce the display clutter produced by the flyout window that occludes the area adjacent to the data block. When the controller moves the cursor off the second tier, the display reverts to the first tier data block.

Figure 4. FEWS second tier data block.

[1] We modified the implementation of this feature for FEWS III. In the prior two FEWS simulations, the controller accessed the second tier by moving the cursor over the first tier data block. We found that simply moving the mouse over the data block caused the controller to bring up the second tier, unintentionally, on too many occasions because of the very high volume of traffic in the sector. Therefore, we changed the activation of this feature so that the controller had to select the call sign in the first tier to bring up the second tier.

The controller accesses the third tier by selecting the call sign on the second tier data block (i.e., double clicking the call sign on the first tier). The third tier includes all of the information available in a full flight strip, and the controller can interact with the data fields to edit the information (see Figure 5). The system displays the third tier data block in a separate area of the radar scope so that it does not obstruct other information.

Figure 5. FEWS third tier data block.

FEWS includes a different designation for Data Comm equipage than the Baseline system. FEWS displays a triangle to the left of the call sign to indicate that an aircraft is Data Comm equipped, but not on the frequency. The system changes the triangle to a square when an aircraft is on the frequency (see Figure 6). The system also displays a blue background around the frequency field of a Data Comm equipped aircraft to indicate that a transfer of communication is in progress.

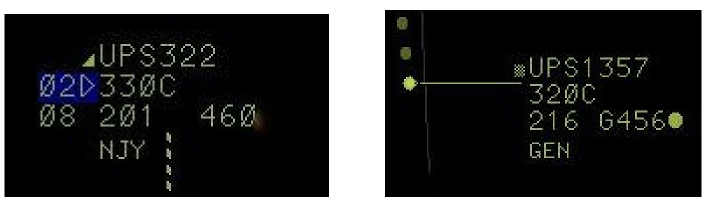

Figure 6. Data Comm symbology in the FEWS system for an aircraft that is equipped but is not on the frequency (left) and for an aircraft that is on the frequency (right).

The researchers designed FEWS so that data that are common to two or more aircraft are clearly displayed. For example, FEWS provides an emphasis feature that allows the controller to quickly identify which aircraft are at a designated altitude, traveling to a designated destination, going over a specified fix, and so forth. The system highlights the relevant field (or data block) of the aircraft that share the feature.

FEWS also aims to reduce controller workload by minimizing the number of steps required to complete an action and by reducing the number of *housekeeping* tasks. FEWS accomplishes this by offering an option that automatically places data blocks at user-designated orientations based on traffic flow and that automatically offsets data blocks when they overlap. FEWS also allows the controller to "drag and drop" a data block to a preferred orientation rather than requiring the controller to select one of the designated locations via the keyboard and provides a reroute feature that enables the controller to bring up an aircraft route, select and drag a node on the route to another location, and send the new route to the aircraft via Data Comm (see Figure 7).

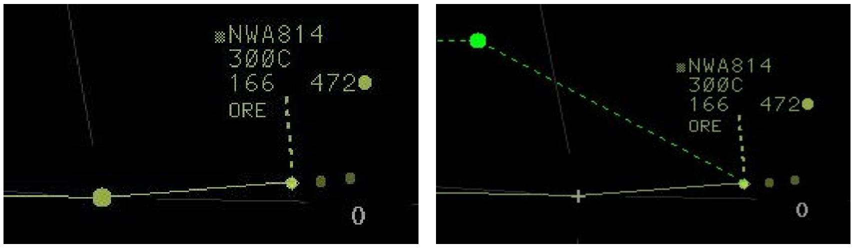

Figure 7. FEWS reroute feature displaying original route (left) and reroute (right).

FEWS automatically accepts handoffs as aircraft enter the sector and automatically drops FDBs of aircraft that have handed off and transferred frequency to the next sector. The system monitors frequency status and only drops FDBs after the next sector has established two-way communication with an aircraft. An aircraft that has left the sector, but still shows an FDB, alerts the controller to a problem with the transfer.

FEWS supports access to system features and functions through the keyboard and the display. To the extent possible, we have continued to implement both keyboard and display access to the features and functions added for FEWS III that support the RNAV, self-spacing, and grouping concepts.

2. CONCEPT IMPLEMENTATION

We integrated two RNAV procedures, a self-spacing procedure, and a grouping procedure into each simulated system. We developed a set of basic steps for each procedure to focus the scope of the development effort and to simplify participant training. We developed the procedures based on knowledge of similar procedures and on input from five air traffic Subject Matter Experts (SMEs) who had prior experience as detail controllers at the RDHFL and who were familiar with the issues we wanted to investigate.

We developed different implementations of the concepts for each system based on their capabilities. We integrated the concepts into the Baseline system without adding new display elements or interaction capabilities. We wanted to evaluate whether the Baseline system could support the concepts without additional system enhancements. If the concepts proved to be feasible and beneficial in the Baseline configuration, they could presumably be implemented in the field and integrated into the operational system more rapidly than if they required additional support.

We developed the FEWS system to include additional concept support features and functions. The SMEs met with us to discuss controller information needs for aircraft flying RNAV routes, using self-spacing or flying as part of a group. We demonstrated a few of our preliminary design features, and we obtained feedback and suggestions from the SMEs. Based on their comments, we refined the design elements and developed others. Programmers at the RDHFL integrated the new system features and functions into the FEWS system. We continued to refine the features and functions with the SME who was on detail to the RDHFL during the simulation preparation phase.

2.1 RNAV Procedures

We implemented two types of RNAVs in the simulation. One type of RNAV required lateral conformance constraints only. The second type of RNAV required both lateral and vertical constraints. When only lateral conformance constraints were in effect, the controller had to issue clearances or crossing restrictions to descend the aircraft on the arrival routes. We referred to this type of RNAV as a Limited RNAV. When lateral and vertical conformance constraints were in effect, the aircraft met the route restrictions on their own and did not require intervention from the controller unless an action needed to be taken because of weather, a potential conflict, and so forth. We referred to the RNAV routes that included both lateral and vertical conformance constraints as Full RNAVs.

2.1.1 Baseline RNAV Implementation

We did not make any changes to the Baseline display to indicate when Limited RNAVs were in use. The data blocks appeared as they do in the existing system. However, when Full RNAVs were in effect, we modified the second line of the data block to include the final altitude (00) to indicate the RNAV type to the controller (see Figure 8).

Figure 8. Baseline data block depicting Full RNAV conformance.

2.1.2 FEWS RNAV Implementation

In the FEWS system, we made modifications to the way in which we designated aircraft flying RNAV routes based on the type of RNAV conformance implemented. For Limited RNAV conformance, we displayed the data blocks the same way as they appeared in the Baseline system; that is, unchanged from their depiction in the existing DSR system. However, for aircraft flying Full RNAVs, we displayed data blocks that we referred to as RNAV data blocks that included only the aircraft call sign, Mode C altitude, and ground speed (see Figure 9). We also included an arrow to the left of the altitude to indicate that the aircraft was descending on the RNAV.

Figure 9. FEWS RNAV data block.

We developed the RNAV data block to reduce display clutter and to provide an indication to the controller that an aircraft was conforming to the RNAV. Kopardekar, et al. (2009) and Lee, Prevôt, Mercer, Smith, and Palmer (2005) have used similar, reduced data block representations to designate that an aircraft is performing a procedure on its own. If an aircraft is adhering to a Full RNAV, the controller may not need to issue clearances to it unless there is a problem. Therefore, we intended to make the FEWS RNAV data blocks less salient than data blocks for other aircraft. However, if the aircraft went out of conformance and was no longer on the RNAV or if the aircraft went into conflict with another aircraft, the system automatically displayed an FDB. We implemented this feature to indicate that the aircraft required attention. In addition, the controller could bring up the FDB at any time by selecting the aircraft position symbol.

2.2 Advanced Procedures

For both the self-spacing and grouping concepts, we assumed that the aircraft would be equipped with ADS-B, a Cockpit Display of Traffic Information (CDTI) to display aircraft position and data from surrounding aircraft to the flight deck, and a Flight Management System (FMS) to control navigation. We assumed that the FMS would allow the pilot to either enter data manually or to select data from a database and that the FMS would also accept Data Comm messages. For our self-spacing procedure, a lead aircraft did not need to be equipped with ADS-B In, but a trail aircraft did. For our grouping procedure, all aircraft needed to be equipped with ADS-B In and ADS-B Out. However, in our simulation, we equipped all aircraft with ADS-B In and ADS-B Out in the scenarios that we used to evaluate the self-spacing and grouping concepts.

2.2.1 Self-Spacing

The self-spacing procedure allowed the controller to manage a single lead aircraft in a string of two or more aircraft. Thus, the controller could issue a single clearance to one aircraft that each trail aircraft subsequently conducted as well. We defined the procedure so that any maneuver conducted by the lead aircraft, including a change in altitude, would also be conducted by the trail aircraft and at the point at which the lead executed the instruction. We developed steps for implementing the procedure and a means to designate procedure use on the display for each system.

We developed a set of basic steps to allow the participants to implement and cancel self-spacing. To initiate the procedure, the participant instructed an aircraft to follow the aircraft immediately ahead of it (e.g., “AAL123 follow DAL789”). The controller could issue the instruction either by voice or Data Comm. We constrained the procedure so that the trail aircraft had to be within an acceptable region (within a 45-degree cone and no more than 100 nm [185.2 km]) behind a lead aircraft for the system to establish the procedure.

The self-spacing procedure allowed the controller to designate a desired spacing interval behind the lead aircraft, if desired (e.g., “AAL123 follow DAL789 at 10 nm”). If the controller did not designate a spacing interval, the trail aircraft followed the lead aircraft at the distance currently between them. We established that a trail aircraft was following its lead at the specified distance as long as it was *no closer than .1 nm* (.19 km) of the designated distance behind the lead or *no farther than .5 nm* (.93 km) of the designated distance behind the lead. For example, if the controller established self-spacing for an aircraft at a distance of 15 nm (27.78 km), we considered the aircraft to be conforming to the spacing interval as long as it stayed within 14.9 to 15.5 nm (27.59 to 28.71 km) behind its lead.

When the controller established self-spacing, he could then instruct the lead aircraft to turn left to a heading of 270 that the trail aircraft would also execute when it reached the point where the lead had turned. If the controller issued any clearance to a trail aircraft, that action terminated the self-spacing procedure.

The controller could instruct several aircraft to self-space, each from the aircraft directly ahead of it, thus creating a chain. We reasoned that by developing the procedure so that each aircraft was following the aircraft directly ahead of it, instead of following a single lead aircraft within a string, the controller could break up longer chains into smaller chains if needed. For example, if the controller issued a clearance to the fourth aircraft in a chain of six aircraft, the fourth aircraft would no longer follow the third aircraft. Instead, the fourth aircraft would become the lead for the fifth aircraft that in turn would become the lead for the sixth aircraft.

In the simulation, we included aircraft that were already self-spacing as they entered the sector. We wanted to ensure that the controllers would have to work with aircraft that were using the procedure, even if they did not choose to implement the procedure themselves.

2.2.1.1 Baseline Self-Spacing Implementation

We designed the procedure for the Baseline system to be consistent with the system's existing functionality. As a result, the controllers had to activate the procedure via the keyboard. To activate self-spacing, the controller entered the 2-letter self-spacing command (*SS*) followed by the Flight Identifiers (FLIDs) of the lead and trail aircraft. If the trail aircraft was Data Comm equipped, the controller could issue the instruction by inserting the Data Comm instruction (*S*) between the *SS* command and the aircraft FLIDs to have the message sent electronically. Otherwise, the controller entered the command and then voiced the self-spacing instruction to the trail aircraft. If desired, the controller could add a designated distance to follow to the end of the command string (e.g., *SS S FLID1 FLID2 10*).

The controller could enter two or more FLIDs in the command string. Each aircraft listed followed the one listed ahead of it. To cancel the procedure, the controller entered the *SS* command followed by the FLID of the trail aircraft. The controller could also cancel the procedure by issuing a clearance to a trail aircraft.

The Baseline system did not provide an automatic indication that the procedure was active. Instead, we provided a means by which the controller could enter a designation of self-spacing in the fourth line of the data block (see Figure 10).

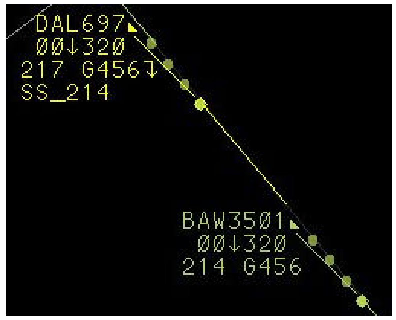

Figure 10. Baseline self-spacing designation for DAL697.

The controller used the existing command (*QS*) to enter *SS* followed by the FLID of the lead aircraft into the fourth line of the trail aircraft data block. For aircraft that entered the sector already self-spacing, the fourth line included this designation under the assumption that the controller in the adjacent sector had established the procedure and entered the information. If the controller cancelled the procedure, he was also responsible for removing the indicator so that the data block accurately reflected the aircraft state. We provide a summary of the self-spacing commands for the Baseline system in Appendix A.

2.2.1.2 FEWS Self-Spacing Implementation

In FEWS, we developed two methods for establishing and canceling the procedure. The keyboard method provided the same interaction capabilities as those provided by the Baseline system, except for the Data Comm entry. In FEWS, the participant included the Data Comm instruction (*DL*) at the end of the command string (e.g., *SS FLID1 FLID2 DL*).

The FEWS system indicated that aircraft were equipped with both ADS-B In and ADS-B Out by displaying a filled circle to the right of the third line of the data block[2] (see Figure 11). All aircraft in the Advanced Procedures condition were ADS-B In and ADS-B Out equipped.

Figure 11. FEWS data block with ADS-B In and ADS-B Out designation.

[2] In our simulation, we equipped all aircraft in the scenarios that included the self-spacing and grouping procedures with both ADS-B In and ADS-B Out, so we used only the filled indicator. However, we propose using an open circle to designate aircraft equipped only with ADS-B Out to differentiate the two capabilities.

The controller could also initiate the procedure via the display by selecting (with the left mouse button) the ADS-B symbol of the lead aircraft and then selecting the position symbol(s) of the trail aircraft. To submit the procedure to the system, the controller selected the position symbol of the (last) trail aircraft with the center mouse button. The system then displayed pink connecting lines between the position symbols of the aircraft The controller then either instructed the aircraft to conduct the procedure by voice, or if the trail aircraft was Data Comm equipped, transmitted the instruction to the aircraft by double clicking the pink connecting line or selecting the Data Comm symbol next to the aircraft call sign.

After receiving the Data Comm message, the system displayed the connecting lines in green. If the trail aircraft was not Data Comm equipped, the line remained pink to indicate that the controller needed to communicate with the aircraft by voice if necessary. In Figure 12, COA378 is Data Comm equipped and is self-spacing behind DAL697. SWA562 is not Data Comm equipped and is self-spacing behind COA378.

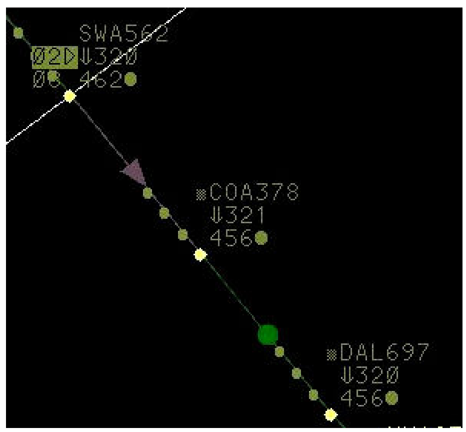

Figure 12. FEWS self-spacing designations.

FEWS also incorporated display elements to indicate whether a trail aircraft was flying at the designated spacing interval behind its lead. We displayed an arrowhead at the midpoint of a connecting line if the distance between the trail aircraft and its lead was not at the designated spacing interval. If the trail aircraft was spaced behind the lead at the designated distance, the system displayed a filled circle (as shown in Figure 12).

When the controller placed the cursor over a connecting line, the system displayed the distance between the aircraft (see Figure 13). If the trail aircraft was not spacing at the designated distance, the system displayed the current distance as well as an arrow pointing to the designated distance (e.g., *12 ←15*). The controller could modify a spacing interval of a Data Comm equipped trail aircraft by selecting the distance indicator. This action made the distance field editable and provided a scroll list of options. The controller selected the desired option and then sent the new interval to the aircraft by selecting the Data Comm symbol. If the trail aircraft was not Data Comm equipped, the participant issued a new spacing instruction by voice.

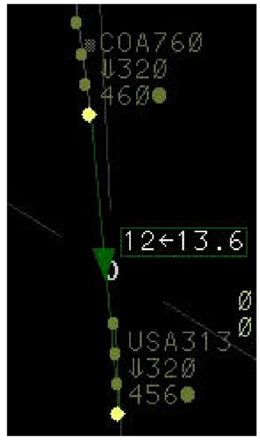

Figure 13. FEWS self-spacing distance designation.

The controller could cancel self-spacing via the display by selecting the connecting line between the lead and trail aircraft with the right mouse button. If the trail aircraft was Data Comm equipped, this action also sent the command to the aircraft. If the aircraft was not Data Comm equipped, the participant issued the instruction to cancel self-spacing by voice. We provide a summary of the self-spacing commands for the FEWS system in Appendix A.

2.2.2 Grouping

We developed the aircraft grouping procedure to allow the controller to manage two or more aircraft as a single unit, similar to the way controllers manage military aircraft in formation flight. Like the self-spacing procedure, the grouping procedure allowed the controller to issue a single clearance that two or more aircraft then conducted. The grouping procedure differed from self-spacing in that the aircraft did not have to be in trail. Instead, two or more aircraft could be flying in parallel or in a cluster. We assumed that the procedure would be used primarily for aircraft traversing a sector in relatively close proximity, but not necessarily going to the same destination. For example, the procedure may be useful for two aircraft traveling from the east coast to the west coast and flying along proximal routes for a large portion of their flights.

In our implementation, grouped aircraft did not have to be at the same altitude, although we expected that they would not differ widely from one another. We required that grouped aircraft be Data Comm equipped due to the complexity of the procedure. We also assumed that the aircraft would require sophisticated FMS capabilities because the aircraft maneuvers had to be precisely timed and executed. In our procedure, we assumed that the aircraft in the group were responsible for managing separation from one another.

To initiate the procedure, the controller instructed two or more aircraft to fly as a group (i.e., “USA654 join Group 1”; “COA321 join Group 1”). Both the Baseline and FEWS systems generated a group call sign (e.g., GRP01) and CID (e.g., G01) when the procedure was established. We generated the default group names in a meaningful sequence to reflect each invocation of the procedure (e.g., GRP01, GRP02). However, we made the group name editable, so that the controller could modify the default name if desired.

When the controller established the procedure, he used the group designation to communicate with the group. The individual aircraft in the group flew relative to the central position of the group members. When the controller issued a clearance to the group (e.g., "Group 1 turn left heading 270"), all members of the group carried out the instruction. Any clearance, other than an altitude clearance, issued to an individual member of a group removed that aircraft from the group but did not affect other group members.

We assumed that the Traffic Management Unit (TMU) would make the primary decisions about when to group aircraft. The TMU would identify candidate aircraft for the procedure based on their routes of flight and their proximity to one another. The TMU would then communicate the potential candidate aircraft to the facility so that the controller could activate the procedure if he determined it to be useful. In our scenarios, we included aircraft that entered the sector already in a group and also provided opportunities for the controller to initiate grouping so that we could determine whether they found the procedure useful.

2.2.2.1 Baseline Grouping Implementation

To initiate the grouping procedure, the controller entered the *GG* command followed by the FLIDs of the aircraft designated to fly in the group and the Data Comm command *S*. When the participant completed this portion of the entry, the system displayed a default group name (e.g., GRP01) in the CRD. If the controller wished to use the default designation, he simply selected *Enter*. If he wished to change the default designation, he edited the default name provided and then selected *Enter*. This action submitted the procedure to the system and to the aircraft via Data Comm.

To remove an individual aircraft from a group, the participant entered the *GG* command followed by the FLID of the aircraft. In addition, any clearance, other than an altitude clearance, issued to an individual aircraft in a group, removed the aircraft from the group. The remaining aircraft (if two or more) continued to fly as a group. To cancel the grouping procedure for all of the aircraft, the controller entered the *GG* command followed by the group call sign or CID.

The Baseline system did not provide an automatic indication that the procedure was active. The controller entered the designation in the fourth line of the aircraft data blocks to indicate that they were flying as part of a group. The controller used the existing command, *QS*, to enter the *GG* designation followed by the group name to indicate use of the procedure (see Figure 14).

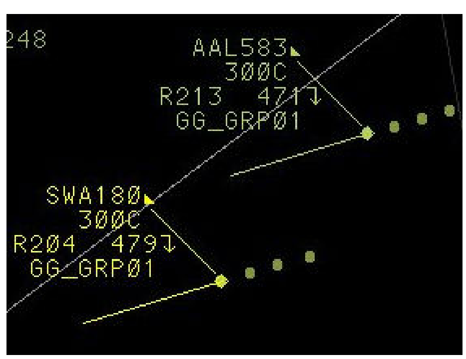

Figure 14. Baseline grouping designation for SWA180 and AAL583.

When an aircraft entered the sector already flying in a group, the fourth line included the designation under the assumption that the controller in the adjacent sector had established the procedure and entered this information. If the controller cancelled the procedure, he was responsible for removing the indicator. We provide a summary of the grouping commands for the Baseline system in Appendix A.

2.2.2.2 FEWS Grouping Implementation

We limited our activation of the procedure to the keyboard method described for the Baseline system due to the complexity of implementing additional display interaction capabilities in time for our simulation. The only difference between activating the procedure using the Baseline system and the FEWS system involved the Data Comm entry. In FEWS, the controller provided the Data Comm instruction (*DL*) after entering both the grouping command and selecting the desired group name.

As soon as a group was established, the FEWS system automatically displayed elements to indicate that the aircraft were conducting the grouping procedure. The system displayed a group position symbol at the central location of the individual aircraft position symbols, but that varied somewhat based on position updates of the aircraft. The system also displayed a group data block and green lines that connected the position symbols of the individual group members to the group position symbol (see Figure 15).

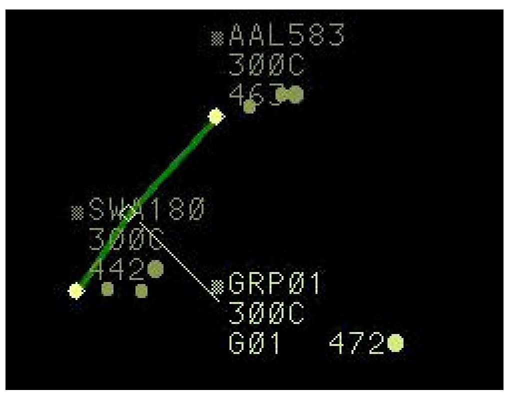

Figure 15. FEWS grouping designation showing SWA180 and AAL583 in Group 1.

The group data block extended from the group position symbol and provided the group name (e.g., GRP01), altitude, group CID (e.g., G01), and ground speed. If a group included aircraft at different altitudes, the data block displayed the altitude range. FEWS also displayed minimized data blocks, similar to RNAV data blocks, for individual aircraft in the group that displayed call sign, altitude, and speed. We used these data blocks to indicate group conformance and to reduce display clutter. The system displayed the FDB of a group member if the aircraft went out of conformance or into conflict with an aircraft outside the group. The controller could also bring up an FDB by selecting an aircraft position symbol.

Although we did not implement display interaction capabilities for initiating the procedure, we did include a method by which the controller could remove aircraft from a group through the display – by selecting the connecting line between the aircraft and the group position symbol with the right mouse button. Alternatively, the controller could remove an aircraft via the keyboard as described for the Baseline system. We provide a summary of the grouping commands for the FEWS system in Appendix A.

3. METHOD

3.1 Participants

We analyzed data from 11 current CPCs (9 men and 2 women) whose median age was 44 (range: 26 to 54).[3] The participants came from five en route facilities (Levels 11 and 12); they all had current medical certificates. They had from 6 to 28 (median = 23) years total experience controlling traffic (including military experience) and from 1 to 23 (median = 18) years experience controlling traffic as CPCs with the FAA. They had from 2 to 27 (median = 15) years experience in the en route environment and all of the participants had actively controlled traffic as CPCs in that environment for the past 12 months. Six of the participants also had from 2 to 12 (median = 4.5) years experience in the terminal environment. The participants rated (1 = *lowest*, 10 = *highest*) their current skill level as high (range: 7–9) and their motivation to participate in the simulation as very high (range: 8–10). As per the recruitment requirements, none of the participants wore bifocals, trifocals, or hard contact lenses due to the design limitations of the oculometer that we used to obtain visual scanning data.

Two of the participants arrived at the RDHFL at the same time, but they worked separately. Each participant worked as the R-side controller throughout training and testing.

3.2 Research Personnel

An experimenter and two assistants monitored the overall administration of the experiment, including the simulator preparation, daily operation, and data collection. Two additional research assistants supported the set-up and administration of the eye tracking system. Two air traffic SMEs served as trainers and D-side controllers. One of the SMEs was a current Front Line Manager on a 1-year detail to the RDHFL. The other SME was a retired CPC who was supporting the RDHFL as a full-time contractor. For consistency, we assigned each SME to one participant for the duration of that participant's involvement in the simulation.

The SMEs trained the participants on the airspace and procedures as well as on the use of the concepts and the system features and functions. The SMEs demonstrated the use of the different system features and functions during training, answered questions, and provided feedback to the participants throughout the practice scenarios. However, we instructed the SMEs to provide assistance during the test scenarios only when requested by the participants. The SMEs also provided ratings and comments on the participants' performance after each test scenario.

Hardware and software engineers prepared all equipment including the systems, displays, and communications system. The engineers were on standby to assist during the simulation (as needed).

[3] We originally recruited twelve participants. However, one participant did not complete the simulation due to a personal matter that required him to leave after completing only half of the test scenarios.

Six simulation pilots participated during shakedown and testing. Three of the simulation pilots managed aircraft and communicated with each of the participants.

3.3 Equipment

We conducted the simulation at the RDHFL. We used the controller workstations and associated equipment in Experiment Room (ER) 3 and the simulation pilot workstations that were located in a separate room of the RDHFL. Video and audio equipment recorded the participants' communications and actions during the simulation so that we could review the simulation at a later date as needed. We also recorded the controller displays and all of the participant system entries for use in data analysis.

3.3.1 Controller Workstations

We equipped the R-side controller workstations differently between the Baseline and the FEWS systems. Both configurations consisted of a high-resolution (2,048 x 2,048 pixels), 29″ radarscope, a keyboard, and CRD. Both systems included Data Comm and the Traffic Management Advisor (TMA) that provided time-based metering data for arrival aircraft.

The two systems implemented different input/pointing devices. The Baseline system used a trackball as does the existing DSR workstation. FEWS used an optical wheel mouse. The mouse allowed the participants to activate and deactivate system features and functions via the display, whereas the Baseline system required keyboard interactions. For this simulation, we chose not to include the electronic flight strip touch panel display because the results of the previous FEWS simulations indicated that the participants rarely interacted with this equipment.

The D-side positions differed between the Baseline and FEWS configurations. In the Baseline system, the D-side position included the CRD and URET. URET provided electronic flight progress strips and conflict probe capabilities. As in the prior FEWS simulations, the FEWS system included a D-side position that consisted of a second 29″ radar display, allowing the D-side to provide a much more comprehensive level of support. We also integrated the Center TRACON Automation System (CTAS) conflict probe on the R-side display in FEWS because we did not display URET in the D-side configuration. However, the CTAS conflict probe did not work consistently during our simulation due to unresolved programming issues. Table 1 summarizes the Baseline and FEWS R-side and D-side features and functions including the additional FEWS modifications designed to support the use of Full RNAV routes and the self-spacing and aircraft grouping procedures.

Table 1. Differences Between the Baseline and FEWS System Configurations

System	Baseline		FEWS III
Position	**Radar (R)-side**	**Data (D)-side**	**R-side & D-side**
Hardware			
Input Device	Trackball	Trackball	Mouse
	Keypad	Keypad	Keypad
Keyboard	R-side DSR keyboard	D-side DSR keyboard	DSR-R + emphasis
Display	29 inch	19 inch	29 inch
Human Computer Interface: Aircraft Representation			
Track data	Track & Position	N/A	Track & Position
Mode C Altitude	FDB	N/A	Integrated in three-tier FDB
Assigned Altitude	FDB	Flight Plan readout	
Indicated Airspeed		Though URET	
Coordinated Heading	Line 4 of FDB	N/A	
Coordinated Speed	Line 4 of FDB	N/A	
Interaction with FDB	Flyout windows	N/A	Edit/Scroll
Conformance to Full RNAV	00 in data block	N/A	Minimized "RNAV" data block (call sign, Mode C altitude, speed); ⇓ next to altitude.
ADS-B Indication	N/A Actual system displays "A" in Range Data Block if ADS-B *unavailable*	N/A	Filled circle to the right of third line of data block to indicate ADS-B In and ADS-B Out.
Indicator for self-spacing aircraft	Entry in 4th line of data block	N/A	Connecting lines between position symbols
Indicator for grouped aircraft	Entry in 4th line of data block	N/A	Connecting lines from centroid of group to each aircraft position symbol. Group data block added and individual data blocks minimized.
Human Computer Interface: Windows and Lists			
Traffic Management Data	TMA list + Range Data Block	N/A	TMA data in Range Data Block only.
Conflict Alert	Conflict Alert List	N/A	Integrated in three-tier FDB
Conflict Probe		URET	
Trial Planning		URET	
Data Communications	Existing CPDLC Build 1A capabilities	Existing CPDLC Build 1A capabilities	
Flight Plan Data (type, destination, etc.)	Continuous Flight Plan Readout window or CRD	CRD	
Emphasis	Multiple Dwell Lock/Fourth line indicators	N/A	Emphasis function
Multiple Flight Strip Readout	CFR Window	N/A	Third tier data block
Flight Progress	Electronic Strips	URET Aircraft List	
Human Computer Interface: Other			
Route Display	Radar Display	N/A	Radar Display
Trajectory Display	Radar Display	URET Graphical Plan Display	Radar Display
Data Block Management	Manual	N/A	Automatic Data Block Offset

Note. DSR = Display System Replacement; FDB = Full Data Block; URET = User Request Evaluation Tool; RNAV = Area Navigation Route; ADS-B = Automatic Dependent Surveillance–Broadcast; CPDLC = Controller-Pilot Datalink Communication; CRD = Computer Readout Display; TMA = Traffic Management Advisor.

3.3.2 Simulation Pilot Workstations

The simulation required six simulation pilot workstations. Each workstation consisted of a computer, keyboard, monitor, and communications equipment. Each workstation also provided a plan view display of traffic, a list of assigned aircraft, information regarding the current aircraft state, and flight plan data. The simulation pilot workstations also presented weather cells on the display when required.

3.3.3 Software

The experimenters used the Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE) ATC simulator and the Target Generation Facility (TGF) to present the scenarios. Software engineers at the FAA William J. Hughes Technical Center (WJHTC) developed both of these systems. DESIREE can simulate en route and terminal functionality, allowing researchers to modify or add information and capabilities to the ATC workstations to evaluate new concepts and procedures. The TGF uses preset flight plans to generate radar track and data block information. DESIREE receives input from the TGF and displays aircraft information on the controller displays, including radar tracks, data blocks, and sector maps. It also allows controllers to perform critical operational functions. The TGF provides an interface that allows the simulation pilots to view the aircraft tracks and enter flight plan changes. The TGF algorithms can control aircraft maneuvers so that they appear to the controllers to represent realistic aircraft climb, descent, and turn rates. Finally, the TGF allows researchers to capture information about aircraft trajectories, aircraft proximity, and other relevant data for use in subsequent analyses. Like TGF, DESIREE has data collection capabilities and can store information such as the controller entries made during a scenario.

For this simulation, the DESIREE programmers also developed a tool that allowed the researchers to hold or redirect aircraft outside the participant's sector. Using the tool, the researchers could select one or more sectors, routes, or individual aircraft to hold outside the participant's sector at predesignated fixes or to redirect aircraft so that they did not hand off into the participant's sector from the sector above or below. This implementation allowed the research team to work without the need for additional controllers to staff the adjacent sectors or to require the simulation pilots to assume this responsibility.

3.3.4 Workload Assessment Keypad

We positioned the Workload Assessment Keypad (WAK) device (Stein, 1985) at each participant workstation. The WAK consists of a touch panel display with 10 numbered buttons in which 1 indicates very low workload and 10 indicates very high workload. The WAK prompts the participants to provide a workload rating by illuminating the buttons and emitting a brief tone. In this simulation, the WAK prompted the participants to provide a rating every 2 minutes. The buttons remained illuminated for the duration of the response period (20 s) or until the participant made a response, whichever occurred first. In the event that the participant did not provide a rating within the response period, the system recorded a missing data value.

3.3.5 Oculometer

We used the oculometer (Applied Science Laboratories, Inc., 1991) to record the participants' eye movements during the simulation. The oculometer consists of an eye- and head-tracking system that records Point of Gaze (POG) and pupil diameter by using near-infrared reflection outlines from the pupil and the cornea. Willems, Allen, and Stein (1999) and Willems and Truitt (1999) provide detailed descriptions of the hardware and software used for eye tracking. Willems et al. reported that exposure to infrared illumination while wearing the oculometer is less than 4% of the intensity of that experienced when outside on a sunny day. The participants wore the oculometer for the last training scenario and for each of the test scenarios.

3.3.6 Communications Systems

We included a simulated Data Comm system in the scenarios as well as a simulated Voice Switching and Control System (VSCS). We used existing knowledge of the Controller-Pilot Datalink Communication (CPDLC) tool to guide Data Comm implementation. DESIREE previously emulated CPDLC Build 1A functionality to support the CPDLC Program and integrated that system into the earlier FEWS simulations. In this simulation, we implemented transmission (uplink and downlink) delay times between 2 and 7 s (Median delay = 5 s) as proposed for Data Comm Segment 2. We also simulated a pilot response time of 6 to 49 s (Median delay = 11 s) for each transmission. We randomly selected a delay for each transmission based on the distribution of delays obtained in the original CPDLC evaluation at Miami Air Route Traffic Control Center (ZMA).

The simulated VSCS provided voice communication links between the participant and the three simulation pilots and Push-to-Talk (PTT) recording capability. We recorded the times and durations of the PTT activity for subsequent analysis.

3.3.7 Situation Awareness Verification and Analysis Tool

We initially implemented a modified version of the Situation Awareness Verification and Analysis Tool (SAVANT) that was developed by Willems and Heiney (2002) to probe participants' on-line situation awareness (SA) at intervals throughout the scenarios. During the SAVANT probe, the system removes the radar display for up to three seconds and displays a question (e.g., *Which aircraft is at a higher altitude?* or *Are the two aircraft at the same altitude?*) in the center of the screen. The system then redisplays the radar with the relevant data omitted from the data blocks of two highlighted (green) aircraft. The participant provides a response by selecting one of the aircraft, with the pointing device, or by entering a "Y" or "N" on the keyboard. When the participant provides a response, or after a 15 s response interval elapses, the system removes the highlighting and redisplays the missing data. The SAVANT prompt is removed immediately if the participant is making an entry into the system so as not to disrupt an entry that is in progress. Because of the high volume of traffic in our scenarios, the participants were frequently interacting with the system at the time the prompt occurred, and we were unable to obtain enough SAVANT measures to conduct a meaningful analysis.

3.4 Materials

3.4.1 Informed Consent Statement

Each participant read and signed an informed consent statement before beginning the simulation (see Appendix B). The informed consent statement summarized the purpose of the study and the participants' rights and responsibilities, including that their data would be kept confidential and anonymous. It informed the participants that we would collect all data using code numbers, rather than participants' names, and that we do not maintain permanent records associating their names and code numbers.

3.4.2 Biographical Questionnaire

Each participant also completed a Biographical Questionnaire before beginning the simulation (see Appendix C). The Biographical Questionnaire contained demographic questions about the participant's age, gender, and level of air traffic control experience.

3.4.3 Post-Scenario Questionnaire

After completing each scenario, the participants provided ratings about their performance, workload, and SA on a Post-Scenario Questionnaire (PSQ), using scales that ranged from 1 (*poor*) to 10 (*excellent*). The participants also rated the difficulty of the scenario using a scale that ranged from 1 (*extremely difficult*) to 10 (*extremely easy*). The PSQ also included items that pertained to interface effectiveness. Using scales that ranged from 1 (*not at all*) to 10 (*a great deal*), the participants indicated the extent to which the system interface was useful in enhancing control efficiency, sector operations or strategies, and the extent to which they agreed with statements about interface usability (e.g., *I could find the information I needed quickly*). We also used this scale for additional questions that pertained only to conditions that included the advanced procedures of self-spacing and grouping (e.g., *I was able to clearly determine which aircraft were conducting the self-spacing procedure.*). Finally, the participants had the opportunity to provide responses to open-ended questions and to include other comments about the scenario that they considered relevant (see Appendix D).

3.4.4 Exit Questionnaire

The participants completed an Exit Questionnaire at the end of the simulation. The participants provided ratings to compare their control of the traffic and their use of system features and functions between Baseline and FEWS using 5-point scales. A rating of 1 indicated that the participant performed the task *much better with FEWS,* 2 indicated that the participant performed the task s*omewhat better with FEWS*, 3 indicated that there was no difference between the systems. A rating of 4 or 5 indicated that the participant performed a task s*omewhat better* or *much better* with the Baseline system.

The Exit Questionnaire also contained items using 10-point rating scales to measure simulation realism (1 = *extremely unrealistic,* 10 = *extremely realistic*); the extent to which the research apparatus interfered with performance (1 = *not at all,* 10 = *a great deal*); and the effectiveness of training (1 = *not at all effective,* 10 = *extremely effective*). The Exit Questionnaire also allowed the participants to comment on other aspects of the simulation that they found relevant (see Appendix E).

3.4.5 ATC Observer Rating Form

The SMEs used a modified version of the Observer Rating Form (ORF; Sollenberger, Stein, & Gromelski, 1997; Vardaman & Stein, 1998) to rate participant performance and use of the procedures after each test scenario (see Appendix F). The ORF items use rating scales that range from 1 (*least effective*) to 8 (*most effective*). The SMEs also provided comments, as necessary, to explain their ratings.

3.4.6 Airspace

We used generic airspace designed by researchers and SMEs at the RDHFL (Guttman & Stein, 1997). Guttman and Stein found that Air Traffic Control Specialists considered the generic airspace to be realistic and that controller performance in generic airspace was comparable to performance in real airspace. Using generic airspace allows researchers to extrapolate simulation results without having to be concerned that some participants are more familiar with the airspace than others.

We used a generic high altitude sector (ZGN08) in this simulation (see Figure 16). ZGN08 has a roughly rectangular shape that extends approximately 120 nm (222.24 km) from North to South, 100 nm (185.2 km) from East to West, and from flight level (FL) 240 to FL340. It contains "highways" called jet (J) routes that traverse the sector (e.g., J30, J12) as well as Very High Frequency (VHF) Omni-directional Range (VOR) navigation aids (e.g., DES), and fixes that are named points in the sky (e.g., BUTTE) that depict intersections. The airspace contains several intersections that contribute to sector complexity and that have crossing restrictions for realism. Figure 16 displays sector names, numbers, altitude limits, and frequencies in boxes over each relevant sector.

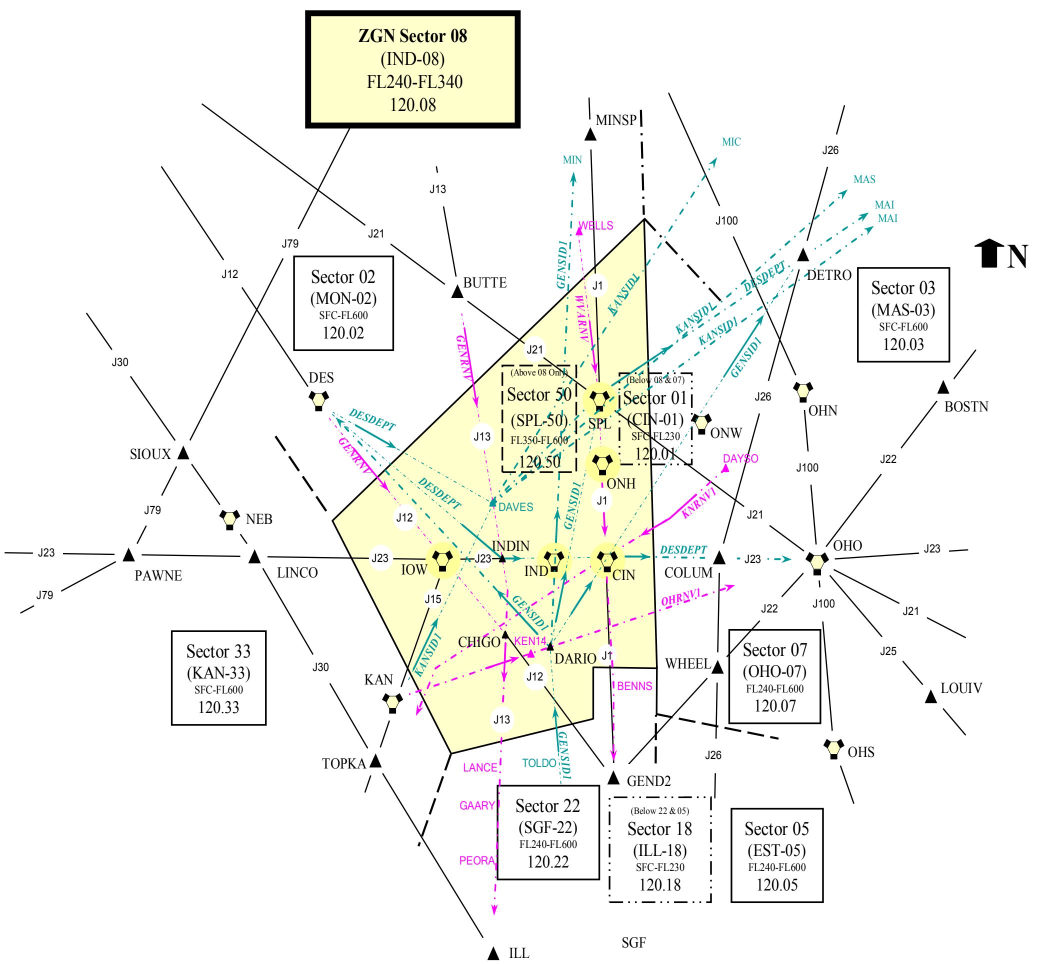

Figure 16. Schematic depiction of generic high altitude sector with arrival and departure routes.

We included four RNAV Standard Terminal Arrival Routes (STARs) into three airports: two into our primary airport, Genera (GEN), and one for each of our two satellite airports, Ohio (OHO) to the east and Kansas City (KAN) to the west. We also included three RNAV Standard Instrument Departure (SID) routes: one from GEN, one from KAN, and one from Des Moines (DES).

ZGN08 arrivals transitioned into sector ZGN22 to the south. The traffic streams to OHO and KAN crossed the arrival and departure streams to and from GEN and added to sector complexity. GEN arrival traffic entered sector ZGN08 between FL320 and FL340. Traffic to OHO entered the sector at FL310, and traffic to KAN entered at FL280. The two streams of traffic to GEN had crossing restrictions of FL 320 at BENNS and LANCE leaving sector ZGN08 for ZGN22. We used fixes or fixed-radial distances outside of ZGN08 as holding fixes if the participants decided to hold arrival traffic outside ZGN08.

3.4.7 Traffic Scenarios

We developed three basic 60-minute scenarios for use in training. None of the scenarios included the Airbus A380 or Very Light Jets (VLJs) because we were unable to find good predications about what proportion of the traffic those aircraft types will comprise. One practice scenario began with a low level (5 to 8 aircraft) of traffic in the airspace and built to about 15 aircraft after 15-20 minutes and remained at that level for the remainder of the scenario. The researchers and SMEs used these scenarios early in training to introduce the participants to the systems, features, and procedures. The second practice scenario began with a low level of traffic and built to a moderate level (15–21) after about 15-20 minutes and remained at that level for the remainder of the scenario. This level of traffic was about the current monitor alert parameter (MAP) value for ZGN08. Finally, the third practice scenario built from a moderate traffic level to a high level (over 30 aircraft) by about 15-20 minutes and remained high for the remainder of the scenario.

We included weather in half of the training scenarios. The weather cell moved eastward toward ZGN08 from the west and affected the RNAV routes in the sector at about 25 minutes into the scenario. At this point, the participants would have started working with the volume of traffic that they would be working for the remainder of the scenario.

Each participant completed an average of 14 practice scenarios for each system. The total number of practice scenarios each participant completed varied between 12 and 16. The participants typically completed more practice scenarios for the first system on which they trained because they needed to become familiar with the airspace and basic procedures in addition to the specific system features and functions. The participants also spent more time working on the low- and moderate-level traffic scenarios initially than they did when they trained on the second system.

We developed an alternate set of 60-minute high level traffic scenarios for use in testing. We made the test scenarios different from the training scenarios by modifying the entry times of some aircraft into the sector. Then we created two sets of test scenarios that differed from one another only with respect to the aircraft call signs. This allowed us to use essentially the same scenario with each system for each test condition, but made the scenarios appear less similar to one another to the participants. We included weather in some of the test scenarios depending on the condition.

3.5 Experimental Design

We used a 2 (system) x 4 (condition) within-subjects design (see Table 2). Each participant completed each of the conditions using the Baseline and the FEWS system. The first test condition used Limited RNAVs in which the aircraft maintained only lateral conformance constraints, and the participants were required to descend the aircraft on the RNAV arrivals while no weather was present (LnoWx). The second test condition used Full RNAVs in which the aircraft maintained both lateral and vertical conformance constraints and weather was not a factor (FnoWx). The third test condition used Full RNAV conformance and included weather (FWx). The fourth condition used Full RNAV conformance, and included the Advanced Procedures (self-spacing and grouping) and weather (APWx).

Table 2. Experimental Design

	Condition			
System	LnoWx	FnoWx	FWx	APWx
Baseline				
FEWS				

Each participant completed a total of eight test scenarios, four for each system. We used a test schedule similar to the one used for the FEWS II simulation in which the participants trained and tested on one system before they trained and tested on another system (Willems & Hah, 2008). We counterbalanced the order of the test systems and the order of the test conditions within each system with the restriction of running the APWx condition first or last because that condition required additional instructions. We used this schedule to help the participants to maximize their familiarity with one system prior to working on the test scenarios and to minimize forgetting and interference from additional learning; Table 3 shows the full counterbalancing order.

Table 3. Counterbalanced Order of Test Conditions

Participant	System	Order of Test Conditions
1 & 2	Baseline	APWx, LnoWx, FnoWx, FWx
	FEWS	FnoWx, LnoWx, FWx, APWx
3 & 4	FEWS	APWx, FWx, FnoWx, LnoWx
	Baseline	FnoWx, FWx, LnoWx, APWx
5 & 6	Baseline	FWx, LnoWx, FnoWx, APWx
	FEWS	APWx, LnoWx, FnoWx, FWx
7 & 8	FEWS	FWx, LnoWx, FnoWx, APWx
	Baseline	APWx, LnoWx, FWx, FnoWx
9 & 10	Baseline	APWx, FWx, FnoWx, LnoWx
	FEWS	FnoWx, FWx, LnoWx, APWx
11 & 12	FEWS	APWx, LnoWx, FWx, FnoWx
	Baseline	FnoWx, LnoWx, FWx, APWx

3.6 Procedure

3.6.1 General Schedule of Events

Each CPC spent a total of 8 days at the RDHFL. The participants traveled in on a Monday, and they left on Friday of the following week (except on weeks that included a holiday). Two participants arrived at the RDHFL at a time, but they worked independently. Each participant worked as an R-side controller throughout the simulation and was therefore responsible for communicating with aircraft and ensuring separation. Each participant worked with one of the confederate D-side SMEs who provided assistance. Table 4 shows a sample schedule of events.

Table 4. Sample Schedule of Events

Week 1

Time	Tuesday	Time	Wednesday	Time	Thursday	Time	Friday
8:00	Introduction, Forms, Airspace, LOA/SOP Familiarization – System 1	8:00	Daily Briefing, Airspace and Procedures Review	8:00	Daily Briefing, Airspace and Procedures Review	8:00	Daily Briefing, Airspace and Procedures Review
10:00	Break	8:45	Practice 5: System 1	8:45	Practice 10: System 1	8:45	Test 1: System 1
10:15	Lab Familiarization; Practice 1: System 1	9:45	Break	9:45	Break	9:45	Break
11:30	Lunch	10:00	Practice 6: System 1	10:00	Practice 11 System 1	10:15	Test 2: System 1
12:30	Practice 2: System 1	11:00	Break	11:00	Break	11:15	Lunch
1:30	Break	11:15	Practice 7: System 1	11:15	Practice 12 System 1	12:15	Test 3: System 1
1:45	Practice 3: System 1	12:15	Lunch	12:15	Lunch	1:15	Break
2:45	Break	1:15	Practice 8: System 1	1:15	Practice 13 System 1	1:45	Test 4: System 1
3:00	Practice 4: System 1	2:15	Break	2:15	Break	2:45	Break
4:00	Caucus	2:30	Practice 9: System 1	2:30	Practice 14: System 1	3:00	Caucus
		3:30	Caucus	3:30	Caucus		

Week 2

Time	Monday	Time	Tuesday	Time	Wednesday	Time	Thursday
8:00	Airspace & LOA/SOP Familiarization: System 2	8:00	Daily Briefing, Airspace and Procedures Review	8:00	Daily Briefing, Airspace and Procedures Review	8:00	Daily Briefing, Airspace and Procedures Review
10:00	Break	8:45	Practice 5: System 2	8:45	Practice 10: System 2	8:45	Test 1: System 2
10:15	Lab Familiarization; Practice 1: System 2	9:45	Break	9:45	Break	9:45	Break
11:30	Lunch	10:00	Practice 6: System 2	10:00	Practice 11: System 2	10:15	Test 2: System 2
12:30	Practice 2: System 2	11:00	Break	11:00	Break	11:15	Lunch
1:30	Break	11:15	Practice 7: System 2	11:15	Practice 12: System 2	12:15	Test 3: System 2
1:45	Practice 3: System 2	12:15	Lunch	12:15	Lunch	1:15	Break
2:45	Break	1:15	Practice 8: System 2	1:15	Practice 13: System 2	1:45	Test 4: System 2
3:00	Practice 4: System 2	2:15	Break	2:15	Break	2:45	Break
4:00	Caucus	2:30	Practice 9: System 2	2:30	Practice 14: System 2	3:00 3:30	Final Debrief
		3:30	Caucus	3:30	Caucus		

Note. LOA = Letters of Agreement; SOP = Standard Operating Procedures.

3.6.2 Initial Briefing

One of the experimenters gave an introductory briefing that described the general purpose of the experiment, an overview of the concepts, and the schedule. She described the scenarios and the requirements for the participants as well as the dependent measures (e.g., WAK, eye movement data). Afterwards, the participants read and signed the informed consent statement. The experimenter and a witness also signed the statement. Next, the participants completed the Biographical Questionnaire. Then, the SMEs instructed the participants on the hardware, airspace, Standard Operating Procedures (SOPs), and Letters of Agreement (LOAs) to be used during the simulation. They also provided an overview of the procedures for the RNAVs, self-spacing, and grouping concepts. The experimenter and SME addressed the participants' questions prior to entering the lab to begin training.

3.6.3 Practice Scenarios

The participants spent 6 of the 8 days at the RDHFL in training and working with the practice scenarios. We did this because the participants had no prior experience with the FEWS system, Data Comm, or the self-spacing and aircraft grouping procedures, and most of them had no prior experience working with RNAV routes or the Baseline system. As a result, we needed to ensure that we provided sufficient time for the participants to become familiar with the systems and procedures before they managed the high traffic test scenarios.

The participants began training with the low-traffic practice scenarios so that they could become familiar with the airspace, system, and procedures. After initially working with the low-traffic scenarios, the participants progressed to the moderate-traffic scenarios, and finally worked with the high-traffic scenarios. Because of the intensity of the traffic levels in the high-traffic scenarios, the researchers alternated between the high- and moderate-traffic scenarios as training progressed.

Early in training, the SMEs demonstrated the system features and functions and instructed the participants on their use. As training progressed, the participants initiated the procedures on their own, but the SMEs continued to provide direction and answered questions about the system throughout training as needed.

We reviewed the relevant instructions prior to the beginning of each practice scenario (see Appendix F). We always included instructions for the WAK so that the participants would become highly familiar with the rating scale. The WAK provided a prompt every 2 minutes throughout each practice scenario. The participants also wore the oculometer during the last training scenario to become accustomed to that device prior to starting the test scenarios.

The researchers instructed the participants about the option to hold aircraft or redirect traffic to keep it out of the sector. The researchers informed the participants that if they felt unable to effectively control the traffic and wished to keep additional traffic from entering the sector, they were to tell the D-side about the decision. The D-side, in turn, used the VSCS landline to communicate with one of the researchers who implemented holds or redirects via the DESIREE automation tool designed for this purpose.

3.6.4 Data Collection Procedure

Before each test scenario, the experimenters reviewed the relevant instructions for the current experimental condition (see Appendix G). They also provided reminders about the WAK and the option to hold or redirect traffic, if needed. The researchers instructed the SMEs not to provide any further demonstrations of the system features and to provide assistance only when requested by the participants. We instructed the participants that we would use the oculometer to record their eye movements during the final training scenario and during each test scenario. We calibrated the oculometer prior to the start of each scenario to correctly correlate POG with elements on the display. During each test scenario, the participants wore the oculometer and provided responses to the WAK prompts.

At the conclusion of each scenario, the participants completed the PSQ and then took a 20-min break before the next scenario began. The participants completed the Exit Questionnaire after completing all of the test scenarios. The researchers held a debriefing session with the participants after they completed the simulation and Exit Questionnaire to discuss the simulation, elicit additional comments, and answer remaining questions that the participants had. The researchers guided the participants through discussions that focused on the positive and negative aspects of the systems, the concepts and procedures, and the need for additional tools or system modifications to support the concepts.

3.7 Dependent Variables

For each scenario, we collected system performance measures, communication measures, and eye movement measures as well as subjective ratings of performance, SA, and workload.

3.7.1 System Performance Measures

We collected system performance measures to assess efficiency and safety for each experimental condition. These measures included the number of flights handled in the sector; the number of altitude, heading, and speed commands issued; the time and distance flown in the sector; the frequency with which participants requested that traffic be held or redirected from their sector; the number and duration of eye fixations on arrival aircraft, and the number of losses of separation (LOS). For the advanced procedures condition, we also evaluated the number of times the participants initiated self-spacing and grouping.

We hypothesized that the participants would manage traffic most efficiently when Full RNAV conditions were in effect, particularly when weather was not a factor. We anticipated that we would find more flights handled, fewer clearances issued, and that the aircraft would travel more efficiently through the sector. We further expected that the display enhancements available in the FEWS interface would result in greater aircraft efficiency compared to the Baseline system. We also expected that there would be greater use of the Advanced Procedures in the FEWS system because of the additional support provided by the interface. Therefore, we expected to find that the participants would be more likely to initiate self-spacing and grouping when they used the FEWS system.

3.7.2 ATC Observer Rating Form

We analyzed the ratings that the SMEs made on the ORF to evaluate each participant's ability to maintain separation and to resolve potential conflicts, sequence aircraft efficiently, use control instructions effectively and efficiently, and to maintain an overall safe and efficient traffic flow. In the APWx conditions, the SMEs also evaluated how effectively the participants used the self-spacing and grouping procedures. We hypothesized that performance ratings would be higher when the participants used the FEWS system. We also expected that the SMEs' ratings of participant performance would be higher in the Full RNAV conditions, particularly when weather was not a factor, because the participants would not be expected to intervene as much to descend aircraft on the arrival routes when aircraft were flying Full RNAVs compared to Limited RNAVs.

3.7.3 Communications

We recorded the number and duration of ground-air PTT transmissions and the time at which they occurred in each scenario. We eliminated transmissions less than 150 msec in duration because it would not have been possible for a participant to issue a meaningful communication within that time. We hypothesized that the participants would make more transmissions in the Limited RNAV condition than the Full RNAV condition because of the need to issue more descent clearances to the arrival aircraft in the Limited RNAV condition. We also hypothesized that the participants would make the fewest ground-air transmissions in the APWx condition because the participants would be able to manage more than one aircraft with a single instruction.

We evaluated the number of times the participants coordinated with the D-sides to send ground-ground requests for aircraft holds or redirects to keep additional traffic from entering the sector. We expected to find more requests to hold or redirect traffic in the Limited RNAV conditions and when weather was a factor because these conditions presumably involved more workload. We expected to find fewer requests in the Advanced Procedures condition, assuming that those procedures enabled greater traffic management efficiency. We also expected to find fewer requests to hold or redirect aircraft when participants used the FEWS system, assuming that FEWS enabled greater traffic management efficiency.

3.7.4 WAK Ratings

The WAK prompted the participants to provide a rating at 2-minute intervals throughout each scenario. We hypothesized that the on-line workload ratings would be lower in conditions in which Full RNAVs were in effect, particularly when weather was not a factor. We also hypothesized that the WAK ratings would be lower in the Advanced Procedures condition assuming that those procedures enabled the participants to work more efficiently. We expected that these workload ratings would also be lower when the participants used the FEWS system, assuming that the FEWS system enabled greater traffic management efficiency.

3.7.5 Eye Movement Data

We evaluated participant eye movement data to determine whether the number and duration of fixations on the arrival aircraft differed when we displayed different data blocks The Baseline system always displayed FDBs. However, the FEWS system displayed the RNAV data blocks to indicate that aircraft were conforming to Full RNAVs. We expected that if the RNAV data blocks were useful in suppressing the salience of these aircraft, the participants would make fewer or shorter fixations on the arrival aircraft when the RNAV data blocks were presented.

3.7.6 Post-Scenario Questionnaire

We analyzed the items on the PSQ to determine if the participants' perceived performance, workload, and SA differed between the systems and across conditions. We hypothesized that the participants would report higher performance in the Full RNAV conditions, particularly when weather was not a factor and in the Advanced Procedures condition, assuming that condition better supported traffic management efficiency. We also hypothesized that participants would rate their performance higher when using the FEWS system if that system provided better task support.

We hypothesized that the participants would rate their perceived SA higher when they used the FEWS system, but we also hypothesized that we may not find their ratings to differ between the test conditions because the participants may interact with the individual aircraft less in the Full RNAV conditions and in the Advanced Procedures condition.

We hypothesized that the participants' PSQ workload ratings would correspond to their on-line workload ratings. We also analyzed the participants' responses to the open-ended questions on the PSQ to determine which features and functions of each system they considered to be the most positive and most negative, if any, and what additional features or functions would improve the use of the procedures implemented in the scenario.

3.7.7 Exit Questionnaire

We summarized the descriptive statistics for data obtained from the Exit Questionnaire. These questions did not correspond to the individual scenarios, but rather allowed the participants to compare their performance and use of the concepts between the Baseline and FEWS systems. We expected that the participants would respond that their performance and use of the concepts was better when they used the FEWS system if FEWS provided better task support. We also summarized the participants' responses to the open-ended questions and the additional comments they provided.

4. RESULTS

We analyzed the data in each 60-minute test scenario between the 2-minute and 58-minute interval to allow time for the participants to acclimate to the scenario and to anticipate its conclusion.

For most of our analyses, we used a 2 (system) x 4 (condition) repeated measures Analysis of Variance (ANOVA) to compare the two systems (Baseline and FEWS) across the four conditions (LnoWx, FnoWx, FWx, and APWx). We report the results as significant when p values were less than .05. We report the F values for each significant result and partial eta-squared (η_p^2) to indicate the effect size.[4] When we found significant interactions, we present

[4] Cohen (1988; 1992) describes the use of partial eta squared to evaluate effect size. For one-way ANOVAs, 0.20 is considered a small effect, 0.50 is considered a medium effect, and 0.80 or greater is considered a large effect. However, these values decrease with increased design complexity such as the one used in this simulation.

only the results of the interactions because any significant main effects would not be meaningful. When we found significant effects, we also ran Tukey's Honestly Significant Difference (HSD) post hoc analyses to determine which pairs of differences were significant from one another. We report only significant results for each measure.

4.1 Holding and Redirecting Traffic

We evaluated the number of times that participants requested to have traffic held or redirected from their sector in each scenario. We included the data from 10 participants.[5] Nine of these 10 participants held or redirected traffic in at least one scenario. Two participants held or redirected traffic twice in a single scenario.

Overall, we found that the participants held or redirected traffic on 23 separate occasions (see Table 5). We analyzed these data by conducting a nonparametric Wilcoxon signed-rank test (α set to .05). The Wilcoxon signed-rank test analyzes the sign and magnitude of rank differences between pairs of measurements when the population distribution of the differences is nonnormal. A requirement of the Wilcoxon signed-rank test is to remove from analysis all zero difference values. We found that the participants requested significantly fewer holds or redirects when using the FEWS system (M = 0.05, SD = 0.72) than when using the Baseline system (M = 0.53, SD = 0.60). This finding suggests that the participants found it much more difficult to keep up with the volume of traffic when they used the Baseline system than when they used the FEWS system. We also analyzed these data using the nonparametric Friedman test to determine if the number of holds differed by condition and found no significant difference.

Table 5. Number of Requests to Hold or Redirect Traffic

	Condition			
System	LnoWx	FnoWx	FWx	APWx
Baseline	8[a]	4	3	6
FEWS	0	0	0	2[b]

[a]Two participants, each held twice in one scenario. [b]One request was issued when the D-side display malfunctioned.

Eight participants requested holds or redirects when they used the Baseline system, whereas only two participants requested holds or redirects when using FEWS. In addition, one of the two requests made in FEWS occurred because the D-side display malfunctioned.

When the participants requested holds or redirects, they either held traffic in Sector 02 for one or both of the RNAV arrival routes into the primary airport (GEN) or redirected the traffic that was climbing out of Sector 01. Redirecting aircraft meant that the aircraft from Sector 01 did not climb into Sector 08, but continued eastbound below the participant's sector.

[5] Due to a system error, we lost data from one of the test scenarios for one of the participants.

The participants typically requested that traffic hold or be redirected at approximately 21 minutes into the scenario (*M* = 20.9*, SD* = 3.56), as traffic was reaching its peak volume, or at about 45 minutes into the scenario (*M* = 44.7*, SD* = 4.97) when traffic volume had been high for about 25 minutes. When the participants requested holds or redirects earlier in the scenario, about half of them requested that traffic resume within 9-22 minutes. In the other situations, the participants continued having aircraft hold or be redirected until the end of the scenario. Overall, these data indicate that the participants found it more difficult to manage the traffic volume when using the Baseline system than when using the FEWS system.

4.2 Number of Aircraft Handled

We evaluated the number of aircraft that the participants managed in the sector at each 2-minute interval throughout the scenarios. The number of aircraft in the scenario reflects the number of aircraft kept out of the sector due to holds or redirects and provides a measure of the volume of traffic the participants could manage. We calculated the average number of aircraft managed across the 2-minute intervals during the scenario. We measured the aircraft count this way, instead of evaluating the total number of aircraft in the scenario, because some scenarios ended earlier than expected due to equipment problems. As a result, the total aircraft counts would differ based on how long the scenario ran. The average number of aircraft measure allowed us to better compare the available data in the scenarios to one another.

Overall, we found that the participants managed an average of over 30 aircraft at a time (Grand Mean = 31.06*, SD* = 1.67). This is about twice the number of aircraft designated by the current MAP value for this sector. However, the counts fluctuated through the scenarios, and the raw aircraft counts at some intervals totaled over 40 aircraft, or nearly three times the current MAP value.

We found a main effect for system type, $F(1, 9) = 32.04$, $p < .001$, $\eta_p^2 = 0.78$, indicating that the participants managed more aircraft when they used the FEWS system (*M* = 31.70*, SD* = 0.33) than when they used the Baseline system (*M* = 30.24*, SD* = 0.83). This result reflects what we expected based on the data for holding and redirecting traffic.

We also found a main effect for condition, $F(3, 27) = 41.38$, $p < .001$, $\eta_p^2 = 0.82$. Tukey's HSD analysis indicated that the participants managed more aircraft in the Full RNAV conditions compared to the Limited RNAV condition (see Figure 17).[6]

[6] Error bars represent standard errors in all figures.

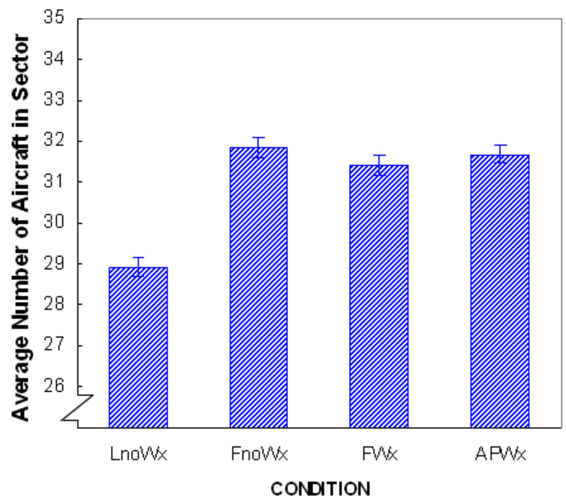

Figure 17. Average number of aircraft in the sector by condition.

This result suggests that the participants were not able to handle as much traffic in the sector when they had to descend the aircraft on the RNAV arrivals. We did not find a significant difference between the FWx condition that included weather and the FnoWx condition that did *not* include weather, so weather did not appear to negatively affect the participants' ability to manage high traffic levels. We also did not find a significant difference between the APWx condition and the FWx condition. We expected to see a higher number of aircraft managed in the APWx condition if the self-spacing and grouping procedures provided benefits to expanding capacity, but the data did not support this hypothesis. However, when we analyzed only the data for the eight participants who did not hold or redirect traffic and who ran these scenarios for the full duration, we found that they controlled significantly more aircraft across the entire scenario, $F(1, 7) = 5.69$, $p = .049$, $\eta_p{}^2 = 0.45$, in the sector in the APWx condition ($M = 239.75$, $SD = 2.05$) than in the FWx condition ($M = 237.13$, $SD = 1.64$). This finding suggests that for those participants who were able to manage higher traffic levels, the inclusion of the Advanced Procedures may have provided some additional benefits.

4.3 Average Time and Distance in Sector

We evaluated the average time and distance that the aircraft traveled through the sector for each test condition. If the aircraft traveled for less time and over shorter distances in the sector, those results would indicate that the participants were handing off the aircraft earlier, presumably as an attempt to reduce workload. On average, the aircraft traveled over 78 miles (Grand Mean = 78.25, $SD = 3.91$) and spent about 10.5 min in the sector ($SD = .49$).

For aircraft distance, we found a main effect for system type, $F(1, 10) = 16.306$, $p = .002$, $\eta_p{}^2 = 0.62$, indicating that the aircraft flew approximately four more miles in the airspace in the FEWS condition ($M = 80.61$, $SD = 3.19$) than in the Baseline condition ($M = 76.55$, $SD = 1.62$).

We also found a significant effect of condition, $F(3, 30) = 18.735$, $p = .001$, $\eta_p{}^2 = 0.65$. Tukey's HSD analysis indicated that the aircraft flew farther distances in the sector in the Full RNAV conditions than in the Limited RNAV condition (see Figure 18).

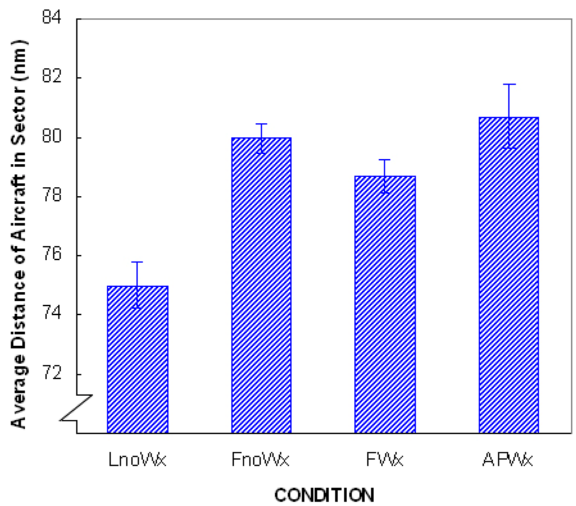

Figure 18. Mean distance flown in sector by condition.

These results suggest that in the Limited RNAV condition, the participants handed off aircraft as early as possible. The Limited RNAV condition required that the participants descend the aircraft on the arrival routes, whereas in the Full RNAV condition, the participants allowed the aircraft to continue on the routes on their own.

For time in sector, we found a significant interaction of system by condition, $F(3, 27) = 3.60$, $p = .026$, $\eta_p^2 = 0.29$ (see Figure 19). Tukey's HSD analysis indicated that the aircraft spent more time in the airspace in the Full RNAV conditions than in the Limited RNAV condition, but the pattern of results differed between the systems. For both the Baseline and FEWS systems, the aircraft spent the least amount of time in the sector when the Limited RNAVs were in effect. As with the results for distance flown, these results suggest that the participants may have been trying to reduce taskload by clearing these aircraft out of their sector more quickly. However, with the Baseline system, the aircraft also spent less time in the sector in the FWx conditions, when weather was a factor and the Advanced Procedures were not available. This result suggests that the participants looked to clear traffic out of their sector more quickly during conditions that, presumably, required more aircraft maneuvering and, therefore, produced higher taskloads. With the FEWS system, the aircraft spent the same amount of time in the sector across all of the Full RNAV conditions.

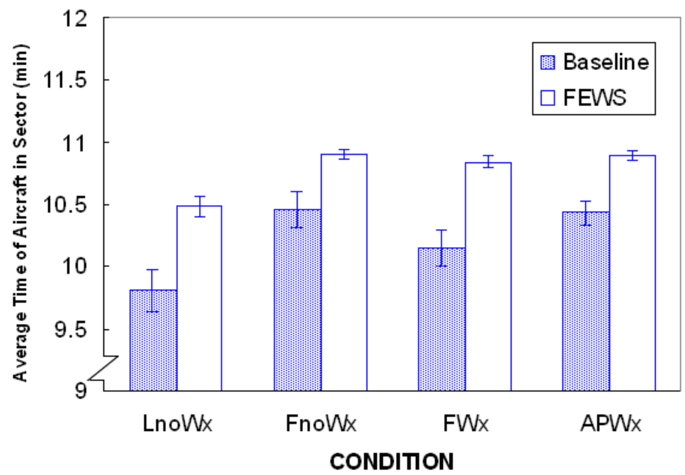

Figure 19. Mean time in airspace by system and condition.

4.4 Altitude Clearances

We evaluated the rate of altitude clearances that the participants issued in each scenario. We used the rate of altitude clearances issued (rather than the raw number) because the number of aircraft differed across scenarios due to aircraft holds or redirects, or because a scenario ended early. We calculated the altitude clearance rate by dividing the number of altitude clearances issued by the total number of aircraft. Using rate as our measure allowed us to directly compare all of the available data across the scenarios. Thus, a participant who issued 50 altitude clearances when handling 200 aircraft would have the same rate (25%) as a participant who issued 75 altitude clearances to 300 aircraft.

Overall, we found that the participants issued altitude clearances at a rate of about 0.3 per aircraft (Grand Mean = .30, *SD* = .16). We found a main effect for condition, $F(3, 27) = 125.26$, $p < .001$, $\eta_p^2 = 0.93$. Tukey's HSD analysis indicated that the participants issued significantly more altitude clearances in the LnoWx condition than in the Full RNAV conditions (see Figure 20). This result is not surprising because the participants had to descend the aircraft on the RNAV arrivals in the Limited RNAV condition but not in the Full RNAV conditions. We did not find any other significant effects.

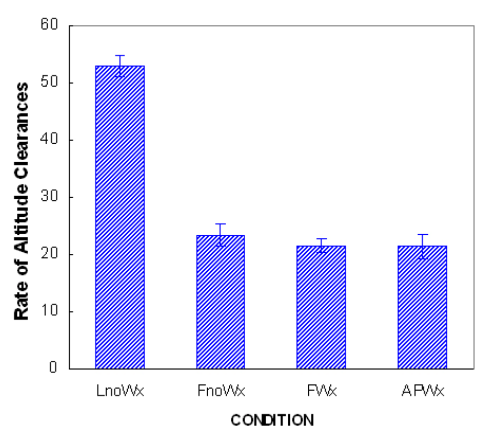

Figure 20. Rate of altitude clearances as a function of condition.

4.5 Heading Commands

We evaluated the rate of heading clearances that the participants issued in each scenario. We calculated the rate of heading clearances in the same manner as we did for altitude clearances, by dividing the number of heading clearances issued by the total number of aircraft.

Overall, we found that the participants issued heading clearances infrequently (Grand Mean = 0.65, *SD* = 0.83). We found a main effect for condition, $F(3, 27) = 3.43$, $p = .031$, $\eta_p^2 = 0.28$. Tukey's HSD analysis indicated that this effect was driven by a significant difference between the FnoWx and APWx conditions (see Figure 21). This result presumably reflects the need for the participants to issue more heading clearances when weather was present and, possibly, as the participants reported, a preference to maneuver individual aircraft around grouped aircraft. We did not find any other significant effects.

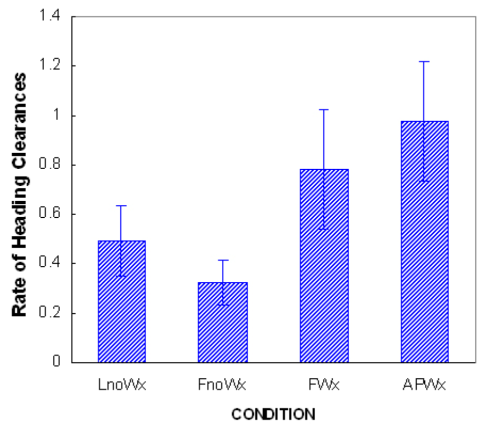

Figure 21. Rate of heading clearances as a function of condition.

4.6 Speed Clearances

We evaluated the rate of speed clearances that the participants made in each scenario. We calculated the rate of speed clearances in the same manner as we did the altitude and heading clearances, by dividing the number of speed clearances issued by the total number of aircraft. Overall, we found that the participants conducted speed changes infrequently (Grand Mean = 0.51, *SD* = 0.77). We did not find any significant effects for this measure.

4.7 Self-Spacing and Grouping Clearances

We examined the participants' use of the self-spacing and grouping procedures and the number of attempts they made to activate the procedures using the Baseline and FEWS systems. We also reviewed the audio recordings to determine when the participants coordinated with the D-sides when activating these procedures. The participants always worked with self-spacing or grouped aircraft in the Advanced Procedures condition, regardless of whether they activated them, because the scenarios included aircraft that entered the sector already self-spaced or grouped.

Overall, we found that the participants rarely activated the advanced procedures. As a result, we were unable to conduct statistical analyses on these data. We found that three of the participants attempted to activate self-spacing when using the Baseline system, and six participants attempted to activate self-spacing when using the FEWS system. None of the participants initiated grouping using either system. However, one participant did request that the D-side create a group of two aircraft and to add an aircraft to another existing group when using the FEWS system. Two participants cancelled the grouping procedure for one or all of the aircraft in a group when using the FEWS system.

The three participants who attempted to activate self-spacing when using the Baseline system did so successfully on three of seven attempts. Format entry errors caused most of the difficulties in initiating the procedure. These errors occurred because the participants entered the CID of a trail aircraft before the CID of a lead or because the participant entered a spacing interval before the aircraft CIDs, rather than after. Another attempt initially failed because the trail aircraft was not yet on the participants' frequency.

We found that when some of the errors occurred, the participants or their D-sides sometimes entered the self-spacing designation in the fourth line of the data block, thereby providing an incorrect indication that the procedure was established. The audio recordings revealed that the participants and D-sides discussed whether the procedure had been activated and whether the fourth line indicator was correct. For example, in one instance, a participant reported, "These two aren't self-spacing. It says self-spacing (points to screen) but they're not doing it." In this situation, the D-side subsequently activated the procedure correctly.

Six participants attempted to activate self-spacing when using the FEWS system. They activated the procedure successfully on 6 of 18 attempts. Five of the 12 errors occurred because the participants erroneously selected an ADS-B symbol of an aircraft when interacting with a data block. This indicates that the action to activate the procedure was unintentional and makes the number of intended activations 13, rather than 18. The other errors occurred because the participant instructed an aircraft to self-space that was either not yet on the frequency or under control or because the participant tried to issue the instruction via Data Comm to a voice-only aircraft.

The participants cancelled the self-spacing procedure several times. The audio recordings revealed that the participants discussed concerns about potential conflicts with the D-sides before canceling the procedure. The audio recordings also revealed that one participant cancelled the procedure accidentally in one instance by right clicking on the connecting line.

The audio recordings indicated that the participants requested assistance from the D-sides to activate self-spacing on five other occasions, and the D-sides made five additional attempts to activate the procedure for which we did not hear a specific participant request. Half of the D-side attempts were unsuccessful for similar reasons described for the participants.

With respect to the grouping procedure, none of the participants attempted to create a group or add aircraft to an existing group when using the Baseline system. The participants also did not request any assistance from the D-side for grouping when using the Baseline system. In FEWS, five participants worked with the grouping procedure, but only one participant sought to create a group or add an aircraft to an existing group. In both of these instances, the participant requested that the D-side conduct the procedure. The other four participants removed aircraft from groups. These participants made 14 attempts to remove aircraft from groups, 11 of which were successful. The unsuccessful attempts occurred because the aircraft were not on the frequency. Two of the four participants removed the aircraft from the groups on their own. The other two participants requested that their D-sides perform this action.

Overall, the data suggest that the participants did not find it very useful to activate the self-spacing or grouping procedures. It is possible that they did not see a value in doing so, did not have sufficient resources to devote to evaluating when or how to use the procedures effectively, or abandoned their attempts to initiate them after encountering errors. The procedures themselves may have been too complicated, and the high traffic level scenarios may have made it difficult for the participants to devote time to working with the new concepts. The participants provided comments on their interactions with these procedures; we discuss their questionnaire and debrief comments in section 4.12.4.

4.8 Voice Communications

We evaluated the number and duration of ground-air PTT transmissions per scenario. We calculated the mean number and duration of PTTs made per aircraft at each 2-minute interval and then calculated an overall 2-minute average for the scenario. We measured the PTT data this way because the number of aircraft the participants managed differed between scenarios due to aircraft holds or redirects or because some scenarios ended earlier than anticipated due to system problems.

Using the average number and duration of PTTs allowed us to have comparable measures across scenarios. In our data, we eliminated PTTs that were less than 150 msec in duration because it would not have been possible for the participants to make a meaningful transmission in that amount of time.

Overall, we found that the participants averaged 0.31 (SD = .049) transmissions per aircraft with an average duration of 1,062.70 msec (SD = 198.78). The simulation pilots made an average of 0.32 (SD = .05) transmissions per aircraft with an average duration of 1,212.51 msec (SD = 205.02). The low proportion of voice communications made per aircraft was not surprising given that 70% of the aircraft in each scenario were Data Comm equipped. For example, if 10 aircraft were in the sector, 7 would be expected to be equipped with Data Comm. If the participant issued one instruction to each of the three voice-only aircraft, that would result in an average of .33 transmissions.

We found that the average number of participant PTTs differed significantly by condition, $F(3, 27) = 19.92$, $p < .001$, $\eta_p^2 = 0.69$ (see Figure 22). Tukey's HSD analysis indicated that the participants made more PTTs in the Limited RNAV condition than in any of the Full RNAV conditions. It is likely that this result reflected the need for the participants to descend the aircraft on the RNAV arrivals when the Limited RNAVs were in effect. The average number of participant PTTs per aircraft did not differ significantly between any of the Full RNAV conditions.

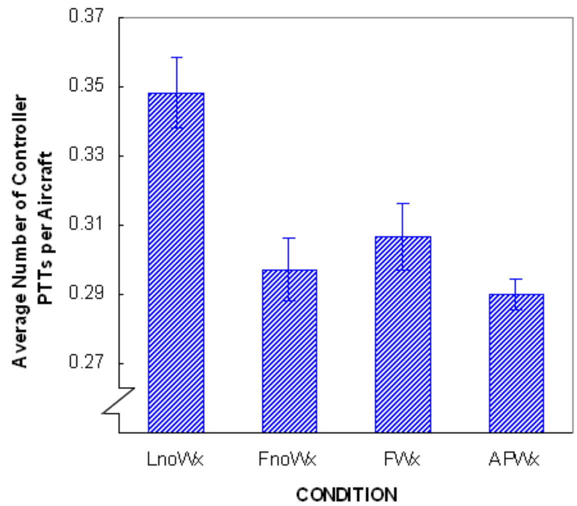

Figure 22. Mean number of participant PTTs per aircraft per 2-minute interval by condition.

We found that the average duration of participant PTTs per aircraft also differed significantly by condition, $F(3, 27) = 38.04$, $p < .001$, $\eta_p^2 = 0.81$ (see Figure 23). Tukey's HSD analysis indicated that the participants made longer average PTTs in the Limited RNAV condition than in any of the Full RNAV conditions. This analysis also revealed that the shortest PTT durations occurred in the Advanced Procedures condition ($p < .05$). These results, along with the average number of participant PTTs, suggest that the Full RNAV conditions, and to some extent the Advanced Procedures, reduced the need for participant voice transmissions.

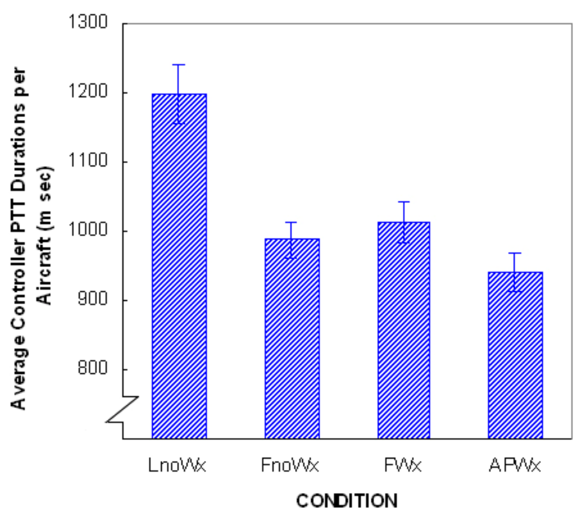

Figure 23. Mean duration of participant PTTs per aircraft per 2-minute interval by condition.

We measured the PTTs made by the simulation pilots in the same manner that we measured them for the participants and found a significant effect of condition for both the mean number, $F(3, 27) = 19.40$, $p < .001$, $\eta_p^2 = 0.68$, and the mean duration, $F(3, 27) = 9.01$, $p < .001$, $\eta_p^2 = 0.50$, of their transmissions (see Figure 24). Tukey's HSD analysis indicated that the simulation pilots also made fewer and shorter PTTs on average when the Full RNAV conditions were in effect.

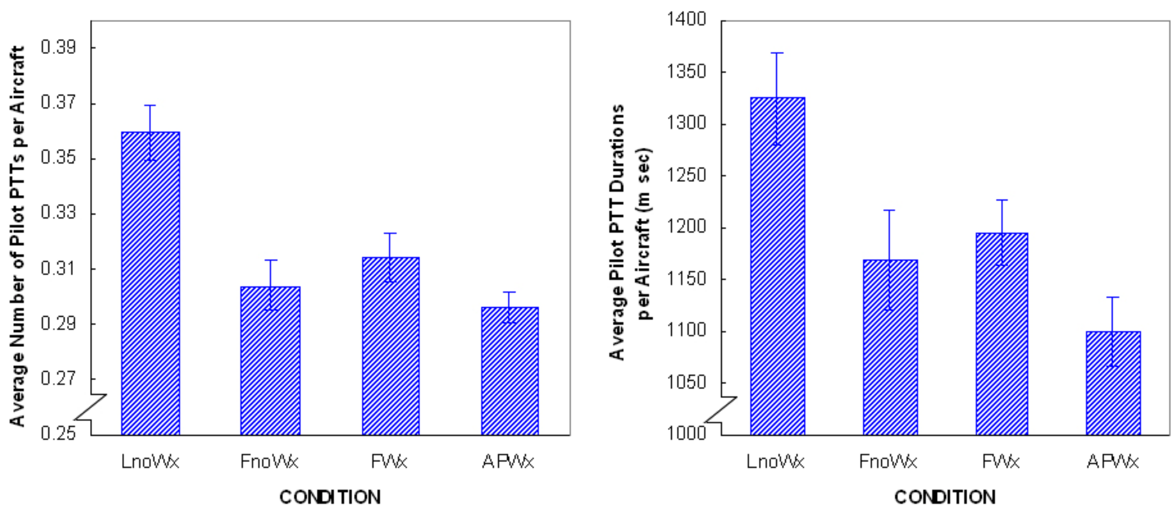

Figure 24. Mean number (left) and duration (right) of simulation pilot PTTs per aircraft per 2-minute interval by condition.

However, unlike the participants' data, the simulation pilot PTTs also differed significantly by system for both the average number, $F(1, 9) = 11.33$, $p < .008$, $\eta_p^2 = 0.56$, and the average duration, $F(1, 9) = 11.97$, $p < .007$, $\eta_p^2 = 0.57$. The simulation pilots made more PTTs when the participants used the FEWS system ($M = .34$, $SD = .03$) than when they used the Baseline system ($M = .30$, $SD = .02$). They also made longer average PTTs with the FEWS system ($M = 1261.85$ msec, $SD = 120.40$) than with the Baseline system ($M = 1132.13$, $SD = 103.02$). However, it is not clear why this occurred.

4.9 Losses of Separation

We examined the instances in which a LOS occurred. We used 3 nm (5.56 km) separation standards in all of our scenarios. Therefore, we used those criteria in evaluating the data. An LOS occurred when aircraft were separated by less than 3 nm (5.56 km) horizontally and 1,000 ft vertically. We eliminated losses of separation that were shorter than a single sweep of the radar (12 s) because the participants would not have been able to detect changes in aircraft position between radar updates. One of the researchers and one of the SMEs then evaluated the remaining LOS to determine whether the occurrences resulted because of a system error or simulation pilot error not attributable to the participant. Overall, we found 11 LOS that averaged 31 s in duration ($SD = 14$). The majority of the LOS occurred when the participants used the Baseline system (see Table 6).

Table 6. Losses of Separation

System	Condition				Totals
	LnoWx	FnoWx	FWx	APWx	
Baseline	2	3	0	3	8
FEWS	0	1	2	0	3
Totals	2	4	2	3	11

One participant experienced two LOSs in a single scenario (FWx in FEWS) and one participant experienced three LOSs in a single scenario (FnoWx in Baseline). Otherwise, only one LOS at most occurred in each scenario per participant. However, upon further investigation, the majority of the LOSs found for the Baseline system occurred for a single participant who was responsible for five of the eight occurrences. Due to the low number of data points and the nonnormal distribution of these data, we conducted a nonparametric Wilcoxon signed-rank test to evaluate the LOS (α set to .05; $n = 5$). We found no significant difference between the Baseline ($M = 0.80$, $SD = 1.55$) and FEWS systems ($M = 0.30$, $SD = 0.67$). We also analyzed the LOS data using the nonparametric Friedman test to determine if the number of LOSs differed by condition and found no significant difference.

The three losses of separation that occurred in the Baseline APWx condition involved the self-spacing and grouping procedures. In one instance, a participant tried to activate the self-spacing procedure unsuccessfully. However, he entered the self-spacing designation in the fourth line of the data block, erroneously indicating that the procedure was activated. The trail aircraft subsequently went into conflict with another aircraft. The second instance also involved self-spacing aircraft that had entered the sector already conducting the procedure. When the participant descended the lead aircraft, the trail aircraft subsequently descended and lost separation with another aircraft. In the third instance, an aircraft climbing through the sector conflicted with an aircraft that was exiting the sector as part of a group. These three losses of separation indicate that it was more difficult for the participants to work effectively with the Advanced Procedures when salient indications of procedure use were not available.

4.10 Eye Movement Results

We examined the number and duration of eye fixations the participants made on the arrival (RNAV) aircraft to determine whether viewing patterns differed between aircraft that displayed FDBs and those that displayed RNAV data blocks. The FEWS system presented RNAV data blocks when aircraft conformed to the Full RNAV routes, but only presented FDBs in the Limited RNAV condition.

We expected the participants to wear the eye tracker for the full 60-minutes of each scenario. However, due to discomfort, a few of the participants requested that we remove the device prior to scenario completion. In addition, we encountered some difficulties maintaining calibration for the full duration of the scenarios for several participants. It is not uncommon to lose calibration because even slight movements of the apparatus reposition the device. After a loss of calibration, we are unable to accurately determine what areas of the display correspond to a participant's

POG. The research assistants continuously monitored the eye tracking systems for losses of calibration and noted when they occurred so that we could eliminate these portions of the data from the analyses. The eye movement data were also likely to have been affected when the participants held or redirected traffic in the scenarios because these actions changed the configuration of the aircraft in the sector.

We analyzed the data from two conditions, both run using the FEWS system, for which we had complete data and that contained the data blocks of interest: the LnoWx and FnoWx conditions. We conducted a paired-samples *t*-test to evaluate whether the number and duration of fixations differed between these two conditions. The participants made an average of 1,874.55 (*SD* = 576.84) fixations and spent an average of 0.56 s (*SD* = 0.14) on the arrival aircraft when the system only displayed FDBs. They made an average of 1,938.64 (*SD* = 609.08) fixations and spent an average of 0.57 s (*SD* = 0.11) on the arrival aircraft when the system displayed RNAV data blocks. These differences were not statistically significant, indicating that the different data block presentation formats did not produce different fixation patterns.

4.11 WAK Results

Overall, the participants responded to 83.7% of the WAK prompts. We replaced missing data points using the mean substitution procedure to prevent loss of data.[7] We did this, rather than assign the highest workload rating of 10 to a missed prompt, because we could not be sure why a participant did not respond. The participant may have been occupied with another task (such as coordinating with the D-side) that took their attention away from the prompt.

First, we analyzed the overall WAK ratings. We obtained an overall WAK rating for each participant in each scenario by calculating a mean of the individual responses. Overall WAK ratings indicated that the task was moderately difficult (Grand Mean = 6.13, *SD* = 1.48). We found a main effect for system type, $F(1, 9) = 37.80$, $p < .001$, $\eta_p^2 = 0.81$, indicating that the participants reported higher workload ratings when using the Baseline system (*M* = 6.86, *SD* = 1.11) than when using the FEWS system (*M* = 5.09, *SD* = 1.16).

The overall WAK results indicated a benefit of the FEWS system in reducing participant workload compared to the Baseline system. This effect was independent of the test conditions, indicating a global benefit of FEWS in reducing workload.

We also analyzed the WAK data by scenario interval. We expected that because traffic levels increased and weather advanced into the sector in some conditions as the scenarios progressed, that we would be likely to find that these patterns affected workload levels. We obtained an average WAK rating for each participant for each of four, 14-minute intervals in the scenarios. The intervals are described in Table 7.

[7] In a repeated measures design, all data for a participant are omitted from the analysis when one or more cells contain missing data. Because the participants had over 200 opportunities to respond to the WAK prompts across all scenarios, it was likely that they would omit some responses. To allow analysis of all the data, we used the mean substitution procedure (e.g., Tabachnick & Fidell, 1989).

Table 7. Scenario Time Intervals

Time Interval	Scenario Events
1st	Traffic building from a moderate to high level; in weather scenarios, weather moving towards, but still outside of sector.
2nd	Traffic continuing to build to max level; in weather scenarios, weather moving into sector.
3rd	Traffic at maximum level; in weather scenarios, weather affecting sector and affected arrival stream is rerouted.
4th	Traffic at maximum level; in weather scenarios, weather affecting sector.

We found a significant interaction of condition by interval, $F(9, 81) = 8.03$, $p < .001$, $\eta_p^2 = 0.47$ (see Figure 25), but no other significant effects.

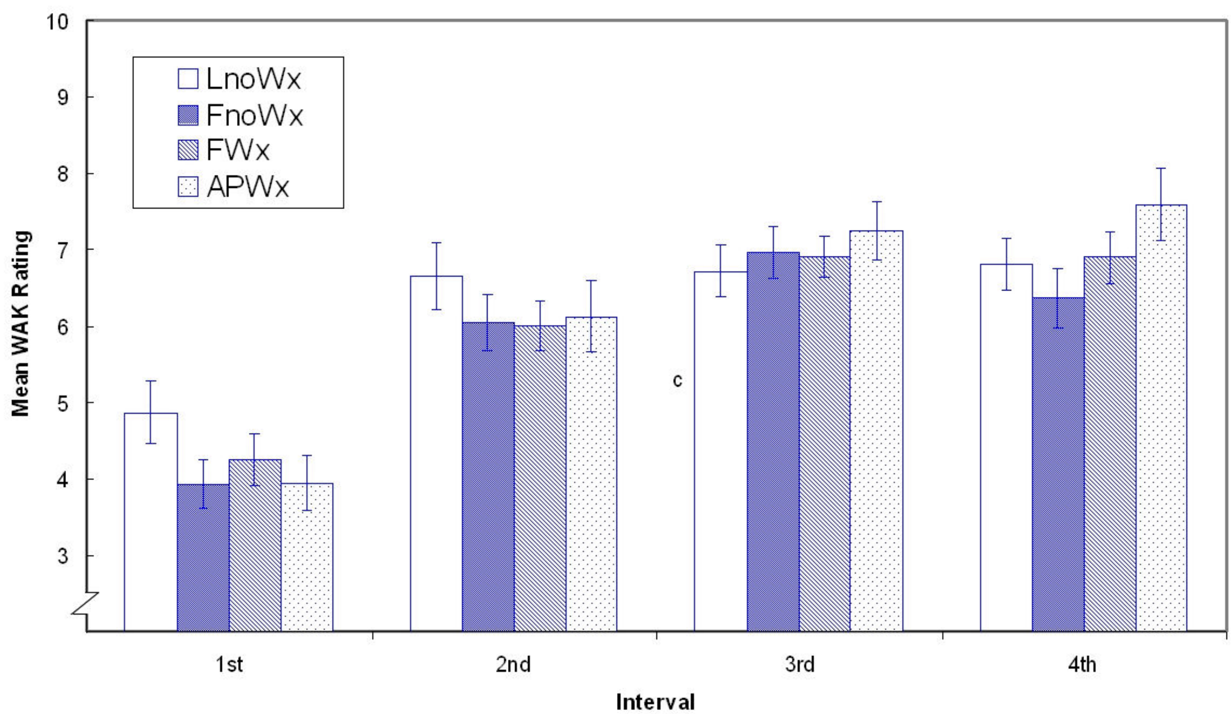

Figure 25. WAK ratings across time intervals and conditions.

We used Tukey's HSD analysis to further examine the condition by interval interaction. We found that in the first interval, the participants rated workload higher in the LnoWx condition than in the FnoWx or APWx conditions. This is not surprising because the participants had to issue clearances to descend aircraft on the RNAV arrivals and had to manage each of the aircraft individually in the LnoWx condition. However, in the fourth interval, the participants rated workload higher in the APWx condition than in all other conditions. These results suggest that although the participants found it easier to work with the Advanced Procedures under lower task demand situations (i.e., lower traffic; weather not yet affecting sector), when task demands increased, the participants found it more difficult to work with self-spacing and grouping. It is likely that when controllers have more time and cognitive resources available, they are able to incorporate additional procedures more effectively. Under higher task demand situations, the integration of the Advanced Procedures may increase complexity.

4.12 Questionnaire Data

We analyzed the participant and SME ratings from the questionnaires. We also summarized the participant comments and responses on the questionnaires and those made during the debriefing sessions.

4.12.1 Observer Rating Form

Unless otherwise stated, we examined the ORF items using a 2 (system) x 4 (condition) repeated measures ANOVA. The SMEs rated the participants on a scale of 1 (*least effective*) to 8 (*most effective*) on six measures. Overall, we found a generalized benefit of the FEWS system compared to the Baseline system. Out of the 6 possible main effects for system, 5 showed a significant benefit for FEWS, for at least some conditions.

4.12.1.1 Maintaining Separation and Resolving Potential Conflicts

We found a significant main effect of system, $F(1, 10) = 18.97$, $p = .001$, $\eta_p^2 = 0.65$, for SME ratings of participant ability to maintain separation and resolve potential conflicts. We found that the SMEs reported the participants to be significantly more effective when using the FEWS system ($M = 6.27$, $SD = 0.97$) than when using the Baseline system ($M = 4.84$, $SD = 1.72$).

4.12.1.2 Sequencing Aircraft Efficiently

We found a significant interaction of system by condition, $F(3, 24) = 3.39$, $p = .034$, $\eta_p^2 = 0.30$, for SME ratings of participant ability to sequence aircraft efficiently. Tukey's HSD analysis of the interaction indicated that the SMEs perceived the participants to be significantly less effective sequencing aircraft in the Advanced Procedures condition when using the Baseline system compared to the FEWS system and compared to the FnoWx condition when using the Baseline system (see Figure 26). We also found that for the LnoWx condition that the SMEs perceived the participants to be less effective when using the Baseline system than when using the FEWS system.

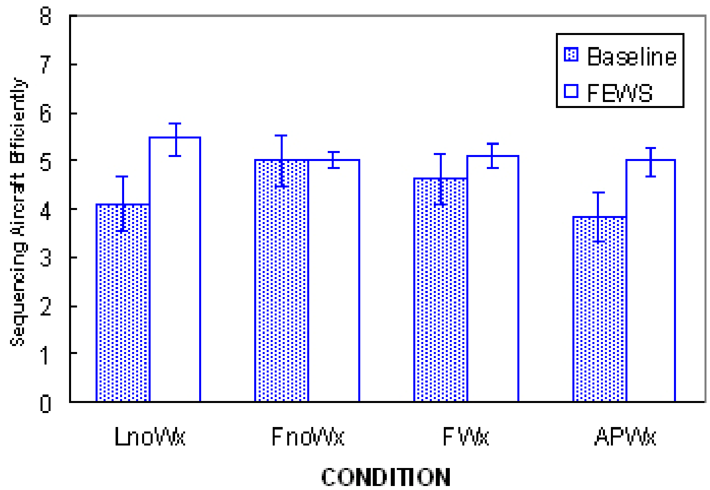

Figure 26. SME rating of ability to sequence aircraft efficiently by system and condition.

4.12.1.3 Using Control Instructions Effectively/Efficiently

We found a significant main effect of system, $F(1, 10) = 17.20$, $p = .002$, $\eta_p^2 = 0.63$, for SME ratings of participant ability to utilize control instructions effectively and efficiently. The SMEs found the participants to be significantly more effective using control instructions when using the FEWS system ($M = 6.12$, $SD = 1.02$) than when using the Baseline system ($M = 4.90$, $SD = 1.70$).

4.12.1.4 Overall Safe and Efficient Traffic Flow Rating

We found a significant main effect of system, $F(1, 10) = 22.28$, $p =.001$, $\eta_p^2 = 0.69$, for SME ratings of participant ability to manage safe and efficient traffic flow. We also found a significant main effect of condition, $F(3, 30) = 5.05$, $p = .006$, $\eta_p^2 = 0.33$. The SMEs found that the participants were more effective managing traffic safely and efficiently when using the FEWS system ($M = 6.10$, $SD = 0.94$) than when using the Baseline system ($M = 4.30$, $SD = 2.02$). Tukey's HSD analysis indicated that the SMEs rated participant ability to maintain overall safe and efficient traffic flow as more effective in the FnoWx condition ($M = 6.02$, $SD = 0.82$) compared to the APWx condition ($M = 4.45$, $SD = 2.04$). This indicated that the SMEs observed the participants to be less able to manage the traffic when weather was present and the Advanced Procedures were in use.

4.12.1.5 Using the Aircraft Self-Spacing Procedure Effectively

We used a univariate ANOVA to evaluate the SME ratings of participant ability to use the aircraft self-spacing procedure effectively because we only compared the responses for the Advanced Procedures condition between the two systems. We found a significant effect of system, $F(1, 9) = 7.31$, $p = .024$, $\eta_p^2 = 0.45$, indicating that the SMEs perceived the participants to be more effective working with the self-spacing procedure when they used the FEWS system ($M = 5.70$, $SD = 1.06$) compared to when they used the Baseline system ($M = 3.50$, $SD = 2.01$).

4.12.1.6 Using the Aircraft Grouping Procedure Effectively

We used a univariate ANOVA to evaluate the participant ability to use the aircraft grouping procedure because we were again only comparing responses for the Advanced Procedures condition between the two systems. We did not find a significant effect. The SMEs rated the participants' ability to use this procedure quite low for both the Baseline system (M = 2.90, SD = 2.02) and the FEWS system (M = 3.20, SD = 2.27).

4.12.2 Post-Scenario Questionnaire

The participants rated their performance, workload, and SA using scales that ranged from 1 (*poor* or *extremely difficult*) to 10 (*excellent* or *extremely easy*). We analyzed the data from the PSQ using 2 (system) x 4 (condition) repeated measures ANOVAs. Out of the 28 possible main effects for system, 15 (approximately 54%) showed a significant benefit for the FEWS system. In two other analyses, we found a system by condition effect favoring FEWS.

4.12.2.1 Perceived Scenario Difficulty

Overall task difficulty ratings, on a scale of 1 (*extremely difficult*) to 10 (*extremely easy*), indicated that the participants found the tasks difficult (Grand Mean = 3.65, SD = 2.05). We found a main effect for system type, $F(1, 10) = 18.96$, p =.001, $\eta_p^2 = 0.65$, indicating that participants perceived more difficulty with the scenarios when using the Baseline system (M = 2.73, SD = 1.65) than when using the FEWS system (M = 4.57, SD = 2.00).

4.12.2.2 Perceived Performance

The participants rated the perceived level of their performance and the performance of the simulation pilots on a scale of 1 (*poor*) to 10 (*excellent*). Ratings of self performance indicated that the participants believed they performed the tasks well (Grand Mean = 6.56, SD = 1.89). In support of our hypothesis, we found a main effect for system type, $F(1, 10) = 6.56$, $p = .028$, $\eta_p^2 = 0.40$, indicating that the participants believed their performance was significantly better when they used the FEWS system (M = 7.23, SD = 1.57) than when they used the Baseline system (M = 5.89, SD = 1.97).

Ratings on the perceived performance of the simulation pilots indicated that the participants believed the pilots performed quite well (Grand Mean = 7.31, SD = 2.09). We did not find any significant differences for this measure.

4.12.2.3 Perceived Workload

The participants rated their overall workload and workload due to communication on a scale from 1(*extremely low*) to 10 (*extremely high*). Ratings of overall workload indicated that the participants experienced moderately high levels of perceived workload (Grand Mean = 6.56, SD = 2.11). We found a significant main effect of condition, $F(3, 30) = 5.10$, $p = .006$, $\eta_p^2 = 0.34$. Tukey's HSD analysis indicated that the participants rated their workload significantly higher in the APWx condition than in either the LnoWx or FnoWx conditions (see Figure 27). This result indicates that the participants perceived significantly greater workload when working with weather and the self-spacing and grouping concepts, regardless of which system they used. This result is similar to the result obtained in the fourth interval of the scenarios for the on-line WAK ratings. Both results indicate that when the participants had a high level of traffic to manage and weather affected the sector, it was difficult to work with the Advanced Procedures.

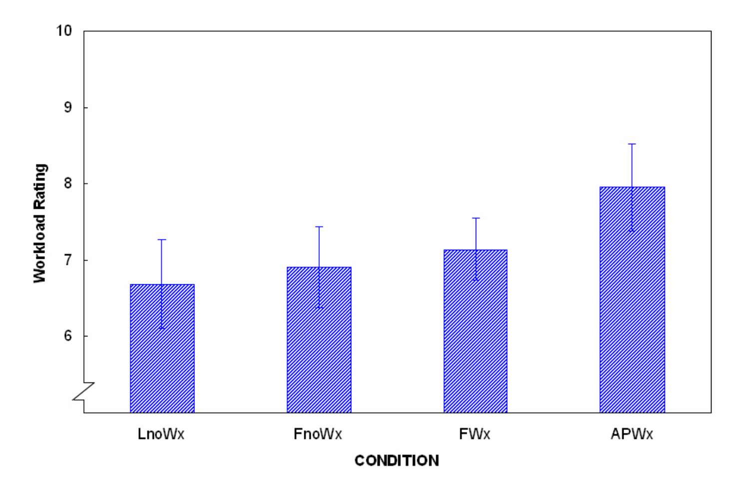

Figure 27. PSQ overall workload by condition.

Participants' ratings indicated that they experienced a moderate level of workload due to communications (Grand Mean = 5.66, *SD* = 2.48). However, we did not find any significant differences for this measure.

4.12.2.4 Perceived Situation Awareness

The participants rated five aspects of SA on a scale of 1 (*poor*) to 10 (*excellent*). Overall, the participants perceived their overall SA to be moderately high (Grand Mean = 6.44, *SD* = 1.82). We found a main effect of system, $F(1, 10) = 5.42$, $p = .042$, $\eta_p{}^2 = 0.35$, indicating that the participants rated their overall SA significantly higher when they used the FEWS system (M = 6.91, SD = 1.61) than when they used the Baseline system (M = 5.98, SD = 1.91).

The participants reported moderately high SA for LOS (Grand Mean = 6.32, *SD* = 2.00). We found a main effect of system, $F(1, 10) = 6.88$, $p = .025$, $\eta_p{}^2 = 0.41$, indicating that the participants rated themselves as having higher SA for LOS when they used the FEWS system (M = 6.75, SD = 2.01) than when they used the Baseline system (M = 5.89, SD = 1.91).

The participants reported that they had moderately high levels of perceived SA for current aircraft locations (Grand Mean = 6.51, *SD* = 1.69), for projected aircraft locations (Grand Mean = 6.08, *SD* = 1.90), and for handoff/airspace violations (Grand Mean = 6.35, *SD* = 2.25). We did not find significant differences for these measures.

4.12.2.5 Perceived Interface Effectiveness

The participants rated five aspects of system interface effectiveness on a scale of 1 (*not at all*) to 10 (*a great deal*). Overall, the participants' ratings indicated that the system interfaces supported safety (Grand Mean = 6.91, *SD* = 1.73). We found a significant main effect of system, $F(1, 10) = 9.66$, $p = .011$, $\eta_p{}^2 = 0.49$, that indicated that the participants believed that the FEWS system (M = 7.50, SD = 1.30) supported safety more than the Baseline system (M = 6.32, SD = 1.90).

The participants' ratings indicated that the system interfaces supported control efficiency (Grand Mean = 7.24, *SD* = 1.64). We found a main effect of system, $F(1, 10) = 13.93$, $p = .004$, $\eta_p^2 = 0.58$, that indicated that the participants believed the FEWS system ($M = 7.93$, $SD = 1.63$) supported control efficiency more than the Baseline system ($M = 6.55$, $SD = 1.34$).

The participants' ratings indicated that the system interfaces supported sector operations (Grand Mean = 7.19, *SD* = 1.53). We found a main effect of system, $F(1, 10) = 23.00$, $p = .001$, $\eta_p^2 = 0.70$, that indicated that the participants believed the FEWS system ($M = 7.92$, $SD = 1.11$) supported sector operations more than the Baseline system ($M = 6.46$, $SD = 1.55$).

The participants' ratings indicated that the system interfaces supported their control plan or strategy (Grand Mean = 6.81, *SD* = 1.70). We found a main effect of system, $F(1, 10) = 9.68$, $p = .01$, $\eta_p^2 = 0.49$, that indicated that the participants believed the FEWS system ($M = 7.46$, $SD = 1.53$) supported control plans and strategies more than the Baseline system ($M = 6.16$, $SD = 1.63$).

The participants' ratings indicated that the system interfaces supported their ability to work with the procedures (Grand Mean = 7.26, *SD* = 1.64). We found a significant interaction between system and condition, $F(3, 30) = 3.48$, $p = .028$, $\eta_p^2 = 0.26$. There was a general benefit of the FEWS system ($M = 8.01$, $SD = 1.19$) compared to the Baseline system ($M = 6.50$, $SD = 1.69$), but Tukey's HSD analysis revealed that this difference was most pronounced in the FWx condition (see Figure 28).

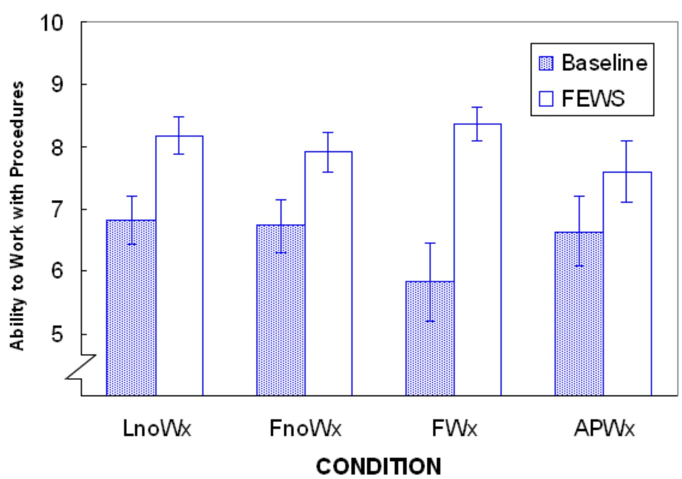

Figure 28. PSQ ratings of ability to work with the procedures by system and condition.

4.12.2.6 Perceived Interface Usability

The participants rated the extent to which they agreed with statements about system usability following each scenario on a scale of 1 (*not at all*) to 10 (*a great deal*). The ratings indicated that the participants agreed with the statement that they could prioritize information easily (Grand Mean = 6.94, *SD* = 1.54). We found a significant interaction between system and condition, $F(3, 30) = 3.00$, $p = .046$, $\eta_p^2 = 0.23$. There was a general benefit to the FEWS system ($M = 7.43$, $SD = .39$) compared to the Baseline system ($M = 6.46$, $SD = 1.55$), but the Tukey's HSD analysis revealed that the difference was most pronounced in the FWx conditions (see Figure 29).

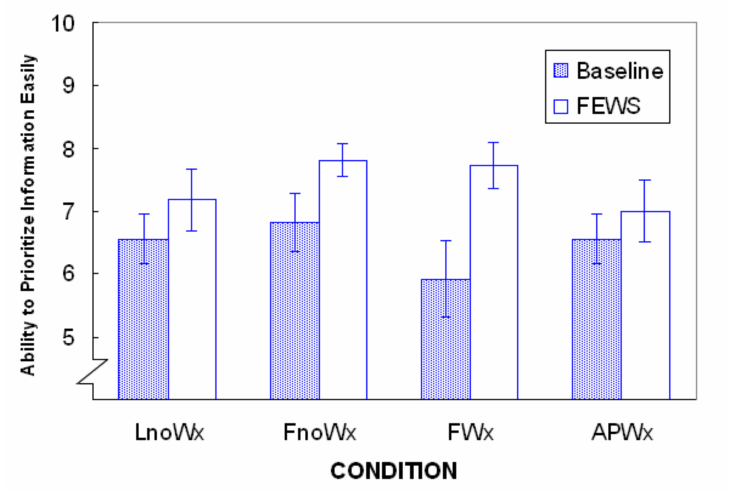

Figure 29. PSQ ratings of ability to prioritize information easily by system and condition.

The ratings indicated that the participants found that the coding of information somewhat supported their ability to quickly locate the information that they needed (Grand Mean = 5.86, *SD* = 2.31).[8] We found a main effect of system, $F(1, 8) = 9.25$, $p = .016$, $\eta_p^2 = 0.54$, which indicated that the participants believed that the FEWS system ($M = 6.81$, $SD = 2.12$) supported faster information retrieval than the Baseline system ($M = 4.92$, $SD = 2.12$).

The ratings indicated that the participants could clearly determine which aircraft had been issued a clearance to join an RNAV route (Grand Mean = 7.77, *SD* = 1.40).[9] Because the participants typically did not issue many clearances for aircraft to join RNAVs, their responses to this item most likely reflected their ability to identify the aircraft that were joining RNAV routes prior to entering their sector. We found a main effect of system, $F(1, 7) = 13.33$, $p = .008$, $\eta_p^2 = 0.66$, that indicated that the participants believed the FEWS system ($M = 8.47$, $SD = 0.88$) provided more support for determining which aircraft would join an RNAV than the Baseline system ($M = 7.07$, $SD = 1.48$).

The ratings indicated that the participants agreed that they could clearly determine which aircraft were flying an RNAV route (Grand Mean = 8.25, *SD* = 1.41).[10] We found a main effect for system, $F(1, 8) = 12.03$, $p = .008$, $\eta_p^2 = 0.60$, which indicated that the participants believed that the FEWS system ($M = 8.89$, $SD = 0.91$) allowed them to better determine which aircraft were flying an RNAV route compared to the Baseline system ($M = 7.61$, $SD = 1.54$). We also found a significant main effect for condition, $F(3, 24) = 3.61$, $p = .028$, $\eta_p^2 = 0.31$. Tukey's analysis indicated that the participants found it more difficult to determine whether the aircraft were on the RNAV routes in the LnoWx condition than in any other condition (See Figure 30). These results suggest that although FEWS was more supportive than Baseline, both systems provided some support in indicating that aircraft were flying Full RNAV routes. Therefore, the "00" indication presented in the data blocks of aircraft in the Full RNAV conditions in the Baseline system may have been a useful indicator.

[8] We excluded two participants from this analysis because they had a large number of missing data points.
[9] We excluded three participants from this analysis because they had a large number of missing data points.
[10] We excluded two participants from this analysis because they had a large number of missing data points.

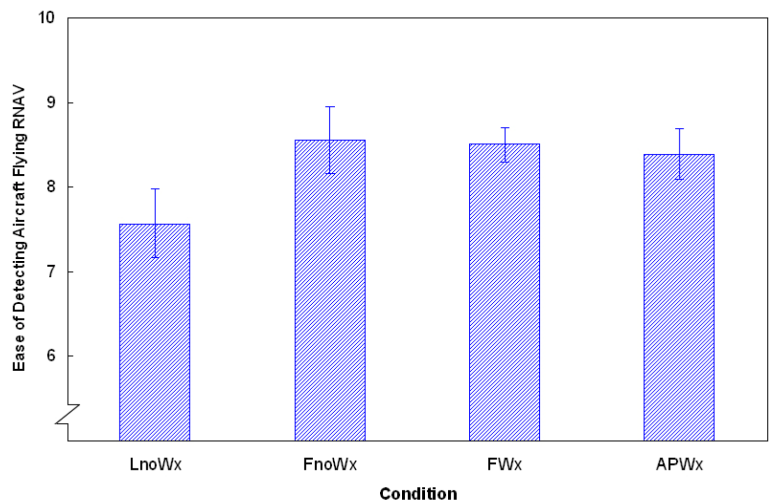

Figure 30. PSQ ease of determining which aircraft were flying RNAV routes.

Due to an error in questionnaire layout, the item that asked participants how clearly they were able to determine which aircraft were no longer conforming to an RNAV route was incorrectly categorized in the Advanced Procedures section. As a result, we only obtained data in two of the test conditions instead of all four conditions as planned. Therefore, we used a paired-samples *t*-test to compare the responses between the two systems for the APWx condition. We did not find a significant difference, $t(10) = 1.71$, $p = .118$, $\eta^2 = 0.23$, indicating that neither system provided better support for detecting conformance to an RNAV. This result may indicate that the participants did not find it salient when the FEWS data block changed from an RNAV data block to an FDB when an aircraft went out of conformance. However, because we did not have all of the data we had anticipated, there may have been too few data points to adequately assess this item.

Overall, the participants' ratings[11] indicated that the systems were easy to use (Grand Mean = 7.33, *SD* = 1.54), the text was easy to read (Grand Mean = 7.85, *SD* = 1.49), and the graphics were easy to interpret (Grand Mean = 7.71, *SD* = 1.78). The ratings indicated that the participants could find the information they needed quickly (Grand Mean = 6.68, *SD* = 1.70), that the displays changed or updated predictably (Grand Mean = 7.57, *SD* = 1.26), that the information was conveyed in an easy-to-understand format (Grand Mean = 7.68, *SD* = 1.19), and that it only took a few simple steps to get information when it was not directly available on the display (Grand Mean = 7.49, *SD* = 1.28). Finally, the participants' ratings indicated that they found the displays to be somewhat cluttered (Grand Mean = 5.22, *SD* = 2.87). We did not find significant differences for these measures.

4.12.2.7 Advanced Procedures Questions

Additional questions on the PSQ pertained only to the Advanced Procedures condition. The participants indicated the extent to which they agreed with statements about self-spacing and grouping on a scale of 1 (*not at all*) to 10 (*a great deal*). We used paired-samples *t*-tests to compare responses between the Baseline and FEWS systems for these items.

[11] We excluded one participant from this analysis because he had a large number of missing data points.

We did not find a significant difference in participants' ratings on the extent to which they reported they could clearly determine which aircraft were eligible to self space between the FEWS system (*M* = 8.18*, SD* = 1.08) and the Baseline system (*M* = 7.00*, SD* = 1.41). We were not surprised by this result because in our simulation all of the aircraft in the Advanced Procedures conditions were able to self-space.

The participants' ratings indicated that they could better determine that aircraft were conducting the self-spacing procedure when they used the FEWS system (*M* = 9.45, *SD* = 0.69) than when they used the Baseline system (*M* = 8.00, *SD* = 1.34), $t(10) = 3.73$, $p = .004$, $\eta^2 = 0.58$. We interpreted this finding to suggest that the self-spacing designation implemented on the FEWS display (i.e., lines between self-spacing aircraft) was more effective than the designation in the Baseline system (i.e., text in the fourth line of the data block).

We did not find a significant difference between the FEWS system (*M* = 8.55*, SD* = 2.30) and the Baseline system (*M* = 7.18*, SD* = 2.32) in the participants' ratings of their ability to clearly determine which aircraft were flying as part of a group. We found this result surprising because of the positive effect we found for the FEWS system in depicting aircraft self-spacing. We expected a similar participant response for grouping because the FEWS designation was similar for both concepts. However, the variability of the responses on this item may indicate that the participants did not find the FEWS designation helpful in depicting grouping because it was too similar to the self-spacing indicator (connecting lines) and was therefore confusing. Alternatively, this result could be reflective of the participants' generally negative reaction towards the grouping concept overall.

We also did not find a significant difference between the FEWS system (*M* = 5.70*, SD* = 1.95) and the Baseline system (*M* = 4.20*, SD* = 1.99) in the participants' ratings of their ability to clearly determine which aircraft were unable to continue flying as part of a group. The ratings on this measure were also lower than the ratings made for the other self-spacing and grouping items. The FEWS system removed the reduced data block and redisplayed an FDB when an aircraft either went out of conformance or was removed from the group. The Baseline system did not display a notification that an aircraft was not able to conform or remain in the group; instead, the participant was responsible for removing the indication from the fourth line of the data block, if that occurred. This result indicates that the FEWS system depiction was not as salient, as we had expected, in depicting aircraft status.

4.12.3 Exit Questionnaire

We evaluated the Exit Questionnaire items to allow the participants the opportunity to compare the two systems in their support of control tasks and the use of the RNAV, self-spacing, and grouping concepts. We found a generalized preference for the FEWS system over the Baseline system (see Table 8). The participants did not rate any of the items on the questionnaire higher than 3, indicating that no one found the Baseline system *somewhat better* or *much better than* FEWS for supporting any of the tasks. This result indicates that each of the participants found that the FEWS interface provided at least the same level of support as the Baseline system for all tasks, but more often, that FEWS provided better support.

Table 8. Exit Questionnaire Ratings

Much better with FEWS	Somewhat better with FEWS	No difference between FEWS and Baseline	Somewhat better with Baseline	Much better with Baseline
①	②	③	④	⑤

Exit Questionnaire Item	Mean (SD)
1. Managing traffic efficiently.	1.27 (0.47)
2. Locating information on the display.	1.82 (0.75)
3. Avoiding potential conflicts.	1.91 (0.54)
4. Resolving conflicts.	1.73 (0.79)
5. Maintaining situation awareness.	1.55 (0.52)
6. Scanning traffic effectively.	1.45 (0.69)
7. Providing timely control instructions.	2.00 (0.63)
8. Maintaining a manageable workload level.	1.18 (0.40)
9. Accomplishing all ATC tasks.	1.36 (0.50)
Using RNAV Procedures	
10. Identifying RNAV-capable aircraft.	2.36 (0.67)
11. Putting aircraft on an RNAV.	2.40 (0.52)
12. Identifying that an aircraft is conforming to an RNAV route that requires only lateral conformance.	2.20 (0.79)
13. Identifying that an aircraft has deviated off an RNAV route that requires only lateral conformance.	2.36 (0.67)
14. Identifying that an aircraft is conforming to an RNAV route that requires both lateral and vertical conformance.	2.30 (0.67)
15. Identifying that an aircraft has deviated off an RNAV route that requires both lateral and vertical conformance.	2.60 (0.70)
Using Aircraft Self-Spacing Procedures	
16. Identifying aircraft capable of self-spacing.	2.00 (0.77)
17. Initiating the self-spacing procedure.	1.36 (0.67)
18. Identifying aircraft conducting the self-spacing procedure.	1.73 (0.79)
19. Managing aircraft conducting the self-spacing procedure.	1.64 (0.69)
20. Identifying that an aircraft is out of conformance when self-spacing.	2.27 (0.65)
21. Canceling the self-spacing procedure.	1.45 (0.82)
Using Aircraft Grouping Procedures	
22. Identifying aircraft capable of conducting the grouping procedure.	2.27 (0.79)
23. Initiating the aircraft grouping procedure.	2.27 (0.65)
24. Identifying aircraft conducting the grouping procedure.	1.73 (0.79)
25. Managing aircraft conducting the grouping procedure.	2.00 (0.77)
26. Identifying that an aircraft is out of conformance when using the grouping procedure.	2.36 (0.50)
27. Removing an aircraft from a group.	2.27 (0.79)
28. Canceling the grouping procedure.	2.18 (0.87)

The participants' ratings indicated that the FEWS system supported essential air traffic control tasks, such as managing traffic and avoiding potential conflicts, somewhat better to much better than the Baseline system. Similarly, the ratings for the items pertaining to aircraft self-spacing indicated that the participants found the FEWS system more supportive than the Baseline system. The participants responded that the FEWS system better enabled them to initiate, manage, and cancel self-spacing as well as to identify which aircraft were conducting the procedure. Their ratings also indicated that FEWS provided somewhat better support for identifying which aircraft were capable of self-spacing and which aircraft were out of conformance with the procedure.

The participants also rated that the FEWS system provided somewhat better support for the use of the RNAV and grouping procedures than the Baseline system. The mean rating for almost all of these items was between 2 and 3. However, the participants' ratings were slightly higher for the FEWS system in supporting the identification of aircraft conducting the grouping procedure.

Although the system comparison ratings favored the FEWS system, overall, we expected to find the ratings for the RNAV and aircraft grouping procedures to be as high as the ratings we found for the general air traffic and self-spacing tasks. We believe that the somewhat lower ratings we found for support of the RNAV and grouping procedures resulted because of the participants' negative reaction to the grouping procedure in general, as well as to their somewhat negative reaction to the use of the FEWS RNAV data blocks. We discuss the participant reactions to the procedures in more detail; see our summary of questionnaire and debrief comments in section 4.12.4).

We also examined the participants' ratings (see Table 9) for simulation realism on a scale of 1 (*not at all realistic*) to 10 (*extremely realistic*), for the extent to which the research apparatus affected performance on a scale of 1 (*not at all*) to 10 (*a great deal*), and the effectiveness of training on a scale from 1 (*not at all*) to 10 (*a great deal*). The participants rated all aspects of simulation realism relatively high. The lowest realism rating occurred for the traffic scenarios. We were not surprised by this result because of the high level of traffic in the test scenarios. This level of traffic would not be reflective of the traffic volume that the participants would experience in their normal operating environment. The participants reported that the WAK did not interfere much with their performance. However, they rated the interference of the oculometer somewhat higher. We were not surprised by this result because we received feedback from some of the participants during the test scenarios that the device produced some physical discomfort. Finally, the questions regarding training effectiveness indicated that the training provided for each system was effective.

Table 9. Simulation Realism and Research Apparatus Ratings

Exit Questionnaire Item	Mean (SD)
29. Rate the realism of the generic airspace compared to actual ATC operations.	6.27 (2.20)
30. Rate the realism of the simulation hardware compared to actual equipment.	8.45 (1.44)
31. Rate the realism of the simulation software compared to actual equipment.	7.91 (0.94)
32. Rate the realism of the simulation traffic scenarios compared to actual NAS traffic.	5.73 (2.00)
33. To what extent did the WAK interfere with your ATC performance?	2.45 (1.21)
34. To what extent did the oculometer interfere with your ATC performance?	4.70 (2.79)
35. How effective was the ERAM training provided?	8.18 (0.87)
36. How effective was the FEWS training provided?	8.45 (1.04)

4.12.4 Questionnaire and Debrief Comments

The participants provided responses to open-ended items on the questionnaires and discussed their reactions to the systems, test conditions, and other aspects of the simulation during the debrief session at the conclusion of the study. We asked the participants to comment on the easiest and most difficult aspects of the scenarios as well as the positive and negative aspects of the systems and the display features. We included all of the participants' comments made on the PSQ in Appendix H and on the Exit Questionnaire in Appendix I.

4.12.4.1 Easiest Aspects of Scenarios

Overall, the participants reported that Data Comm, macros, Full RNAVs, and the self-spacing procedure were the easiest or most useful aspects of the scenarios regardless of which system they used. However, although the participants found that Data Comm was very useful, the comments also indicated that they found the transmission delays to be problematic. We implemented the delays anticipated by Data Comm Release 2 that included an average system transmission delay of 2.7 s and an additional average pilot-response delay of 10 s. The actual delay time for a single transmission varied around these averages as a function of a normal distribution, so some single transmissions would have been quite long. Because of the volume of traffic in the scenarios, we did not find the negative reaction to these delay times surprising.

Although the participants commented on the general usefulness of the macros, they reported using macros more frequently with the Baseline system. We were not surprised by this reaction because the participants had the opportunity to interact with the FEWS system directly through the display and could perform actions quickly without the need for macros. Some of the participants commented that it would be useful to include macros on function keys, so that they can be used more readily by those who typically prefer to use the keyboard (instead of the display) to access features.

Although the participants commented positively about self-spacing, they did so more when they used the FEWS system. Additionally, most of the participants reported that they did not want to have altitudes linked with the procedure. For example, they did not find it useful to have a trail aircraft descend at the same point at which a lead aircraft descended. Upon further discussions in the debriefing session, a few participants indicated that they thought it would be useful to have the altitude component available as an option, though not as a default.

4.12.4.2 Hardest Aspects of Scenarios

The participants reported that display clutter, grouping, and the need to "double-drop" data blocks (because of the additional data blocks provided) were the hardest or least useful aspects of the scenarios regardless of which system they used. They also reported that it was difficult to manage a mixture of voice and Data Comm-equipped aircraft in the scenarios. We were not surprised that the participants found clutter to be a problem given the number of aircraft in the scenarios. Finally, the participants reacted negatively to the conflict probe that was not functioning consistently in the FEWS system during the simulation and, therefore, made it unreliable.

4.12.4.3 Positive System Features

The participants' comments expanded on their ratings and indicated more positive aspects of the FEWS system than the Baseline system. The participants reported that the use of a mouse, the ability to drag-and-drop datablocks, and the ability to reroute aircraft via the display (by selecting and dragging a route) as the most beneficial features of the FEWS system and the features they would most like to begin using in the current operational environment. In particular, the participants found that the mouse allowed them to move to and select display elements more quickly than the trackball allowed. The mouse enabled them to move the data blocks quickly, which was essential due to the high volume of traffic in the scenarios. Additionally, the participants found it very useful for the FEWS system to automatically hand off aircraft and have data blocks automatically drop off when aircraft exited the sector. Due to the volume of traffic in the airspace, this feature allowed the participants to reduce their efforts on these tasks.

The participants also found that the FEWS system provided more useful display designations than the Baseline system. We found that the participants made more positive comments about the FEWS system designation that a voice-only aircraft needed the frequency shipped than the Baseline system. FEWS highlighted the frequency field The Baseline system displayed an "H" to indicate a held transfer of communication. Overall, the participants found it somewhat difficult to differentiate a Data Comm-equipped aircraft from one that was not equipped. However, the comments indicated that the FEWS indicator was more effective than the Baseline system indicator. In FEWS, the Data Comm symbol always appeared to the left of the call sign. It appeared as a triangle when the aircraft was off the frequency and as a square when it was on the frequency. In the Baseline system, the symbol appeared to the left of the call sign before the aircraft was on the frequency and moved to the right of the call sign when the aircraft was on the frequency.

Finally for FEWS, the participants generally commented positively on the use of the full radar capabilities on the D-side and on the use of color on the displays in FEWS. However, these features also generated some negative responses as we describe in the following section.

For the Baseline system, the participants commented very positively on the use of the flyout windows used to change altitudes, headings, and speeds. The participants generally preferred the flyout windows to the FEWS scroll function. The flyout windows are currently in use in the field, so the participants are familiar with them. In addition, the participants experienced some difficulty with the scroll function. For example, when they selected a field (e.g., altitude) and used the mouse wheel to scroll to another option, the participants often found it difficult to select the desired option without error. They appreciated that FEWS was attempting to minimize the display space required to access these data. However, given the problems the participants had with accurately selecting the desired option, they did not find the current FEWS implementation to be effective.

4.12.4.4 Negative System Features

For FEWS, the participants reported that they did not find the third tier data blocks useful. We were not surprised by this because the participants in the previous FEWS simulations did not use the third tier much; they had the ability to access the desired information elsewhere. The participants in the current simulation also commented negatively on some aspects of the FEWS D-side implementation. Although they generally responded favorably to the advanced assistance that the FEWS D-side configuration enabled, they also expressed concerns about how the D-side controller would be trained for this position in the operational environment and about how the roles and responsibilities of the R- and the D-sides would be defined.

The participants commented negatively on the green highlighting of an R-side data block when the D-side interacted with an aircraft. They reported that this feature was too obtrusive and distracting. The participants also reacted somewhat negatively to the use of some of the other colors used in FEWS, specifically the green connecting lines designating the self-spacing and grouped aircraft. Although the participants generally found the FEWS indicators to be more salient than the Baseline indicators, they also reported some aspects of the FEWS implementation to be distracting.

Finally, most of the participants reacted negatively to not having the dwell function to highlight aircraft in FEWS. The Baseline system maintained this feature. Many of the participants commented that they use the dwell feature regularly in the field. The FEWS system, instead, provided the emphasis feature to highlight a shared characteristic (e.g., altitude) or datablocks of aircraft in blue. Although the participants found the emphasis feature useful, they wanted the dwell feature to be retained as well.

4.12.4.5 Positive and Negative Aspects of Concept Implementation

The participants commented on the positive and negative aspects of the use and depiction of the RNAV, self-spacing, and grouping concepts in the Baseline and FEWS systems. In FEWS, the participants reacted negatively to the RNAV data blocks and commented that these data blocks made the aircraft too easy to ignore. Although this was our intent, the participants reported feeling uneasy about not having all of the information immediately available to them that they typically have for aircraft under their control. The participants also reacted negatively because they were unable to drag and drop the RNAV data blocks as they could the FDBs in the FEWS conditions. This was an oversight in our concept implementation, and it required that the participants bring up the FDB before they could reposition it. This increased participant taskload when the RNAV data blocks overlapped and also contributed to display clutter. The participants did comment that the use of the double down arrow displayed to the left of the altitude in the RNAV data block was a helpful indicator for depicting that an aircraft was on the RNAV arrival.

For the Baseline system, the participants reacted negatively to the “00” indicator that was used in the data blocks of aircraft descending on the Full RNAV arrivals. The participants found this designation confusing. Although they reported that it helped them identify that the aircraft was on the arrival, it did not represent what the aircraft was actually doing while in their sector.

The participants commented that it was easier to implement the self-spacing procedure and to determine that aircraft were conducting the procedure using the FEWS system. They also reported that it was too easy to cancel the procedure unintentionally. This was more of a problem in the Baseline system. If the participants canceled the procedure inadvertently when using the Baseline system, the fourth line indicator (e.g., SS_143) remained, suggesting that the aircraft was still following a lead. When a participant canceled the procedure either intentionally or unintentionally using the FEWS system, the system automatically removed the lines connecting the aircraft, alerting the participant that the aircraft was no longer self-spacing from a lead.

The participants commented negatively about grouping, regardless of the system. They reported that they did not see a benefit of the concept, that the procedure was not useful or safe, that it increased workload and display clutter, and that it was too time-consuming to initiate. The only positive comments indicated that the procedure could potentially be used with much lower traffic levels and to move a few aircraft around weather. In this simulation, the comments indicated that the participants typically moved other aircraft around a group, rather than to move the group.

5. SUMMARY AND CONCLUSIONS

We conducted this simulation to provide an initial assessment of the feasibility and benefits of three concepts that are designed to increase airspace capacity to meet NextGen goals. We evaluated an emerging concept, the increased use of RNAVs, and two advanced concepts: (a) the delegation of self-spacing responsibility to the flight deck and (b) a grouping procedure that enabled the controller to manage two or more aircraft as a single unit, similar to the way military aircraft are managed in formation flight. We evaluated these concepts under very high traffic level (two to three times the current level) scenarios using a Baseline system and the enhanced FEWS system that provided additional controller workstation features and functions. We used 3 nm (5.56 km) separation standards in all of the scenarios and equipped 70% of the aircraft with Data Comm.

We found that the FEWS system provided more benefits than the Baseline system. The participants managed more aircraft, held or redirected traffic outside of their sector less, and reported lower workload ratings and higher subjective performance ratings. The participants also reported that FEWS provided better task support and better display designations.

We found that the use of Full RNAVs resulted in greater system and performance benefits than the use of Limited RNAVs. The participants managed more aircraft, and the aircraft spent more time and flew a greater distance in the sector in the Full RNAV conditions than in the Limited RNAV condition. In the Limited RNAV condition, the participants handed off the aircraft earlier, presumably to reduce workload. The participants made fewer voice communications in the Full RNAV conditions because they did not need to issue descent clearances to the arrival aircraft.

Workload ratings indicated that early in the scenario, when traffic levels were relatively low, the participants found it easier to work with Full RNAVs and the Advanced Procedures than with Limited RNAVs. However, later in the scenario, when traffic volume increased and weather affected the sector, the participants reported higher workload when they worked with the Advanced Procedures. However, these are the circumstances in which some would expect the delegated procedures to be most useful because the procedures are assumed to allow the controller to focus attention on the aircraft that require conventional control. It is possible that if controllers had more experience with the procedures, they may be able to manage them more efficiently in high task-demand situations, but additional research would need to address this.

We did not find strong benefits for the Advanced Procedures. However, when we evaluated the data for only the participants who did not hold or redirect traffic, we found that this group managed more traffic when self-spacing and grouping were in use. This suggests that the Advanced Procedures may provide some benefit to controllers who are able to manage high density traffic.

The participants did not initiate many self-spacing or grouping procedures, particularly when using the Baseline system. With the Baseline system, the participants had to enter information in the fourth line of the data block to indicate that a procedure was in effect. This increased the likelihood that the information could erroneously indicate that a procedure was in effect when it was not. We observed instances of this in the simulation. We also observed three losses of separation involving aircraft conducting the procedures in the Baseline system, suggesting that the procedures may be risky if not effectively supported. We strongly recommend that the system, not the controller, provide the notification that an aircraft is conducting a procedure. We incorporated this philosophy into FEWS, and the participants reported that the FEWS indicators helped them better determine which aircraft were self-spacing.

Although the participants did not initiate self-spacing often, they reported that the procedure was useful. However, they did not want altitudes to be part of the procedure unless it was allowed as an option. In contrast to self-spacing, the participants reacted negatively to the grouping procedure. They reported many concerns and expressed difficulty working with this procedure. We observed that on the few occasions when the participants interacted with groups, it was typically to remove aircraft from a group. The participants reported that they believed the procedure was unsafe.

Display clutter remained a problem regardless of which system the participants used because of the very high traffic levels in our scenarios. In FEWS, we tried to reduce clutter by presenting RNAV data blocks for aircraft that were complying with Full RNAVs. We expected that this indication would suppress the salience of the RNAV data blocks by conveying to the participant that the aircraft did not require as much attention as others. We did not find support for this in the eye movement data. The participants fixated equally often on the arrival aircraft whether the aircraft displayed RNAV data blocks or FDBs. The participants reported that the RNAV data blocks appeared too much like data blocks of aircraft for which they did not have responsibility. They reported that this was disconcerting because they still had to manage these aircraft even though they needed to interact with them less. The utility of the RNAV data blocks was also degraded in our implementation because the participants could not separate them from one another by selecting and dragging them with the mouse as they could the FDBs.

Overall, our findings indicate that many of the FEWS display enhancements have the potential to increase system efficiency and productivity and to reduce controller workload. They also show that the use of Full RNAVs improves airspace efficiency and can reduce workload. The self-spacing procedure also appears promising, with appropriate system support, but the grouping procedure does not. Future research must evaluate the RNAV and self-spacing procedures in other conditions to more fully investigate their feasibility and benefits. The research must include a full evaluation of the use of these procedures in degraded conditions, such as equipment outages, to determine how effectively the system and controller can manage under these circumstances.

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Acronyms

ADS-B	Automatic Dependent Surveillance - Broadcast
ANOVA	Analysis of Variance
APWx	Advanced Procedures, Weather
CDTI	Cockpit Display of Traffic Information
CID	Computer Identification
CPC	Certified Professional Controller
CPDLC	Controller-Pilot Data-link Communications
CRD	Computer Readout Display
CTAS	Center TRACON Automation System
Data Comm	Data Communications
DC	Display Control
DESIREE	Distributed Environment for Simulation, Rapid Engineering, and Experimentation
D-side	Data-side
DSR	Display System Replacement
ERAM	En Route Automation Modernization
FAA	Federal Aviation Administration
FDB	Full Data Block
FEWS	Future En Route Workstation Study
FLID	Flight Identifier
FMS	Flight Management System
FnoWx	Full RNAV, no Weather
FWx	Full RNAV, Weather
GEN	GENERA
HITL	Human-in-the-Loop
HSD	Honestly Significant Difference
JPDO	Joint Planning and Development Office
LDB	Limited Data Block
LnoWx	Limited RNAV, no Weather
LOA	Letter of Agreement
LOS	Loss of Separation
MAP	Monitor Alert Parameter

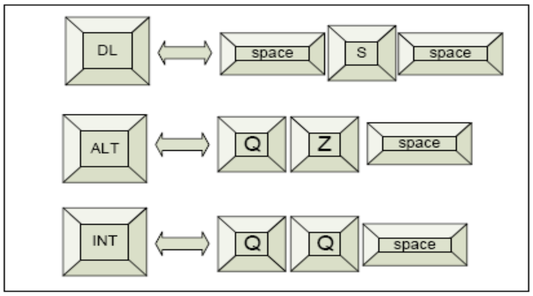
N/A	Not Applicable
NAS	National Airspace System
NextGen	Next Generation Air Transportation System
ORF	Observer Rating Form
PBN	Performance-Based Navigation
POG	Point of Gaze
PSQ	Post-Scenario Questionnaire
PTT	Push-to-Talk
RDB	Range Data Block
RDHFL	Research Development and Human Factors Laboratory
RNAV	Area Navigation
RNP	Required Navigation Performance
R-side	Radar-side
SA	Situation Awareness
SAVANT	Situation Awareness Verification and Analysis Tool
SME	Subject Matter Expert
SOP	Standard Operating Procedure
TBO	Trajectory-Based Operations
TGF	Target Generation Facility
TMA	Traffic Management Advisor
TMU	Traffic Management Unit
TRACON	Terminal Radar Approach Control
URET	User Request Evaluation Tool
VSCS	Voice Switching and Control System
WAK	Workload Assessment Keypad
WJHTC	William J. Hughes Technical Center
Wx	Weather

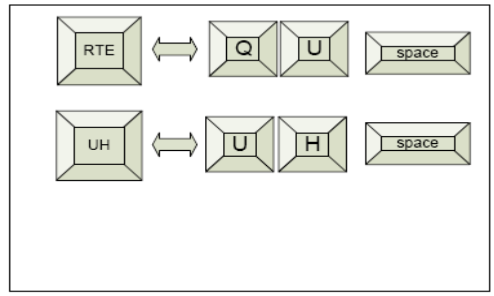
Appendix A

Basic and Advanced Procedures for the Baseline and FEWS Systems

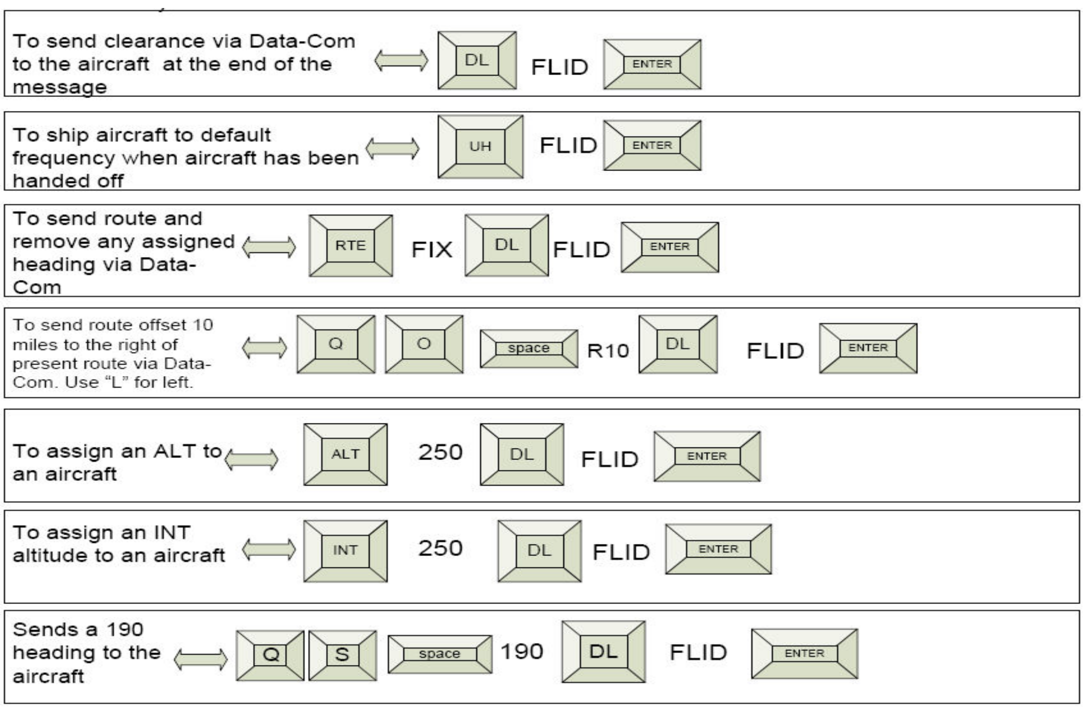
Basic Procedures: Baseline System

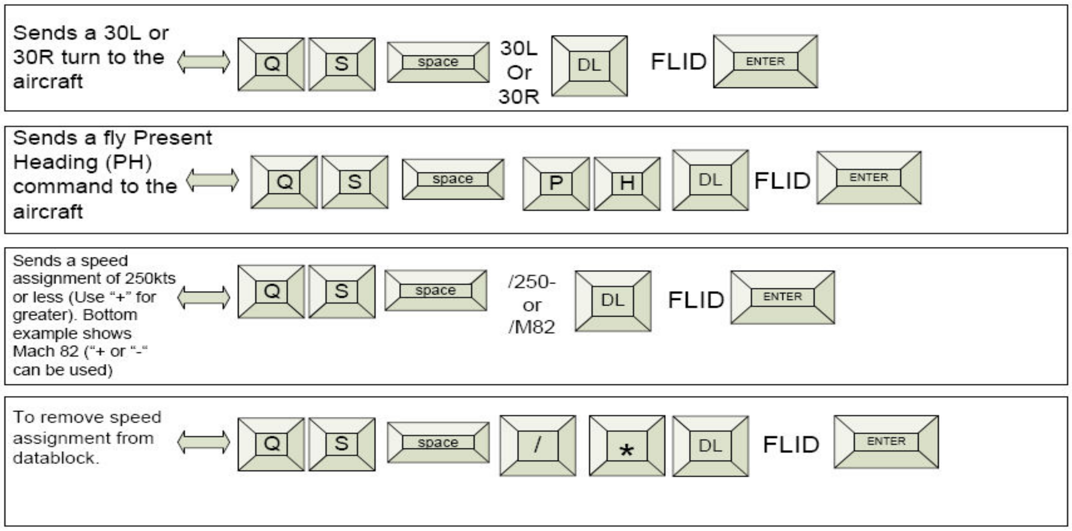
Below, shortcut keys are displayed alongside their keyboard entry equivalents for some of the basic procedures in the Baseline system: Data Comm (DL), altitude (ALT), interim altitude (INT), route (RTE), and “unhold” (UH) transfer of communication.





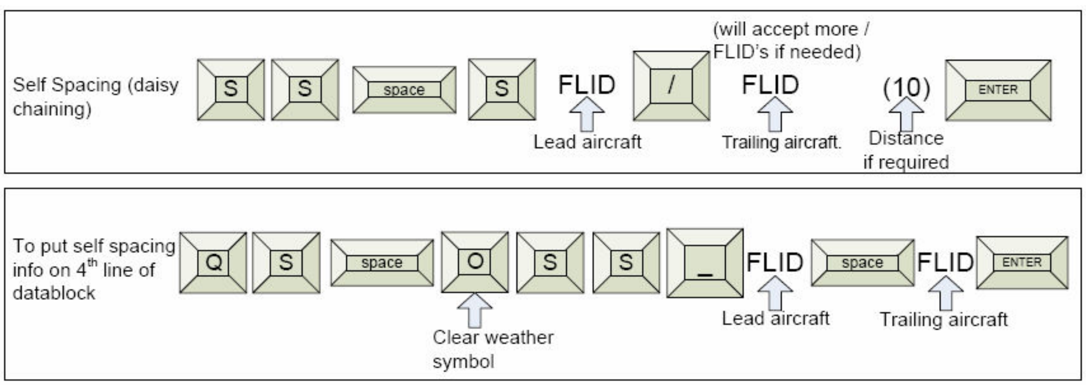
Depicted below are the keyboard entries used to initiate some of the basic procedures in the Baseline system. The Baseline system accepted only keyboard entries for the commands. Note that the Data Comm entry (if applicable) is entered prior to the flight identifier (FLID).



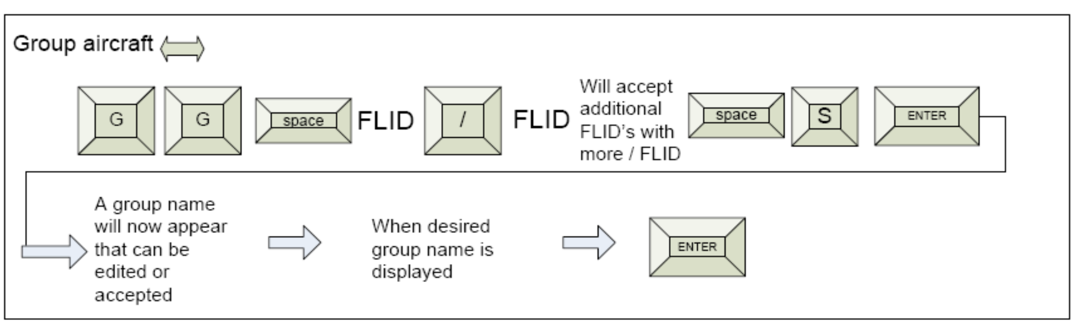


Self-Spacing Procedure: Baseline System

Depicted below are the keyboard entries used to initiate the self-spacing and grouping procedures in the Baseline system and the entries used to indicate that the procedures have been activated. The Baseline system accepted only keyboard entries for these commands.

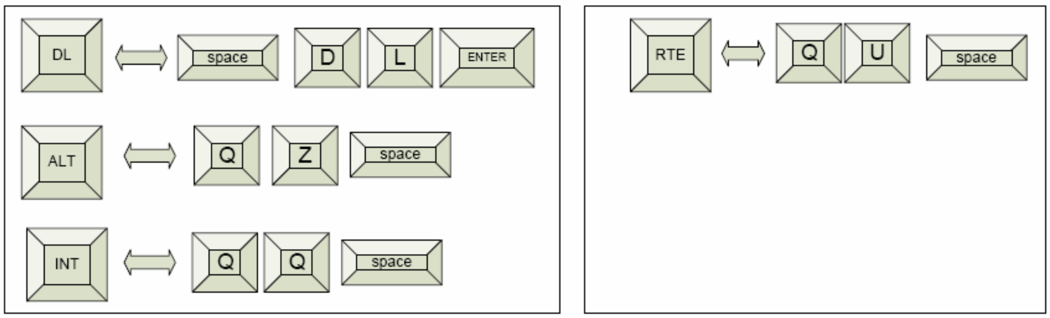


Grouping Procedures: Baseline System

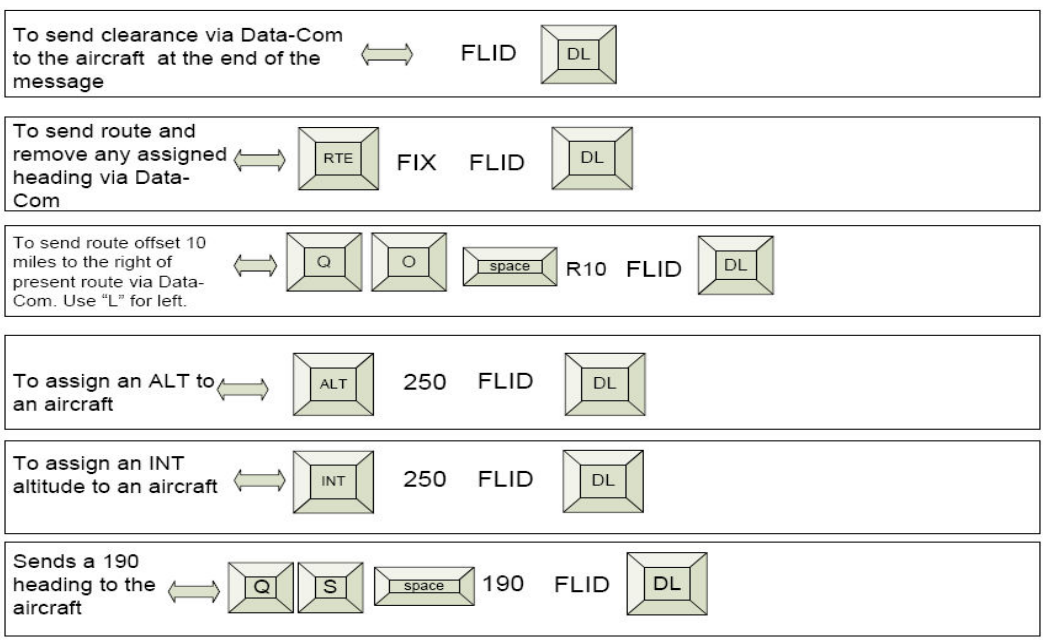


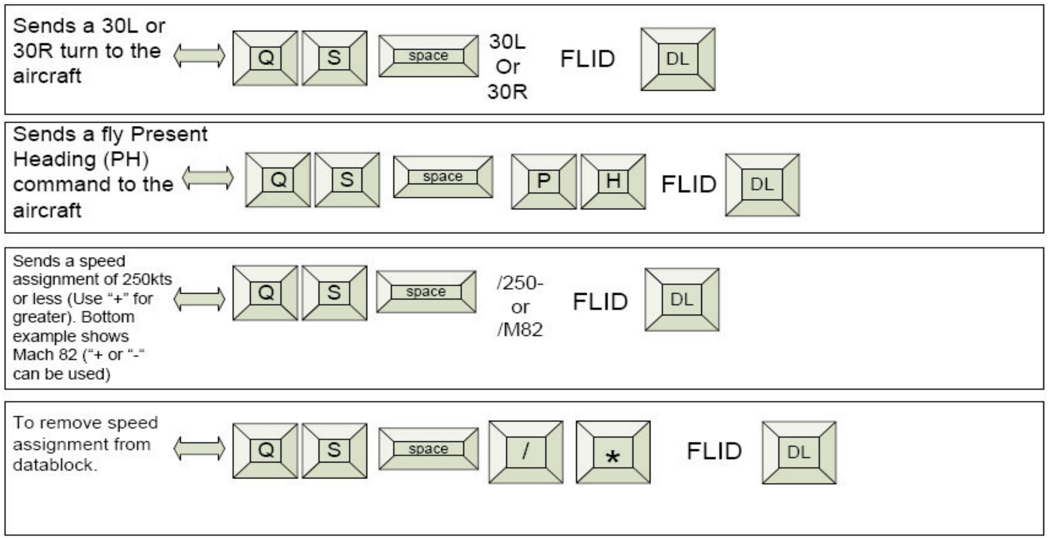
Basic Procedures: FEWS System

Below, shortcut keys are displayed alongside their keyboard entry equivalents for some of the basic procedures in the FEWS system: Data Comm (DL), altitude (ALT), interim altitude (INT), and route (RTE). In FEWS, these commands could also be entered via the display.



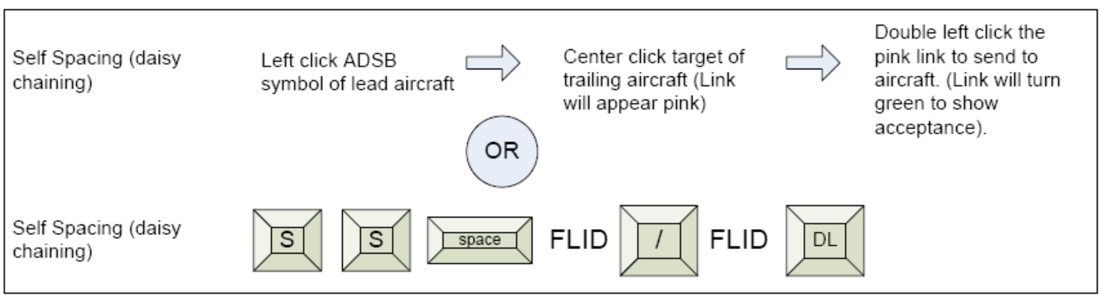
Depicted below are the keyboard entries used to initiate some of the basic procedures in the FEWS system. The FEWS system also allowed the participants to enter these commands via the display (not depicted). Unlike the Baseline system, the FEWS Data Comm entry (if applicable) is entered at the end of the command string.





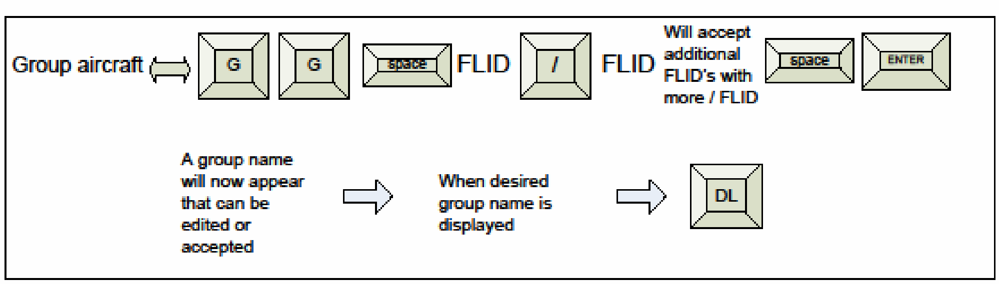
Self-Spacing Procedures: FEWS System

Depicted below are the keyboard and display entry methods used to initiate the self-spacing procedure in the FEWS system. The system automatically displayed indicators when the procedure was activated. No additional participant entries were required.



Grouping Procedures: FEWS System

Depicted below is the keyboard entry method used to initiate the grouping procedure in the FEWS system. Due to command complexity, no display method of activation was available. The command sequence is the same as that available in the Baseline system, except that the Data Comm entry is made at the end of the command string. Also, unlike the Baseline system, the FEWS system automatically displayed indicators when the procedure was activated. No additional participant entries were required.



Appendix B

Informed Consent Form

Informed Consent Form

I, ______________________________, understand that this simulation, entitled "Future En Route Workstation - III" is sponsored by the Federal Aviation Administration (FAA) and is being directed by Dr. Carolina Zingale.

Nature and Purpose:
I have been recruited to volunteer as a participant in this simulation. The purpose of the simulation is to evaluate emerging air traffic concepts that are designed to increase airspace capacity, including the increased use of Area Navigation routes and the delegation of some procedures (self-spacing) to the pilot. The simulation also includes an aircraft grouping concept that enables the controller to manage two or more aircraft as a single unit. The simulation will evaluate these concepts in high traffic scenarios under optimal and suboptimal (e.g., weather) conditions using a simulated En Route Automation Modernization (ERAM) system and the Future En Route Workstation (FEWS). FEWS includes additional interface elements beyond those proposed for ERAM that are designed to support the use of these concepts. The results of the study will be used to determine the benefits and feasibility of implementing these procedures and interface components.

Experimental Procedures:
Twelve en route Certified Professional Controllers from Level 11 and 12 facilities will participate for 8 days over a 2-week period. Two participants will work simultaneously but independently during the two weeks. Each participant will work as an R-side controller to manage complex training and test scenarios using each system. The participants will work from about 8:30 a.m. to about 5:00 p.m. every day, with a lunch break and at least two rest breaks. The first morning will consist of an in-briefing to review project objectives and participant rights and responsibilities, and will include initial familiarization training on the airspace, systems, and procedures. The participants will then begin training on the first of the two systems. They will complete a minimum of 5 hours of training each day on scenarios that are up to 60-minutes long. After training is completed on one system, the participants will complete four 60-minute test scenarios using that system. The order of the systems and the test scenarios will be counterbalanced. A daily caucus will be scheduled at the end of each day. On the final day, the participants will gather for a final debriefing session to provide feedback on the systems and procedures. During the last two training scenarios and all of the test scenarios, the participants will wear a head-mounted oculometer to record eye movement data. They will also respond to workload and situation awareness prompts at designated intervals throughout each scenario. In addition, the Subject Matter Experts will serve as D-side controllers and record observations about each scenario. An automated data collection system will record system operations and generate a set of standard Air Traffic Control (ATC) simulation measures, including safety, capacity, efficiency, and communications. After each scenario, the participants will complete questionnaires to report their overall workload, situation awareness, and performance and to provide an assessment of the system and test condition. The simulation will be audio and video recorded.

Anonymity and Confidentiality:
My participation is strictly confidential. Any information I provide will remain anonymous: no individual names or identities will be associated with the data or released in any reports.

Benefits:
I understand that the only benefit to me is that I will be able to provide the researchers with valuable feedback and insight into the effects of emerging ATC concepts and alternative workstation interface designs for use in en route airspace. My data will help the FAA to establish the benefits and feasibility of these procedures within this environment.

Participant Responsibilities:
I am aware that to participate in this study I must be a certified professional controller who is qualified at my facility and holds a current medical certificate. I must also have normal or corrected-to-normal (20/20) vision and do not wear bifocals, trifocals, or hard-contact lenses that are incompatible with the eye-tracking device used in this simulation. I will control traffic and answer questions asked during the study to the best of my abilities. I will not discuss the content of the experiment with anyone until the study is completed.

Participant Assurances:
I understand that my participation in this study is completely voluntary and I can withdraw at any time without penalty. I also understand that the researchers in this study may terminate my participation if they believe this to be in my best interest. I understand that if new findings develop during the course of this research that may relate to my decision to continue participation, I will be informed. I have not given up any of my legal rights or released any individual or institution from liability for negligence.

The research team has adequately answered all the questions I have asked about this study, my participation, and the procedures involved. I understand that Dr. Zingale or another member of the research team will be available to answer any questions concerning procedures throughout this study. If I have questions about this study or need to report any adverse effects from the research procedures, I will contact Dr. Zingale at (609) 485-8629.

Discomfort and Risks:
I understand that I will not be exposed to any foreseeable risks or intrusive measurement techniques. I agree to immediately report any injury or suspected adverse effect to Dr. Carolina Zingale at (609) 485-8629. Local clinics and hospitals will provide any treatment, if necessary. I agree to provide, if requested, copies of all insurance and medical records arising from any such care for injuries/medical problems.

Signature Lines:
I have read this informed consent form. I understand its contents, and I freely consent to participate in this study under the conditions described. I understand that, if I want to, I may have a copy of this form.

Research Participant:____ Date:__________

Investigator:____ Date:__________

Witness:____ Date:__________

Appendix C

Biographical Questionnaire

Biographical Questionnaire

Instructions:
This questionnaire is designed to obtain information about your background and experience as a certified professional controller (CPC). Researchers will only use this information to describe the participants in this study as a group. Your identity will remain anonymous.

Demographic Information and Experience

1. What is your gender?	○ Male	○ Female

2. What is your **age**?	_____ years

3. How long have you worked as **an Air Traffic Controller (include both FAA and military experience)**?	_____ years _____ months

4. How long have you worked as a **CPC for the FAA**?	_____ years _____ months

5. How long have you **actively controlled traffic** in the en route environment?	_____ years _____ months

6. How long have you **actively controlled traffic** in the terminal environment?	_____ years _____ months

7. How many of the **past 12 months** have you actively controlled traffic?	_____ months

8. Rate your current **skill as a CPC**.	Not Skilled	①②③④⑤⑥⑦⑧⑨⑩	Extremely Skilled

9. Rate your **level of motivation** to participate in this study.	Not Motivated	①②③④⑤⑥⑦⑧⑨⑩	Extremely Motivated

Appendix D

Post-Scenario Questionnaire

Post-Scenario Questionnaire

Instructions:
Answer the following questions based upon your experience in the scenario just completed.

Overall Performance, Workload, Situation Awareness, and Simulation Ratings

1. Rate the **overall difficulty** of this scenario.	Extremely Difficult	①②③④⑤⑥⑦⑧⑨⑩	Extremely Easy
2. Rate your **overall level of ATC performance**.	Poor	①②③④⑤⑥⑦⑧⑨⑩	Excellent
3. Rate your **overall workload**.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High
4. Rate your **workload due to communications** with pilots.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High
5. Rate your **overall level of situation awareness**.	Poor	①②③④⑤⑥⑦⑧⑨⑩	Excellent
6. Rate your **situation awareness for *current* aircraft locations**.	Poor	①②③④⑤⑥⑦⑧⑨⑩	Excellent
7. Rate your **situation awareness for *projected* aircraft locations.**	Poor	①②③④⑤⑥⑦⑧⑨⑩	Excellent
8. Rate your **situation awareness for potential aircraft loss-of-separation**.	Poor	①②③④⑤⑥⑦⑧⑨⑩	Excellent
9. Rate your **situation awareness for potential handoff/airspace violations**.	Poor	①②③④⑤⑥⑦⑧⑨⑩	Excellent
10. Rate the **performance of the simulation pilots** in terms of their responding to control instructions and providing callbacks.	Poor	①②③④⑤⑥⑦⑧⑨⑩	Excellent

11. What aspects of this scenario were easiest to work with? Why?

12. What aspects of this scenario were hardest to work with? Why?

13. Do you have any additional comments or clarifications about your experience in this scenario?

Interface Effectiveness

How useful was the system interface in supporting…

14. ...**safety**?	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal

15. …your **control efficiency**?	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal

16. …your **sector operations**?	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal

17. …your **control plan or strategy**?	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal

18. …your **ability to work with the procedures**?	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal

19. What display features (e.g., highlighting) were most positive? Why?

20. What display features (e.g., highlighting) were most negative? Why?

21. What system functions were most useful? Why?

22. What system functions were least useful? Why?

23. What additional features or functions would improve your use of the new procedures?

24. Do you have any comments or clarifications about the interface?

Interface Usability

Rate the *extent to which you agree* with each of the following:

25. This system was easy to use.	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
26. The displays were uncluttered.	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
27. I could find the information I needed quickly.	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
28. I was able to prioritize information easily.	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
29. Information was updated or changed on the display in a predictable manner.	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
30. The information was presented in an easy-to-understand format.	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
31. It took only a few simple steps to get the information I needed when it wasn't available directly on the display.	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
32. The coding of the information (e.g., colors) helped me locate what I needed quickly.	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
33. The text was easy to read.	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
34. The graphics were easy to interpret.	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
35. I was able to clearly determine which aircraft had been issued a clearance to join an RNAV route.	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
36. I was able to clearly determine which aircraft were flying an RNAV route.	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
37. I was able to clearly determine which aircraft were no longer conforming to an RNAV route.	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal

Complete the following questions ONLY for scenarios that used the self-spacing and aircraft grouping procedures.

Rate the *extent to which you agree* with each of the following:

38. I was able to clearly determine which aircraft were *eligible* to self-space.	Not At All	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩	A Great Deal
39. I was able to clearly determine which aircraft were conducting the self-spacing procedure.	Not At All	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩	A Great Deal
40. I was able to clearly determine which aircraft were flying as part of a group.	Not At All	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩	A Great Deal
41. I was able to clearly determine which aircraft were unable to continue flying as part of a group.	Not At All	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩	A Great Deal

Appendix E

Exit Questionnaire

Exit Questionnaire

Instructions:
Please respond to each of the following items based upon your overall experience in the simulation. For each statement, fill in one circle to indicate your response.

SYSTEM COMPARISON

	Much Better with FEWS	Somewhat Better with FEWS	No Difference Between FEWS and ERAM	Somewhat Better with ERAM	Much Better with ERAM
1. Managing traffic efficiently.	①	②	③	④	⑤
2. Locating information on the display.	①	②	③	④	⑤
3. Avoiding potential conflicts.	①	②	③	④	⑤
4. Resolving conflicts.	①	②	③	④	⑤
5. Maintaining situation awareness.	①	②	③	④	⑤
6. Scanning traffic effectively.	①	②	③	④	⑤
7. Providing timely control instructions.	①	②	③	④	⑤
8. Maintaining a manageable workload level.	①	②	③	④	⑤
9. Accomplishing all ATC tasks.	①	②	③	④	⑤
Using RNAV Procedures					
10. Identifying RNAV-capable aircraft.	①	②	③	④	⑤
11. Putting aircraft on an RNAV.	①	②	③	④	⑤
12. Identifying that an aircraft is conforming to an RNAV route that requires only lateral conformance.	①	②	③	④	⑤
13. Identifying that an aircraft has deviated off an RNAV route that requires only lateral conformance.	①	②	③	④	⑤
14. Identifying that an aircraft is conforming to an RNAV route that requires both lateral and vertical conformance.	①	②	③	④	⑤
15. Identifying that an aircraft has deviated off an RNAV route that requires both lateral and vertical conformance.	①	②	③	④	⑤

Using aircraft self-spacing procedures					
16. Identifying aircraft capable of self-spacing.	①	②	③	④	⑤
17. Initiating the self-spacing procedure.	①	②	③	④	⑤
18. Identifying aircraft conducting the self-spacing procedure.	①	②	③	④	⑤
19. Managing aircraft conducting the self-spacing procedure.	①	②	③	④	⑤
20. Identifying that an aircraft is out of conformance when self-spacing.	①	②	③	④	⑤
21. Canceling the self-spacing procedure.	①	②	③	④	⑤
Using aircraft grouping procedures					
22. Identifying aircraft capable of conducting the grouping procedure.	①	②	③	④	⑤
23. Initiating the aircraft grouping procedure.	①	②	③	④	⑤
24. Identifying aircraft conducting the grouping procedure.	①	②	③	④	⑤
25. Managing aircraft conducting the grouping procedure.	①	②	③	④	⑤
26. Identifying that an aircraft is out of conformance when using the grouping procedure.	①	②	③	④	⑤
27. Removing an aircraft from a group.	①	②	③	④	⑤
28. Canceling the grouping procedure.	①	②	③	④	⑤

SIMULATION REALISM AND RESEARCH APPARATUS RATINGS

29. Rate the **realism of the generic airspace** compared to actual ATC operations.	Not at all Realistic	①②③④⑤⑥⑦⑧⑨⑩	Extremely Realistic
30. Rate the **realism of the simulation hardware** compared to actual equipment.	Not at all Realistic	①②③④⑤⑥⑦⑧⑨⑩	Extremely Realistic
31. Rate the **realism of the simulation software** compared to actual equipment.	Not at all Realistic	①②③④⑤⑥⑦⑧⑨⑩	Extremely Realistic
32. Rate the **realism of the simulation traffic scenarios** compared to actual NAS traffic.	Not at all Realistic	①②③④⑤⑥⑦⑧⑨⑩	Extremely Realistic
33. To what extent did the **WAK online workload rating technique interfere** with your ATC performance?	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
34. To what extent did the **oculometer** interfere with your ATC performance?	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
35. How effective was the **ERAM training** provided?	Not At All Effective	①②③④⑤⑥⑦⑧⑨⑩	Extremely Effective
36. How effective was the **FEWS training** provided?	Not At All Effective	①②③④⑤⑥⑦⑧⑨⑩	Extremely Effective

Please include any additional comments about the simulation that you would like us to know about.

Appendix F

Observer Rating Form

Observer Rating Form

This form is designed to be used by Subject Matter Experts (SMEs) to evaluate the effectiveness of controllers working in simulations. You will observe and rate the controller's performance on several different performance dimensions using a rating scale of 1 to 8, with 1 indicating the *least effective performance* and 8 indicating the *most effective performance*. Most controller performance is at or above the minimum standards regarding safety and efficiency. The goal of the rating system is to differentiate performance above this minimum. The lowest rating should be assigned for meeting minimum standards and also for anything below the minimum which should be a rare event. It is important for the observer to be comfortable using the entire scale and to understand that all ratings should be based on behavior that is actually observed.

The rating scale is provided at the top of the Observer Rating Form (ORF), so you can refer to it as you make your ratings.

- Use the entire scale range, if warranted.

- Write down your observations.
- Space is provided on the second page of the ORF for comments. Wait until the scenario is finished before making your final ratings. Remain flexible until the end of the scenario so you have an opportunity to see all the available behavior.

- At all times, focus on what you actually see and hear.
- This includes what the controller does and what you might reasonably infer from the actions of the pilots. If you do not observe relevant behavior or the results of that behavior, you may leave a specific rating blank.

- Do not write your name on the form.
- Enter only the observer code assigned to you.

- The observations you make may include other areas that you think are important.

Rating Scale Descriptors

Least Effective	①②③④⑤⑥⑦⑧	Most Effective

I - MAINTAINING SAFE AND EFFICIENT TRAFFIC FLOW								
1. Maintaining Separation and Resolving Potential Conflicts................................ • using control instructions that maintain appropriate aircraft and airspace separation • detecting and resolving impending conflicts early • recognizing the need for speed restrictions and wake turbulence separation	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
2. Sequencing Aircraft Efficiently .... • using efficient and orderly spacing techniques for arrival, departure, and en route aircraft • maintaining safe arrival and departure intervals that minimize delays	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
3. Using Control Instructions Effectively/Efficiently .... • providing accurate navigational assistance to pilots • issuing economical clearances that result in need for few additional instructions to handle aircraft completely • ensuring clearances require minimum necessary flight path changes	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
4. Overall Safe and Efficient Traffic Flow Rating	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Complete the following questions ONLY for conditions using self-spacing and aircraft grouping procedures								
5. Using the self-spacing procedure effectively	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
• activating self-spacing appropriately between eligible aircraft								
• managing self-spacing aircraft efficiently								
• canceling self-spacing if appropriate								
6. Using the aircraft grouping procedure effectively...	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
• taking advantage of opportunities to implement the grouping procedure								
• adding or removing one or more aircraft from a group when appropriate								
• canceling the aircraft grouping procedure when appropriate								

Notes on Observations:

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Explanatory comments supporting the ratings:

Appendix G

Instructions for Participants

Instructions for Participants

General Training Scenario Instructions

During the training scenarios, you will have the opportunity to become familiar with your position and the features and functions of the system you will be working with. You will also have the opportunity to become familiar with the simulated VSCS, the oculometer, the Workload Assessment Keypads, and the SAVANT probe. The training scenarios are designed to help you prepare for the test scenarios that will follow, and we encourage you to ask questions as needed throughout training to make sure that you understand the use of all available capabilities. (We will then provide the relevant instructions for the training condition that will follow.)

Limited RNAV Test Conditions

During this scenario, you will be using the (ERAM or FEWS) system to manage a high volume of traffic through your airspace. Many of these aircraft will be on or able to fly RNAV routes that require lateral conformance. You must issue the appropriate altitude and speed commands or crossing restrictions as required. Three nautical mile lateral separation will be in effect throughout the sector. Although the traffic level will be higher than the levels you currently experience in the field, please control the traffic with separation of aircraft and safety as your primary concerns. As in every scenario, you will be making workload ratings using the WAK and responding to the SAVANT probe. I will now read the WAK and SAVANT instructions to you.

Full RNAV Test Conditions

During this scenario, you will be using the (ERAM or FEWS) system to manage a high volume of traffic through your airspace. Many of these aircraft will be on or able to fly RNAV routes that require lateral and vertical conformance. Three nm lateral separation will be in effect throughout the sector. Weather may also be a factor in the scenario. Although the traffic level will be higher than what you currently experience in the field, please control the traffic with separation of aircraft and safety as your primary concerns. As in every scenario, you will be making workload ratings using the WAK and responding to the SAVANT probe. I will now read the WAK and SAVANT instructions to you.

Advanced Procedure Conditions Instructions (Practice and Experiment)

During this scenario, you will be using the (ERAM or FEWS) system to manage a high volume of traffic through your airspace. Many of these aircraft will be on or able to fly RNAV routes that require lateral and vertical conformance. Three nm lateral separation will be in effect throughout the sector. Weather will also be a factor in the scenario. You will have two additional procedures available. One is the self-spacing procedure in which aircraft can be instructed to follow the aircraft immediately ahead of it. Several aircraft can be instructed to self-space so as to form a chain. The second procedure is the grouping procedure in which two or more aircraft can be controlled as a unit, similar to military aircraft in formation flight. The aircraft that are eligible to perform the grouping procedure will be indicated to you by one of the experimenters and you then have the option to use the procedure as the aircraft traverse your sector. Some aircraft will also enter your sector already flying in a chain or as a group. You have the option to continue to control the aircraft as a chain or group or to break a chain or disband the group and control the aircraft individually. Although the traffic level will be higher than what you currently experience in the field, please control the traffic with separation of aircraft and safety as your primary concerns. As in every scenario, you will be making workload ratings using the WAK and responding to the (SAVANT) probe. I will now read the WAK and SAVANT instructions to you.

WAK Instructions
(The full set of instructions will be read at the beginning of each test day). An abbreviated set of instructions will be read prior to each experimental run. The abbreviated instructions will omit the first paragraph below.)

One purpose of this research is to obtain an accurate evaluation of controller workload. By workload, we mean all the physical and mental effort that you must exert to do your job. This includes maintaining the "picture," planning, coordinating, decision making, communicating, and whatever else is required to maintain a safe and expeditious traffic flow. Workload is your perception of how hard you must work to perform all of the tasks necessary to meet these demands, not necessarily a measure of how much traffic you are working. Workload levels fluctuate. All controllers, no matter how proficient, will experience all levels of workload at one time or another. It does not detract from a controller's professionalism to indicate that he or she is working very hard at certain times or is hardly working at other times.

Every 2 minutes the WAK device located at your position will emit a brief tone and the 10 buttons will illuminate. The buttons will remain lit for 20 seconds. Please tell us what your workload is at that moment by pushing one of the buttons numbered from 1 to 10.

At the low end of the scale (1 or 2), your workload is low - you can accomplish everything easily. As the numbers increase, your workload is getting higher. The numbers 3, 4, and 5 represent increasing levels of moderate workload where the chance of making a mistake (e.g., leaving a task unfinished) is still low but steadily increasing. The numbers 6, 7, and 8 reflect relatively high workload where there is some chance of making a mistake. At the high end of the scale are the numbers 9 and 10, which represent a very high workload, where it is likely that you will have to leave some tasks unfinished. Feel free to use the entire rating scale and tell us honestly how hard you are working at the instant that you are prompted. Do not sacrifice the safe and expeditious flow of traffic to respond to the WAK device.

SAVANT Instructions
At intervals through the scenario, you will see a probe question appear in place of the radar display for 3 seconds. The probe question will ask you to make an evaluation about two aircraft, such as, *Which aircraft is at the higher altitude?* When the radar is redisplayed, two aircraft will be highlighted and the probed data (for example, the altitude fields) will be missing. You are to provide an answer by selecting one of the two aircraft at which time the highlighting will be removed and any missing data will be redisplayed. We encourage you to respond as accurately and as quickly as you can, but do not sacrifice the safe and expeditious flow of traffic to respond to the probe. If you need to return the display to the non-highlighted state and redisplay any data that have been removed, you may do so by clicking any area on the map.

Do you have any questions?

Appendix H

Post-Scenario Questionnaire Comments

Post-Scenario Questionnaire Comments

		Condition			
PSQ Question	System	LnoWx	FnoWx	FWx	APWx
11. What aspects of this scenario were easiest to work with? Why?	Baseline	• “The macros help a lot, saves typing.” • “No easy aspects, reduced freq congestion helps.” • “After a week knowing what altitudes are the ones to watch out for.” • “Descending limited RNAV a/c as soon as possible helped w/ data block congestion.” • “Descending a/c - got them out of sector quicker.” • “Macro buttons are a big help.” • “Acft in descent issued rather than descend via get down faster.” • “Datalink aircraft”	• “Datalink comm changes. This goes a long way to eliminating freq. congestion.” • “All full RNAV, no descent clearances.” • “Full RNAV acft require no descent clearances” • “RNAV procedures, less keyboard entries.” • “Full RNAV due low workload.” • “Relying on RNAV arrivals doing the right thing.” • “Datalink, reduces verbage.” • “Datalink aircraft”	• “Descending aircraft on RNAV arrivals; eliminates the need to issue the clearance.” • “Macros” • “RNAV procedures, less keystrokes.” • “RNAV procedures in effect, because I didn't have to make extra keyboard entries or give extra clearances.” • “Full RNAV due little work load.” • “Full RNAV a/c make workload easier.” • “Datalink, reduces workload.” • “Full R-NAV, reduced my having to descend.” • “Datalink”	• “Datalink x-fer of communications. This goes a long way to reducing freq congestion.” • “Less frequency congestion, less chance of hear/readback errors.” • “Automatic descents on RNAV routes” • “RNAV less keyboard entries.” • “Self-spacing, when you turn a/c for weather.” • “Daisy chain & datalink because take care of themselves with little time req.” • “Auto arrivals - not having to issue descent save much time.” • “Datalink, less comm.” • “Didn't need to descend any arrivals, only a few crossing airplanes.” • “Datalink- reduces verbiage.” • “Datalink aircraft because it is user friendly and allows for less work.”

Post-Scenario Questionnaire Comments					
		Condition			
PSQ Question	System	LnoWx	FnoWx	FWx	APWx
11. What aspects of this scenario were easiest to work with? Why?	FEWS	• “Datalink change to routes.” • “Initially FDB in RNAV a/c made it easier to move data. Drag/drop data, data comm, reroutes.” • “Mouse, quick entries, shortcut keys, datalink, cuts down on workload.” • “Like the use of mouse-quicker, easier to use.” • “Not having the RNAV data blocks. Limited and [illegible] can use vector lengths.” • “Data comm a/c easier to work with.” • “Macro buttons, reduces workload.” • “No wx.” • “I like full data blocks on all aircraft.” • “Descending the aircraft for Ohio, Kansas helped my situational awareness and scan.”	• “Datalink of route changes, requires less radio comm with pilots.” • “Drag/drop data, data comm route amendments, data/non-data identifier prompt.” • “Lack of wx helped greatly” • “RNAV arrivals, less freq congestion, less inputs.” • “Automatic handoffs (taken & given) allows you to work more traffic.” • “Full RNAV/ no weather lower workload. A/c stay on more predictable routes.” • “Departures seemed to work better.” • “Not talking to most aircraft, reduce workload. • “Aircraft on RNAV arrival w/ datalink flew through sector and required very limited attention.” • “Datacom, reduces workload.” “The datalink aircraft”	• “Datalink routing aircraft around wx; this is very time consuming without datalink.” • “Full RNAV procedures - Drag/Drop FDB - Data Rt. Amendments.” • “The mouse reroute, very helpful in weather situations.” • “Full RNAV take care of themselves for the most part.” • “Data comm is great!! Easy and don't have to listen to readbacks.” • “Easy trackball reroute around wx.” • “Weather reroutes” • “Lack of radio communications.”	• “Datalink routing of aircraft around wx; much faster and eliminates frequency congestion.” • “Full RNAV reduced comm.” • “The acft ‘on a rail’ because it is easy to sterilize that route and ‘forget about them’” • “Mouse vs. slewball, easier data entry, easier data block.” • “RNAV, Self-spacing, Auto making and taking handoffs, less for controller to watch.” • “Nothing seemed easier.” • “Daisy chain” • “Self-spacing, makes life easy.” • “Advanced RNAV.” • “Datacom route issuance due to point and click and send ability.” • “Advanced RNAV data comm. aircraft”

Post-Scenario Questionnaire Comments					
		Condition			
PSQ Question	System	LnoWx	FnoWx	FWx	APWx
12. What aspects of this scenario were hardest to work with? Why?	Baseline	• "Moving data blocks, dropping tracks - much clutter & overlap." • "Mix of datacomm/non comm. Using macro for non data a/c do not descend." • "Lack of RNAV procedures, increased computer inputs = less looking at scope." • "A lot of data block overlapping." • "Data block overlap." • "Descending all a/c - more talk / listen." • "Having to double-click to drop data blocks." • "Double-click to drop DB's [data blocks]." • "Too many data blocks, screen cluttered."	• "Dropping datalinks. • Requires double entries." • "Data block overlap, determining data/non-data a/c." • "The computer not able to switch acft to next freq." • "Data block overlapping." • "Data block overlap. Excessive traffic." • "Pilot communication, waiting for dept. a/c to become my control." • "Conflict alert w/ other sectors aircraft, big distraction." • "Leader placement, need mouse and free range movement to unclutter." • "Overload of traffic, scope was cluttered and completely unviewable, not being able to move data blocks to necessary positions."	• "Aircraft climbing to fl 230 without checking on frequency do not always get clearance to climb right away." • "Data congestion, hard to see." • "Weather, had to route acft around creating new conflictions." • "Amount of traffic. Data block overlay." • "Data block overlap." • "Communicating with pilots." • "Trackball entries are hard to enter with so many data blocks." • "Weather deviations w/ too much traffic." • "Frequency congestion, scope clutter, unable to move data blocks manually."	• "Data block overlap. Deter-mining whether a/c is on freq. Indicator is quite small." • "Volume, determining data comm aircraft." • "Self-spacing, not familiar enough with procedure to be effective." • "Amount of traffic (overlay)- Grouping- unfamiliar." • "Volume & data block overlap because can't keep total awareness of traffic situations." • "Groups cleared into sector - takes up too much time/AS." • "Too many data block to see traffic." • "Overtaking speeds." • "Self-spacing- the commands are too difficult and visual aide lacking. Grouping- cause conflict w/ multiple acft, bad idea to group." • "Too many aircraft, too much clutter on scope not being able to manuever data blocks to be able to see."

Post-Scenario Questionnaire Comments					
		Condition			
PSQ Question	System	LnoWx	FnoWx	FWx	APWx
12. What aspects of this scenario were hardest to work with? Why?	FEWS	• "There is still some clutter due to data block overlap, although this is much improved." • "After "rail" full RNAV scenarios, it is difficult to remember voice descents." • "The additional clutter." • "Looking at full strip too much clicking with mouse." • "Having to descend non-data com a/c on RNAV routes." • "Having to descend a/c: pilot communication." • "Too many data blocks." • "The eye tracker makes it hard to stay focused." • "The massive amounts of traffic."	• "Conflict Probe, this activated more than once on aircraft that were not traffic." • "FDB congestion/ RNAV data- no CID." • "RNAV a/c data blocks were too small." • "Full RNAV reduced data block because you have to click on data block for more info and vectors." • "Working w/ pilots w/o DC" • "Not having full data blocks to look for traffic." • "Noticing if next sector was not accepting handoffs." • "Data blocks on F-RNAV, they need to be full data tags, easier to see and gauge traffic." • "Data block clutter."	• "Aircraft climbing from low altitude often level at fl 230 because they don't check on freq." • "Sim Pilots - Volume data block congestion." • "Limited data blocks on RNAV aircraft, hard to scan for potential conflicts. Learned behavior." • "Lack of ability to run out vector lengths on full RNAV data blocks makes it take longer to scan for traffic situations." • "Comm with pilots, waiting to have 'control of a/c / data block.'" • "Reroutes around wx made traffic search w/ LOB difficult." • "Recognizing conflict alert on southbound full RNAV are @ fl340 w/ westbound @340." • "The weather."	• "Dialing in the altitude on the data block takes more time than selecting from menu." • "Data block congestion." • "The climbing acft… because of my work habits ie., provide the best service possible and get them to their req. alt." • "Groups, had to separate too much clutter among the group." • "Grouping- doesn't make sense; smaller data block on RNAV a/c- sometimes don't include in traffic scans." • "Groups - too complex." • "Group - not good or safe." • "Groups, make life difficult, also lines for self-spacing and groups need to be brightness controlled. (Too bright)" • "Wx" • "Blending overflying aircraft w/ acft in climb/descent profiles due to volume of traffic and ability to see all conflicts." • "Scanning the overwhelming massive amounts of traffic."

Post-Scenario Questionnaire Comments					
		Condition			
PSQ Question	System	LnoWx	FnoWx	FWx	APWx
13. Do you have any additional comments or clarifications about your experience in this scenario?	Baseline	• I never was able to get on top of this problem. I was always a few steps behind, and very little got accomplished in a timely fashion” • “Felt more in control than previous problem because of lack of weather easier to project possible conflictions.” • “You stay a lot in 'survival' mode more than controller mode.” • “Having aircraft on advanced RNAV routes and not having to give (down arrow) 240 clearances greatly decreased workload in previous problems.” • “Need some other way to move data blocks.”	• “Volume and data congestion made scenario hardest.” • “The eye monitor was too tight, creating a lot of personal discomfort for majority of problem became somewhat of a distraction. Afraid to loosen, didn't want to lose sensor.” • “Hour long problems are a bit much. Without shutting off sectors, these problems just wear me out!” • “Transfer of aircraft using macros on datalink aircraft could be more efficient. I liked in FEWS just being able to click above DB [data block] on the h/o symbol.” • “This amount of traffic is unsafe and not workable unless you have absolutely ideal conditions.”	• “Data block overlap is a huge distraction; it makes it more difficult to see traffic and provide service with this amount of traffic. Overall, frequency congestion is greatly reduced using datalink. However, with this level of traffic it is still very diffi” • “Overwhelming in numbers, but without usual ATC distractions, ie., phone calls, pilots asking about r' des. In a real world situation most aircraft would probably be rerouted earlier to manage flow in and out of sector.” • “Too many aircraft w/ wx conditions and current equipment capabilities. I should have shut off one or two flows.” • “This problem is too difficult to maintain safe ATC control using ERAM. FEWS was workable- this isn't. One hour problems are a bit too long. Headache and more confusion occur the last 15 minutes. The problems appear easier the last 15 minutes, fewer conflictions. Incorporate /0 [2-line data block for aircraft no longer under control] A/C to include voice/data control switch to next sector.” • “Last problem when had linked aircraft, didn't need to be concerned about speeds on arrival.” • “If we were able to drag data blocks with a mouse, my overall performance and level of tolerance would increase.”	• “Overwhelming volume, confusion with identifying data/non-data aircraft, data block overlap is extreme. When self-spacing, an altitude change breaks chain without warning. Data blocks do not correctly reflect aircraft movement (0 "down arrow" 320).” • “There were some physical distractions during the problem the URET flashed to a blue screen several times during the problem.” • “Datalink is better than voice. Grouping, don't see it being very useful. Self-spacing useful. RNAV makes problem better with such a large number of a/c.” • “This scenario can only work if all a/c on structured routes, structured altitudes, self-spacing and datalink. (No groups, too complex)” • “ERAM problems are much more difficult and having to talk to a/c is time consuming. Datalink is awesome. Time to control departures is too long, climb clearances should be allowed as soon as handoff taken.” • “Grouping of aircraft command is complex and requires too much typing. Grouping also is bad especially grouping acft @ different altitudes. Grouping of aircraft is also extremely annoying to deal with.” • “The departures are unrealistic. They are not spaced out coming from the low sector (1). If they were correctly spaced out and the data blocks could be manually moved, then ERAM could work for this scenario.”

Post-Scenario Questionnaire Comments					
		Condition			
PSQ Question	System	LnoWx	FnoWx	FWx	APWx
13. Do you have any additional comments or clarifications about your experience in this scenario?	FEWS	• "Conflict probe doesn't seem to work all the time." • "I was mostly out of control during most of this scenario. I thought having the full data blocks would increase my situational awareness, but the opposite was true. Also of note, this being the 4th scenario in a row wearing the oculometer, I had a mild headache through the entire scenario that might have contributed to being 'out of control'" • "Even though had more data input than previous problem, seemed to have more awareness of conflictions, especially on the Genera arrival." • "Pilot comm still workload intensive." • "Thought it ran well w/ exception of overflying traffic that fly from NE to SW that don't lose sep until 100 flying miles. Can't judge it early and too busy to notice @ the end." • "Conflict probe doesn't seem to work all the time."	• "With this level of traffic it is still difficult to provide full service; ie., getting aircraft to requested altitude or fully exploring ways to route separate aircraft." • "RNAV DB [data block] need CID." • "Becoming more familiar with procedures makes the problems easier. Also, tend to see similar conflictions in each problem, so you kind of know what to look for." • "It was easier to work more traffic under this system. Still not comfortable with the smaller data blocks (on RNAV). Eyetracker still very uncomfortable." • "Problem seemed somewhat slower, may be due to familiarity with equipment." • "Good problem." • "Looking for traffic with the limited data block I believe will become easier with more practice."	• "Eye tracker distracting." • "The volume makes it very difficult to scan overtake situations." • "I feel I'm improving well as I get more used to traffic patterns and computer commands."	• "If this were real traffic, I'd buy stock in Boeing!" • "Really don't understand purpose of groups, it's almost a distraction and it's hard to separate from each aircraft within the group." • "Groups too complex with this volume of traffic." • "Lighten the intensities hooking up the groups / daisy chain." • "Voice acft on ADV RNAV hard to see the data block callsign at times due to congestion and display, need to pull out to FDB to see callsign. With so many acft positive control is difficult and you must rely on probe and CA."

Post-Scenario Questionnaire Comments					
		Condition			
PSQ Question	System	LnoWx	FnoWx	FWx	APWx
19. What display features (e.g., highlighting) were most positive? Why?	Baseline	• "Multi macro flash." • "Highlighting, helped distinguish non-datalink from datalink aircraft." • "Slant zero data block [2-line data block for a/c no longer under control] of switch a/c. That way I knew who had been switched." • "Data com indicators. Dwell. Ability to use minute vector lengths to study TFC situations." • "Knowing which a/c were data comm." • "Highlight full data blocks." • "Highlighting is very helpful to me." • "Like the highlight of DB's [data blocks] to bring attention to potential issues w/ certain aircraft."	• "Highlighting of non-datalink aircraft as a reminder to comm change later." • "Block highlight for data a/c in transition." • "Highlighting" • "Highlighting, helped distinguish datalink from non-datalink aircraft." • "Highlighting. Made a/c stand out, but so many a/c it wasn't as helpful." • "Brown H for need to switch datalink. Full RNAV designation." • "3 mile J-ring (Halo)" • "Highlighting" • "I like being able to highlight DB's [data blocks] of interest in ERAM, just like our current system." • "Conflict alert."	• "The indication for aircraft descending on RNAV arrivals is now easy to see." • "Multiple trackball pick/enter switch." • "Highlighting, helped to distinguish non datalink from datalink aircraft." [2-line data block for a/c no longer under control] • "Slant zero data block when I switched the a/c." • "Full RNAV depiction, i.e, (down arrow) 00. 2. Brown H depicting data com switch needed. 3. Dwell good." • "Identifier in DB [data block] to tell us to transfer a/c to next sector. Different colors would be better." • "Macro buttons, they reduce workload." • "Highlight DB's [data block] works well." • "The "H" when handoff was accomplished because it stands out and easily seen."	• "Full RNAV arrival aircraft are easy to see and determine that they are going to descend." • "Multiple switch shortcut usage." • "Highlighting… because it reduces the number of places you have to look when an acft checks on." • "Highlighting to tell non-datalink aircraft vector lines to look for conflicts." • "Highlighting of voice guys made it easier to keep up with & slant zero." [slant zero = 2-line data block for a/c no longer under control] • "Dwell good to identify traffic situations." • "H's over data block to transfer datalink control reduced DB [data block] after h/o - takes up less space." • "Auto handoff, Datalink reduces workload." • "Small triangle by datalinked aircraft, easy to distinguish but didn't distract from other data." • "Dwell worked extremely well to help decipher different streams." • "The "H" above the callsign which specifies handoff. This is in a good position and is clearly identifiable."

Post-Scenario Questionnaire Comments					
		Condition			
PSQ Question	System	LnoWx	FnoWx	FWx	APWx
19. What display features (e.g., highlighting) were most positive? Why?	FEWS	• "D-side being able to help by moving data blocks and highlighting." • "Voice a/c prompt." • "The shortcut keys, since I had to issue [illegible] a lot, it was great to do it with one key click. Indicator to switch non-datalink aircraft." • "Same as run 1." (Run 1 = "Reverse video reminds to change frequencies. Blue in data block shows clearance given.") • "Looked forward to having d/c a/c entering sector - easier." • "Easy route line." • "Highlighting of frequency changes." • "Full data blocks and no ADV RNAV." • "Having full data blocks."	• "Highlighting of data blocks from the D-side; This draws attention to something that needs to be done without verbal communication." • "Emphasis, R/D-side highlight, route points, drag/drop data." • "Indicators on non-datalink equipped aircraft. Brings attention to aircraft that are handed off & need to be verbally switched." • "Use of trackball, quicker." • "Reverse video that tells you to switch frequency." • "Highlighted sector numbers - ensure manual coordination was accomplished." • "One button route line on data blocks." • "Highlighting of sector number to switch aircraft." • "Ease of data block moving." • "Being able to move data blocks with the mouse."	• "D-side help via highlighting and moving data blocks." • "Trackball route amendments, data comm." • "Non-datalink indicator- brings attention to required action." • "Reverse video reminds to change frequencies. Blue in data block shows clearance given." • "Grey boxes - great to use during DB [data block] overlap. Data comm - great not having to communicate w/ pilots. 3 mile halo!!! Highlight to change frequency - great too!" • "Big handoff box, improves initial traffic search." • "Highlighting of sector for frequency change." • "Use of click and drag of data block to any position helps to free up scope congestion." • "Being able to have limited data blocks to reduce clutter."	• "The highlighting that indicates the need to comm switch a voice only aircraft works well." • "Emphasis, route ammendments (data a/c), self-spacing & full RNAV, drag/drop FDBs." • "EM [emphasis] command. D-side tied to R-side so he can move or highlight your db's [data blocks] etc." • "Reroutes via mouse & datalink, cut down on verbiage and could route to a specific point without using an actual fix." • "Slant zero." [2-line data block for a/c no longer under control] • "Same as previous." (Previous run = "Reverse video that tells you to switch frequency.") • "Intensities hooking up groups / Daisy chains are too bright and very distracting." • "Highlight frequency change." • "One simple display is nice. Only one screen to use opposed to a URET, or other eqpt we currently use." • "Being able to pull certain feature display tabs off and save them on the radar."

Post-Scenario Questionnaire Comments					
		Condition			
PSQ Question	System	LnoWx	FnoWx	FWx	APWx
20 What display features (e.g., highlighting) were most negative? Why?	Baseline	• "The datalink indicator is too small. Difficult to tell if the aircraft is on freq or not." • "Carrot for data aircraft not easy enough to identify." • "Slant zero aircraft that had been switched. A lot of overlapping with data blocks." • "Data block overlap." • "Clutter" • "I do not like the highlighting of limited data blocks when the trackball goes over them." • "As I mentioned previously, color coding on features would be helpful." • "Double-clicking to drop tags is obnoxious!!!! Need more lee-way on db [data block] movement (click and drag)." • "The triangle datalink indicator tough to see when you're busy."	• "Datalink indicator is still difficult to see and determine if a/c is on freq." • "Colored data-comm indicator?" • "Would like a key just for 3 mile circle, the keyboard entry is pretty cumbersome." • "Highlighting started out helpful, but so many a/c it was as helpful as it started out." • "Data block overlap. Lack of intensity level setting on different type data blocks, i.e., limited vs. full." • "It is too difficult to get rid of DBs [data blocks]." • "Movement of DBs [data blocks] is too restricted, want mouse and free movement like in FEWS, to help reduce clutter." • "The small triangle that indicates datalink. When your screen is cluttered it is too hard to see."	• "The small triangle to indicate datalink equipped aircraft is difficult to see & to determine which side of the data block it is on." • "Still need better determination from data/ no-data a/c." • "Slant zero data block. Overlapping of data blocks." • "Brightness of data blocks. Overlap of data blocks." • "Full DB [data block] on sector after HO made all /0" • "Double-clicking data blocks to remove is too much. The data com symbol is hard to see. Need a better CA that sees farther for "?"" • "The datalink triangle. It is very difficult to see when there is heavy traffic."	• "The triangle next to the callsign. It's difficult to determine if the aircraft is on freq or not." • "Group ID (GRP01) 1 use of CID breaks group." • "The ability to automatically orient dbs [data blocks] based on route. (I wish I'd taken advantage of that)" • "Because of the amount of traffic, highlighting also made it difficult as well as slant zero." • "Data block overlap. 4th line data hard to decipher." • "A/c need to be different colors to ID which need to be transferred to next sector or to ID which a/c you have control of!!!" • "Double-clicking to drop data block. Too long of a wait from handoff to enter commands." • "Way to display linked aircraft didn't stand out in busy traffic, would be helpful to color code 4th line remarks." • "The 4th line to show self-spacing and groups is not clear enough." • "The small triangle next to the callsign which indicate datalink. This is very difficult to see when you have heavy traffic. Having to double-click or keyboard enter ID twice to remove a data block from the scope. This is a waste of time when you have heavy."

Post-Scenario Questionnaire Comments					
		Condition			
PSQ Question	System	LnoWx	FnoWx	FWx	APWx
20. What display features (e.g., highlighting) were most negative? Why?	FEWS	• "No dwell." • "Would like to have the ability to highlight data blocks so when running out vector lines, able to distinguish which aircraft I'm looking at." • "Green highlight overbearing- should make so the R side can remove if put on scope." • "Same as run 1." (Run 1 = "Full RNAV data blocks all tend to overlap causing extreme clutter.") • "The failed datalink messages box, should be a way of these timing out." • "Green block highlighting, too distracting." • "The gray shading sometimes gets in the way."	• "No vector lines on LDBs without bringing up full data block." • "No dwell lock :)" • "The bright green box can be quite distracting when the "D" side brings it up, it really captures your attention." • "Smaller data blocks, you sometimes overlook almost like a limited data block. Use of the green highlight overpowering." • "None except full RNAV reduced data block does overlap." • "ADSB and target symbols are both circles, too hard to distinguish when data blocks are close together." • "Issuing descent to F-RNAV requires taking DB [data block] out of limited state enter alt and return to limited. Be easier if they were FDB." • "The little square that indicates datalink. It is hard to see, it should be on the other side after the callsign."	• "Not being able to quickly display aircraft type via AIK [supplementary keypad]." • "Limited data on full RNAV a/c - forced to open or flight plan readout or use callsign for amendments." • "Green box very distracting. To a small degree, linked data blocks on RNAV aircraft." • "Full RNAV data blocks all tend to overlap causing extreme clutter." • "I don't get green boxes yet." • "Having to go back to a/c to enter alt. I would like it better if I could enter alt routes etc., H.O. [hand off]" • "Green Dwell, too large distraction, hard to click." • "Limited data blocks on full RNAV make it more congested due to stagnate position." • "Picking tabs from toolbar and saving them on the screen."	• "The Group data blocks were difficult to see and move around other data blocks." • "Groups! No dwell lock." • "Hard to see the small inverse freq indicator when scope is cluttered. Hard to differentiate DL symbol from a history." • "Limited data blocks on overflight arrivals. It made it harder to scan for conflictions because you had to make an additional entry to run out vector lines." • "Smaller data blocks for guys on RNAV. You tend not to scan as much for traffic. Line on self-spacing- don't like, too cluttered." • "Groups" • "Groups - unsafe." • "Group and self-spacing lines are too bright." • "Limited data blocks for advanced RNAV, difficult to see due to overlap. Then difficult to find circle to click to expand, extra step to move data block." • "Grouping is deceptive in that it creates clutter and back acft can be at diff alt so you must separate individually opposed to as group." • "The group formation and spacing lines. There is already too much clutter on the scope and the joined/group green lines are very distracting and in the way." •

Post-Scenario Questionnaire Comments

PSQ Question	System	Condition: LnoWx	Condition: FnoWx	Condition: FWx	Condition: APWx
21. What system functions were most useful? Why?	Baseline	• “Macros, great time savers.” • “No time from volume to use features.” • “Datalink- cut down radio congestion, made sector manageable.” • “A/c with data comm created less communication that was good.” • “Data comm symbols. Macros for descent & slant zero. [2-line data block for a/c no longer under control]” • “Macros - ease of work.” • “Macro switches.” • “Datalink, advanced RNAV were the most useful. Linking a/c was also helpful, but you need to be very wary of changing the altitude or direction of one and having the entire link follow.” • “Macros, reduce key entries, and allows for multiple commands.” • “Datalink”	• “Route changes via datalink.” • “Macros.” • “Datalink, cut down on freq congestion.” • “Slant zero [2-line data block for a/c no longer under control], help to know who I had switched.” • “Conflict alert, Full RNAV, Datalink, Macros - all reduce controller time & attention.” • “Being able to multi add to single function.” • “Datalink” • “Macros help out, to cut down on keyboard entries.” • “Datalink, but they take too long to transfer communication.”	• “Datalink re-routes around weather. Eliminates frequency congestion.” • “Reduced comm for data a/c, trackball reroutes a/c.” • “Vector lines, helped to look at potential conflictions. Datalink reduced voice workload made freq manageable.” • “Slant zero. [2-line data block for a/c no longer under control” • “Conflict alert to avoid conflicts. Data com to avoid voice. Macros.” • “Full RNAV - easier.” • “Trackball reroutes around wx.” • “Datalink” • “Datalink, no talking is good.” • “Datalink”	• “Self-spacing is a useful function if you have time to use it; it eliminates the need to keep watching speeds.” • “SS, Data-comm, shortcuts.” • “Datalink aircraft coming into sector self-spaced, less I have to worry about.” • “Self-spacing because of volume it was one less thing to watch constantly.” • “Datalink. Self-spacing becacuse help handle volume. Brown helps to remember to datalink w/o voice.” • “Macros are nice - easier - maybe integrate macros on to keyboard.” • “Self-spacing, reduces workload.” • “Datalink, eliminates great deal of communication, better use of time. Also advanced RNAV procedures.” • “Macros, reduce key strokes.” • “Conflict alert because it helps with separation.”

Post-Scenario Questionnaire Comments

PSQ Question	System	Condition: LnoWx	FnoWx	FWx	APWx
21. What system functions were most useful? Why?	FEWS	• “Datalink comm changes/eliminate much frequencing congestion.” • “Drag/drop FDB.” • “Automated taking handoffs and dropping data blocks. Allowed me to focus on traffic instead of housekeeping duties.” • “Data comm due to less time communicating.” • “Auto route d/c (up arrow) a/c” • “Using datalink to make control clearances, alt, spd, headings.” • “Auto handoffs, decreases workload.” • “Macros, one step alt and flash issues to multiple acft cuts down on workload.” • “Being able to move the data blocks with the mouse.”	• “Auto dropping of data blocks outside the sector. This reduces much clutter on display.” • “Drag/drop FDB, route amendments.” • “Mouse for easier inputs. Datalink for less radio congestion. Sector would not be workable if we had to talk to every aircraft.” • “Auto handoff (taken/given).” • “Full RNAV to reduce communication. Red dot probe when working properly gave early warning of traffic.” • “Auto descent for arrivals.” • “Point and click reroutes for separation.” • “Full RNAV” • “Datacom / love it!” • “Point and click of routes on datalink aircraft.”	• “Datalink clearances. This level of traffic would be impossible without it.” • “Track reroutes for wx.” • “Mouse for inputs- can get things done quickly. The ability to reroute aircraft around weather via datalink makes a difficult situation workable.” • “EM [emphasis] function helped look at 2 aircraft of a/c at one particular altitude.” • “Route with data comm - easy to use and no comm w/ pilots.” • “TB [track ball = mouse (FEWS)] reroute around wx.” • “Datalink, full RNAV.” • “Datacom route and altitude issuance, it's simple, quick and easy.” • “Amending routes of datalink aircraft.”	• “Datalinking a reroute to an aircraft is the best feature. This really cuts down on the workload.” • “Self-spacing. To get a string of acft to descend for crossing traffic with one ‘clearance.’” • “The indicator to switch non-datalink aircraft, it draws your attention that something needs to be done which is always useful as a controller.” • Automatic handoff- making & taking. More efficient. • “Daisy chain - awesome.” • “Advanced RNAV and datalink.” • “Route assignment w/ data comm its simple and effective. Self-spacing is nice due to lack of monitoring overtakes.” • “Being able to point and click on a route of flight and being able to issue it to a datalink aircraft without voice communications.”

Post-Scenario Questionnaire Comments

PSQ Question	System	Condition: LnoWx	FnoWx	FWx	APWx
22. What system functions were least useful? Why?	Baseline	• “No time from volume to use features.” • “Data comm was useful except when I didn't remember the a/c had it.” • “Group least useful.” • “Double-clicking DBs [data blocks] to drop is redundant.” • “Double-clicking or having to hit the ID twice to remove a data block.”	• “SS, grouping, no time (TMU function?)” • “Not being able to uplink an altitude to an acft immediately after taking the h/o. I had to keep checking back to see if he was ‘on’.” • “Slant zero [2-line data block for a/c no longer under control], caused more data block overlay.” • “Too much volume.” • “Auto handoff inhibited / different color.” • “CA [conflict alert], couldn't tell if it was working correctly.” • “Having aircraft climbing into each other and not separated coming from the low sectors.”	• “I had no time at all to check URET for conflicts.” • “No comm on a/c transitions low to high stratum (overlooked).” • “Slewball, mouse would be easier to get information in quickly using shortcut keys.” • “Being unable to drop data blocks in one click. Also, need diff. intensities for limited data block.” • “Too difficult to retire DB [data block] out of a/s.” • “Movement of DBs [data blocks] is prehistoric.” • “Double-clicking data blocks for removal.”	• “All good in concept.” • “When two db’s [data blocks] overlap each other, you have no access to either one if both CIDs and target symbols are obliterated.” • “Self grouping- don't really understand concept or usefulness.” • “Grouping not very useful.” • “Groups make sector too complex.” • “Group, wasn't time to examine aircraft to see if group would be useful and too hard to use, too many keystrokes to create group, label group, give commands to group.” • “Grouping, confict waiting to happen. Double-click data block dropping, creates excess workload.” • “Grouping and self-spacing. There is no use for these functions.”

Post-Scenario Questionnaire Comments					
		Condition			
PSQ Question	System	LnoWx	FnoWx	FWx	APWx
22. What system functions were least useful? Why?	FEWS	• “Conflict probe- doesn't work in all situations.” • “Scroll ALT selection, easy to error or misclick outside 2nd tier DB [data block] and lose entry.” • “Probe did not work. Potential conflictions not shown until conflict alert. The probe would have reduced workload.” • “Altitude scroll window system hard to do quickly.” • “Seems to me you need to be very precise in selecting an alt to be updated. This takes extra time.” • “The auto handoffs. I like being able to take my handoffs so I can review the flight path.”	• “Auto handoffs are swell. This reduces workload on aircraft coming into sector.” • “RNAV DB [data block]. No CID. Forces flight plan readout prior to amendments.” • “Probe, just not consistent in showing potential conflictions. Could really be a useful tool if operating properly.” • “Full RNAV reduced data blocks.” • “Auto handoff accept - hard to tell where a/c are when checking in. Needs to be different color until activated?” • “F-RNAV- I prefer full data blocks and to be able to alter position of DB [data block].” • “Auto taking of handoffs.”	• “Emphasis on data blocks; haven't had a chance to use it much.” • “All useful (no dwell lock).” • “Probe- didn't work consistently.” • “Changing alt with mouse is not as efficient.” • “Updating assigned altitudes slow due to needing to highlight data block and roll wheel of mouse.” • “Auto handoff taken - no data comm a/c. Where sometimes difficult to find (different colors).” • “Conflict probing on deviating traffic. With so many aircraft you may miss conflict and heavily rely on CA too much.” • “Auto-taking of handoffs.”	• “Grouping of aircraft. I can’t think of a reason why I'd want to do this.” • “Grouping in large groups.” • “Probe. Wasn't working properly. Worked an hour long problem and never got a single probe indicator. First indication there was a problem was conflict alert.” • “Taking handoff. You're not as sure where a/c is located or where he's going (traffic planning).” • “Groups too complex.” • “Groups - unsafe.” • “Groups, too many data blocks and lines that are very bright and are distracting.” • “Group, creates much more clutter on scope, not worth the other benefits.” • “Grouping of aircraft seems pointless and non efficient.” • “The group function. I don't see it being useful in the field.”

Post-Scenario Questionnaire Comments					
		Condition			
PSQ Question	System	LnoWx	FnoWx	FWx	APWx
23. What additional features or functions would improve your use of the new procedures?	Baseline	• “Auto dropping of tracks that are outside of airspace and have been comm shipped.” • “Color of aircraft doing different arrivals or non-datalink aircraft.” • “Adding color to a/c with data comm.” • “Different color DB [data block]- handoff / transfer control.” • “Use of mouse, and DB [data block] colors.” • “Being able to move data blocks manually with mouse.”	• “A clearer indicator of which aircraft are datalinked and on frequency.” • “Drag and drop data blocks.” • “Suppress conflict alert for acft (up arrow) fl230… very distracting.” • “Help with data block overlap & dropping targets clear of airspace would also be useful if aircraft that were a potential conflict would change color in advance, might be changing altitudes unnecessarily.” • “Use of color.” • “Early conflict probe. All a/c on structured routes & altitudes.” • “Different color DB [data block]. /0 [2-line data block for a/c no lunger under control] does everything to DC a/c.” • “Mouse, color coding data blocks, a better conflict probe.” • “Being able to drag your data blocks to any position using the mouse.”	• “Auto dropping of data blocks outside your sector when handoff and x-fer of communication has been made.” • “drag and drop data blocks.” • “Different colors for non-datalinks and maybe distinguishing arrivals to different airports for sequencing.” • “Better early conflict probe. Weather probe.” • “Colored DB [data block].” • “Mouse, colors, ease of movement on DB's [data block], one click on DB [data block] for transfer.” • “Manual data block movement with a mouse.”	• “When aircraft is cleared for self-spacing via datalink message should automatically go into fourth line of data block.” • “D-side macros, a/c comm switch if voice switched.” • “A SS shortcut key.” • “Use of color to easy ID who is voice link.” • “FEWS reroute functions.” • “Develop a QHK on keyboard, or mouse, or slewball to ID macros.” • “Something that would auto separate data blocks.” • “Give single command and it displays in all data blocks of linked planes.” • “A mouse to click and drag DB's [data blocks] anywhere. The ability to color coat data blocks.” • “Being able manually move data blocks in times of heavy traffic to reduce scope clutter.”

Post-Scenario Questionnaire Comments					
		Condition			
PSQ Question	System	LnoWx	FnoWx	FWx	APWx
23. What additional features or functions would improve your use of the new procedures?	FEWS	• “Fly[out] windows on ALT/SPD/HDG selection.” • “More positions for acft with no leaders, hard not to overlap data blocks.” • “The time lapse from when the handoff is taken until you can data comm the a/c too long.” • “Dwell features.” • “Data comm to all a/c.” • “Self-spacing” • “Colors and a better conflict probe to alert of potential long term problems.”	• “Push & hold keys on AIK [supplementary keypad] to display TYPE & DEST in 4th line.” • “Dwell lock. CID in RNAV data.” • “Highlighting data blocks to run out vector lines to look at potential conflictions. Also, a trial plan probe on the "D" side, if you put in a proposed route to show additional potential conflictions.” • “Making all manual comm a/c different color coming into sector until activated.” • “Self-spacing” • “Color options of data blocks.” • “Color options of data.”	• “Multi-flight plan readout similar to what we have in DSR.” • “CID in full RNAV data blocks and dwell lock.” • “Highlighting data blocks to look at potential conflictions when running out vector lines.” • “Different intensities of different data blocks. A dwell function to look at a situation.” • “Different colored data blocks for certain events - conflict alert.” • “Self-spacing around wx.” • “Colors/ full data block on full RNAV acft.” • “Making all aircraft datalink and having a small leader line between 0 and 1.”	• “The requested altitude in the data block should be highlighted with a different color when scrolling.” • “Dwell lock.” • “The ability to change elements of a data block not under your control anymore with a / ok [command to regain control of aircraft] box or mouse click.” • “Have the ability to change intensities or maybe have different ways to ID these functions.” • “Use of coloring data blocks (example Dep- blue, Overflights- orange).” • “If all aircraft were datalinked equipped.”

Post-Scenario Questionnaire Comments					
		Condition			
PSQ Question	System	LnoWx	FnoWx	FWx	APWx
24. Do you have any comments or clarifications about the interface?	Baseline		• "Don't like making/taking h/o's [hand offs]."		• "The small datalink triangles are difficult to see."

Post-Scenario Questionnaire Comments					
		Condition			
PSQ Question	System	LnoWx	FnoWx	FWx	APWx
24. Do you have any comments or clarifications about the interface?	FEWS **(No comments were received for this system)**				

Appendix I

Exit Questionnaire Comments

Exit Questionnaire Comments
• "Excellent for a "scratch" simulation. Wind effect would make it much more realistic in terms of a/c performance. DESIREE is as effective as the current DYSIM for DSR."
• "Any particular sector might have an airport they serve that has as much traffic as GEN, OHO, or KAN generates, but not 2 or 3 big airports in any given sector."
• "The simulation was a good opportunity to see some tools that would make our job easier and allow us to work more aircraft effectively. The one thing you can't simulate are other distractions that we deal with on a daily basis such as plane calls, pilot request, issuing ride reports, telling pilots about weather or NOTAMs or various other items we deal with. There are some truly useful items that could & should be incorporated as soon as practical. The mouse vs the slew ball, URET conflicts next to the datablock, datalink. These are improvements that could definitely make both the controller and therefore the system more efficient."
• "Savant major distraction."
• "Savant was a major distraction! Training was quick, useful and generally what we needed for the situation given to us. Grouping is bad/unsafe!"
• "Whichever scenario is run the second week will be slightly improved performance relatively to systems due to familiarity with airspace and systems. 2nd week frequencies, airspace, and scenarios are all memorized so there is less for the brain to process. FEWS overall is much easier system to work with. Group feature is too time consuming to initiate and alter, combined with clutter on scope, not worth initiating. Would be beneficial to have a means to change the altitude of a single aircraft that is linked without needed to break the link. Need different symbol for ADSB in FEWS, too easily confused with target symbol when datablocks are close together."
• "I would like to see tools used in FEWS implemented into ERAM. The use of a mouse, would ease the movement of datablocks like allowed in fuse. Also in FEWS the ability to click icon on datablock to transfer datalink aircraft is much easier than the "UH" function in ERAM. To me if the FAA is predicted to see the high levels of traffic ERAM is already pre-historic, and development and implementation of FEWS should be fast-tracked. Don't take so long implementing, and get the tools to the field."
• "The departures are not realistic. There is no separation provided from the low sector (1). All other traffic and equipment is extremely realistic."