An Analysis of En Route Air Traffic Control System Usage During Special Situations

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16. Abstract

The Federal Aviation Administration is developing the En Route Automation Modernization (ERAM) system to replace the legacy en route air traffic control automation system consisting of the Host Computer System (HCS), the Display System Replacement (DSR), and the User Request Evaluation Tool (URET). Because controllers will use ERAM to respond to both routine and special situations, it is important that ERAM be evaluated in a variety of conditions. This technical note provides an analysis of how controllers use the legacy system during special situations and corresponding evaluation metrics. The special situations include weather, traffic management initiatives, emergencies, and outages. The metrics may be useful in future evaluations of the effectiveness of ERAM as compared to the legacy system. We used a qualitative analytic method in which we interviewed subject-matter experts (SMEs). The SMEs characterized each situation and provided information about the actions controllers typically take to respond. We discuss how the results of the analysis can be applied to ERAM testing and provide guidance for future studies to create a rich set of human factors metrics for system testing.

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Executive Summary

The Federal Aviation Administration (FAA) is developing the En Route Automation Modernization (ERAM) system to replace the legacy en route air traffic control (ATC) automation system consisting of the Host Computer System (HCS), the Display System Replacement (DSR), and the User Request Evaluation Tool (URET). An ERAM Critical Operational Issue (COI) requires that the new system support en route operations with at least the same effectiveness as the legacy system. To allow the FAA to evaluate the new system against this COI, we must measure the effectiveness of the legacy system. This technical note provides an analysis of how controllers use the legacy system during special situations and provides corresponding evaluation metrics.

En route controllers face a wide range of operational situations while working traffic. On most days, traffic follows established patterns. On other days, however, additional factors appear that increase controller workload, reduce operational efficiency, or increase safety risk. These factors include severe weather, traffic management initiatives, emergencies, equipment outages, and law enforcement activities. Because controllers will use ERAM to respond to both routine and special situations, it is important that the new system be evaluated in a variety of conditions. Evaluations of ERAM in special situations should focus on the interactions controllers need to address the situation, regardless of the overall frequency of those interactions.

In this technical note, we describe how controllers interact with the legacy system during selected special situations. In particular, we examine controllers' use of uncommon commands and how their use of common commands changes in special situations. We used a qualitative analytic method in which we interviewed subject-matter experts (SMEs) about usage of the legacy system. We discuss the following special situations in this technical note: display outage, radar outage at an adjacent facility, radar outage requiring transition to nonradar control, flight data processing outage at an adjacent facility, intruder in Special Use Airspace, moving Temporary Flight Restrictions (TFRs), severe weather with pilot deviations, severe weather with Playbook action, heavy congestion, in-flight emergency, and onboard medical emergency. For each situation, we describe the actions controllers typically take, the measurable potential differences between the special situation and routine operations, and considerations for testing.

The majority of the controller commands used to respond to special situations appear in the list of 30 most frequently used commands summarized in our earlier report (Allendoerfer, Zingale, Pai, & Willems, 2006). However, the current analysis revealed several other commands that were not among the most commonly used. These include airport information command, reported altitude command, hold command, URET Aircraft List checkbox, URET Trial Plan, and DSR annotation tools. We recommend that these commands be treated like the 30 most frequently used commands during ERAM testing because they are critical for dealing with special situations. We provide guidance on how to apply the findings of this analysis to ERAM testing and discuss further steps that are necessary to compile a thorough set of human factors metrics.

1. Introduction

The Federal Aviation Administration (FAA) is developing the En Route Automation Modernization (ERAM) system to replace the legacy en route air traffic control (ATC) automation system consisting of the Host Computer System (HCS), the Display System Replacement (DSR), and the User Request Evaluation Tool (URET). En route controllers use the legacy system to control thousands of flights each day at 20 Air Route Traffic Control Centers (ARTCCs) in the continental United States. Lockheed Martin Corporation is the primary ERAM contractor.

The *Test and Evaluation Master Plan* for ERAM (FAA, 2003) requires that the ERAM Test Program verify critical operational issues (COIs). The first COI requires that ERAM support en route operations with at least the same effectiveness as the legacy system. To allow the FAA to evaluate ERAM against this COI, the effectiveness of the legacy system must be measured to provide benchmarks for comparison to ERAM.

1.1 Purpose

This technical note provides an analysis of how controllers use the legacy en route system during special situations. These situations include display outage, radar outage at an adjacent facility, radar outage requiring transition to nonradar control, flight data processing outage at an adjacent facility, intruder in Special Use Airspace, moving Temporary Flight Restrictions (TFRs), severe weather with pilot deviations, severe weather with Playbook action, heavy congestion, in-flight emergency, and onboard medical emergency. For each special situation, we provide metrics that may be useful in future ERAM evaluation activities. This technical note is one of several produced by the Automation Metrics Test Working Group (AMTWG) described in the *ERAM Automation Metrics and Preliminary Test Implementation Plan* (FAA, 2005).

1.2 Background

The FAA ERAM Test Group formed the AMTWG in 2004. The team supports ERAM testing by developing metrics that quantify the effectiveness of key system capabilities. The targeted capabilities are the Surveillance Data Processing (SDP), Flight Data Processing (FDP), Conflict Probe Tool (CPT), and the Display System (DS) modules. The team designed the metrics to measure the effectiveness of the legacy system and to allow valid comparisons to ERAM.

The AMTWG conducted the metrics development project in several phases. First, it generated a list of approximately 100 metrics and mapped them to the services and capabilities found in the *Blueprint for the National Airspace System Modernization 2002 Update* (FAA, 2002). The initial metrics were published in a progress report (FAA, 2004b). Second, the team prioritized the metrics for further refinement and created an implementation plan (FAA, 2005). The implementation plan lists the selected metrics, gives rationales for their selection, and describes how the high-priority metrics were identified. The implementation plan allows each metric to be traced to basic controller decisions and tasks, COIs, and the ERAM contractor's technical performance measurements. The categories of high priority metrics are

- SDP radar tracking,
- SDP tactical alert processing,
- FDP flight plan route expansion,

- FDP aircraft trajectory generation,
- CPT strategic aircraft-to-aircraft conflict prediction,
- CPT aircraft-to-airspace conflict prediction,
- additional system level metrics, and
- DS human factors and performance metrics.

In the final project phase, the AMTWG will further refine and apply the metrics to the legacy en route system. In 2005, the National Airspace System (NAS) Human Factors Group examined the frequency of use of controller commands on the legacy system (Allendoerfer, Zingale, Pai, & Willems, 2006). That report described controller usage of the system during routine, "day-in-the-life" operations at Washington ARTCC (ZDC). The current technical note is complementary in that it describes how controllers use the legacy system in situations that occur in the NAS regularly but not every day. Special situations have the potential to increase controller workload, reduce efficiency, or increase safety risk above the levels experienced during routine operations. This technical note is the second in a series that propose metrics for the ERAM DS module related to safety, efficiency, and workload.

1.3 Special Situations

En route controllers face a wide range of operational situations while working traffic. On most days, traffic follows patterns of lighter and heavier traffic loads. Complexity and corresponding workload levels vary throughout the day and show regional and seasonal differences. The patterns are well established, fairly predictable, and do not normally create major operational problems. On other days, however, additional factors are introduced to the operational situation that increase controller workload, reduce operational efficiency, or increase safety risk. These factors include severe weather, traffic management initiatives, emergencies, equipment outages, law enforcement activities, and special occurrences like major sporting events. Because controllers will use ERAM to respond to both routine and special situations, it is important that ERAM be evaluated in a variety of conditions.

Obviously, the situations discussed in this technical note do not include every nonroutine situation encountered in the NAS. Instead, they represent a sample of events that occur regularly enough that controllers have developed procedures or common work practices to respond to them. In addition, these situations represent categories of similar situations. For example, TFRs are put in place for many reasons. In this technical note, we discuss TFRs implemented for a presidential motorcade and a major sporting event.

1.4 System Usage in Special Situations

A careful examination of the legacy en route system should evaluate how controllers interact with it during both routine and special situations. For routine situations, the examination should focus on controller interactions that occur most frequently. Our previous technical note (Allendoerfer et al., 2006) provided frequency of use data for 134 controller commands during routine operations at ZDC. It also provided data regarding the method controllers commonly use to execute the commands and how often controllers make mistakes using these commands.

For special situations, the examination should focus on the controller interactions that are needed to address the situation regardless of their frequency of use. Some controller commands that are uncommon overall are critical in special situations. For example, if an aircraft has an onboard emergency and must land at the nearest suitable airport, controllers may need to access the detailed characteristics of nearby airports. Using the legacy system, controllers can use the Emergency Airport Display (AI) command to obtain this information. Though the AI command ranked in the middle (77 out of 134) in frequency of use during normal operating conditions (Allendoerfer et al., 2006), it is critical for addressing this situation. If the examination of the legacy system and subsequent ERAM evaluations focused on only the most frequent controller commands, the AI command probably would be excluded. However, its importance in emergency situations suggests that it be included in the evaluations despite its low frequency.

In addition, controllers may change how frequently they use common commands during special situations, or they may change the method they used to enter those commands. For example, the Point Out (QP) command is used frequently during routine operations, with nearly 250 made per hour at ZDC (Allendoerfer et al., 2006). However, in a situation where numerous aircraft are deviating around weather, the number of point outs could increase substantially, with accompanying increases in communications and controller workload. When point outs increase, controllers may change the method they choose to enter the QP command or the speed with which they enter it. The number of data entry errors may also increase. It is important to ensure that controllers can use the QP command effectively in all situations.

In this technical note, we describe how controllers interact with the legacy system in special situations, their use of uncommon commands, and ways in which their use of common commands may change in response to the situation. We conducted our analysis across the HCS, DSR, and URET components of the legacy system. Our analysis also discusses effects on other ATC equipment such as the Voice Switching and Control System (VSCS). Changes in how controllers use other systems may reflect changes in overall workload, efficiency, or safety risk resulting from changes in the primary system and may therefore be affected by new ERAM capabilities. For example, when the HCS at an ARTCC fails, controllers at adjacent ARTCCs will communicate over the landline to manually obtain flight plan information resulting in more use of the VSCS. However, ERAM may require fewer manually transferred flight plans because it provides an expanded flight plan database. In addition to reducing the workload associated with re-entering the flight plans, the new ERAM capability may result in fewer landline calls between ARTCCs during such a situation.

1.5 Previous Research

During the development process for the DSR, the NAS Human Factors Group conducted baseline simulations of the HCS with the original Plan View Display (PVD) (Galushka, Frederick, Mogford, & Krois, 1995) and the HCS with the DSR (Allendoerfer, Galushka, & Mogford, 2000). These studies simulated a busy but routine day at ZDC. The traffic scenarios did not contain special events that increased complexity or workload. We designed the metrics used in the original baseline simulations to measure how well the PVD and DSR systems allowed controllers to handle routine situations only. For example, we did not create any metrics or conduct any simulations to measure how well DSR helped controllers respond to a radar outage. In the current project, we address this limitation by describing the actions controllers take to respond to several special situations.

2. Method

In our earlier report, we analyzed recordings from ZDC to examine controller usage of the legacy system during routine operations (Allendoerfer et al., 2006). We used the recordings to develop quantitative descriptions of controller usage, such as the number of times controllers made a particular entry or issued a specific command. However, no equivalent recordings exist for special situations, so similar quantitative analyses are not currently feasible. Instead, in this technical note, we used a qualitative analytic method in which we interviewed subject-matter experts (SMEs) about their usage of the legacy system in various situations. The analysis method contained the following steps:

1. The psychologists brainstormed special situations that currently occur in the NAS but are not considered everyday occurrences. We considered a special situation to be one that had potential to increase controller workload, reduce efficiency, or increase safety risk above normal levels. At this step, we described the situations in very general terms (e.g., Emergency).
2. We reviewed the list of situations with one SME. The SME added important operational details, such as the traffic volume, and created the descriptions of situations used in the interviews. We added details to ensure that the situations described were ones for which controllers have developed procedures or common work practices. We excluded extremely rare situations (e.g., a terrorist attack) because neither the psychologists nor the SME had enough experience with such situations to draw conclusions about what controllers typically do in these situations.
3. The psychologists used the final interview form (Appendix A) to collect data from two en route SMEs. The SMEs described each situation at their facilities, in terms of controller actions and what commands controllers might use on the legacy HCS/DSR/URET system. We also discussed interactions with other ATC systems, such as communication and information display systems.
4. The SMEs characterized each situation in terms of its effect on safety risk, efficiency, and workload. In these characterizations, we drew a distinction between safety and safety risk. As one of our SMEs described it, controllers take action to maintain safety. The likelihood of an accident or a collision is extremely small, in even the most serious special situations. The likelihood of operational errors or deviations, however, does increase in some cases, and controllers characterize these as increasing safety risk.

3. Results

The following sections describe the situations and the actions controllers typically take as described by the SMEs. For each situation, we provide a table of measurable potential differences between the special situation and routine en route operations. In the tables and accompanying discussions, a "standard metric" is one that is normally collected in human-in-the-loop baseline ATC simulations (Allendoerfer et al., 2000; Galushka et al., 1995). A list of standard metrics is provided in Appendix B. Standard metrics include the number of operational errors, the number of aircraft handled, and the number of data entries. In cases where the situation may have a substantial impact on a standard metric or it was mentioned specifically by our SMEs, we include it individually in the table. Finally, for each situation, we describe considerations that should be taken into account in human-in-the-loop simulations of the situation during ERAM testing.

3.1 Display Outage

Description: "The display goes out at your workstation. You need to move to another position and bring up another workstation."

Losing a display unexpectedly is not common in the field, but it is disruptive and can negatively affect en route operations. The SMEs rated this situation as creating a moderate increase in safety risk, a large decrease in efficiency, and a large increase in workload for controllers.

The preferred option for handling this situation is for the affected controller to move to a spare DSR position, preferably in the same operational area. The SMEs estimated that the process of moving to a spare position in the same area would take about 5 minutes to complete. Once the move is complete, the new sector is fully operational. To do this, controllers take the following actions.

a. The controller selects the necessary radio frequencies on the VSCS at the spare position.

b. The controller signs onto the DSR at the spare position.

c. The controller selects the necessary video maps.

d. The controller adjusts the DSR display settings (e.g., range, brightness). Alternately, the controller may apply an appropriate preference set.

Sometimes no spares are available in the area, so the controller must use a position elsewhere in the ARTCC. This is a much more involved process, including reconfiguration by the supervisor to make necessary maps, landlines, and radio frequencies available at the new position. Because such large reconfigurations do not occur often, supervisors may need to refer to manuals or contact other supervisors or Technical Operations personnel who have more current knowledge. According to our SMEs, a reconfiguration of this type takes about 15 minutes. Once the move is complete, the new sector is fully operational.

Instead of moving to a spare position, the affected sector may be consolidated with a nearby, unaffected sector. To do this, controllers and supervisors take the following actions.

a. The receiving controller (i.e., the controller staffing the unaffected sector) quick looks the originating sector.

b. The controller and supervisor determine what the traffic level would be in the combined sector. If the combined traffic volume is acceptable, the consolidation process continues. If the combined traffic would be too heavy, they might explore a different approach, such as moving the sector to a spare position outside of the area.

c. If needed, a Data (D)- or Assistant (A)-side controller may be added to the combined sector. The additional controller must sign onto the position.

d. The receiving controller determines if the necessary radio frequencies and landline communication capabilities are available on the VSCS. The frequencies are available in most cases, so the controller activates the frequencies, and the audio is routed to the receiving position. The controller confirms that it is operating properly. If the necessary frequencies or landlines are not available, the supervisor will make a configuration change using the VSCS.

e. The supervisor (or at some facilities, the receiving controller) will execute the consolidation in the system with the necessary commands. In HCS, this is the Resector (CS) command that can be issued from D- or A-position or from a Keyboard Video Display Terminal (KVDT).

The SMEs estimated that a consolidation of this type takes only 1 or 2 minutes if the HCS and VSCS are already configured to allow the two sectors to be consolidated. If the sectors are not normally consolidated, the process will take longer because the supervisor must make the appropriate maps, landlines, and radio frequencies available at the receiving position. Once the consolidation is complete, the combined sector is fully operational, but the controller staffing the combined position now has increased workload.

3.1.1 Potential Differences from Routine Operations

Consolidation occurs often in routine operations and is normally associated with changes in traffic volume. For example, supervisors open many sectors in the morning to respond to the morning push and then consolidate them later in the day. However, the time pressure of the display outage situation may increase the likelihood for errors while completing the consolidation process.

In addition, if the controller must move to a position outside the area or two sectors are not normally consolidated, the supervisor may need to reconfigure the HCS and the VSCS. In a situation where ATC services need to be restored as quickly as possible, the reconfiguration may be slow, especially if it has been a long time since the supervisor has completed a similar reconfiguration.

Until the new position is operational and the controller has had an opportunity to reestablish complete control over the traffic situation, there may be a moderate increase in safety risk and a large decrease in efficiency. Controllers at other adjacent sectors may identify conflicts that arise during the outage and try to resolve them. The controller may begin to use nonradar procedures to keep the aircraft safely separated. The controller may put aircraft into hold or may stop issuing any clearances other than those needed to preserve safety. The controller staffing the position will devote as much effort as possible to maintaining the safety of the sector using just the radio while others make reconfigurations of positions. Considerations of efficiency will become secondary.

The primary metric for this situation is the time required to return to the same level of efficiency as before the outage. This measure includes the time needed to recognize the problem, notify the supervisor, move to the spare position, sign on, set up the position, and resolve any traffic problems that had occurred in the meantime.

An important secondary metric is the error rate, for both omission and commission errors, in issuing commands associated with consolidating sectors and reconfiguring the system. People are more likely to make errors when performing rare actions and when working under time pressure. Though sector consolidation is common, the unexpected nature of the outage increases the chances for error. Furthermore, if the supervisor is not well practiced on consolidating these particular sectors or in reconfiguring the system, the likelihood of error is increased.

Table 1 presents measurable potential differences between this special situation and routine operations. Because controllers and supervisors can fully resolve this situation quickly, , any differences will be short-lived and should return to baseline once the new or consolidated position is operational.

Table 1. Potential Effects Resulting from Display Outage

Construct	Metric	Possible Direction & Magnitude of Effects
Safety Risk	**Standard metrics**	**Moderate increase over routine operations**
Efficiency	**Standard metrics**	**Large decrease over routine operations**
	Elapsed time from the display outage until controller is working at the same efficiency as before the outage.	Metric does not directly compare to routine operations.
Workload	**Standard metrics**	**Large increase over routine operations**
	Number of quick look commands	Increase
	Number of sign on commands	Increase
	Number of preference set commands	Increase
	Number of display control commands	Increase
	Number of consolidation and reconfiguration commands	Increase
	Error rate for consolidation and reconfiguration commands	Increase especially in situations where the two sectors are not normally consolidated or when reconfiguration across areas is necessary
	Number of map selection commands	Increase
	Number of ground-ground communications	Increase

3.1.2 Considerations for Testing

A human-in-the-loop simulation of a display outage is straightforward on both the legacy and ERAM systems. A display cable can be removed at a designated time to simulate the display failure. No special traffic scenarios or scripting is necessary. If the intended controller response is to move to a spare position, an appropriate spare must be available and the automation and communication systems must be configured appropriately. A supervisor will need to be included either as a participant (i.e., a subject of data collection) or as a "ghost supervisor" (i.e., a supervisor akin to a pseudopilot who serves as part of the simulation and whose behavior is not the subject of data collection) to execute supervisory actions.

For a more rigorous test, we could configure the system to require extensive changes to the spare position before the controller can move to it. This would place additional pressure on the participants and would encourage them to use the system in ways that they often do not. It would also increase workload on adjacent sectors that would need to monitor traffic in the affected sector while they complete the reconfiguration.

3.2 Radar Outage at the Terminal Radar Approach Control Facility

Description: "The radar goes out at the TRACON and your center must now manage the aircraft within that airspace."

A radar outage, especially near an airport where aircraft are tightly spaced, is a serious operational situation. The SMEs rated this situation as creating a large increase in safety risk, a large decrease in efficiency, and a large increase in workload for the affected en route controllers.

The preferred approach for handling this situation is for the en route sectors surrounding the Terminal Radar Approach Control (TRACON) to absorb the traffic and apply en route separation standards. To do this, controllers typically take the following actions.

a. The terminal controllers inform the affected aircraft to switch to the appropriate en route frequencies.

b. The en route controllers may need to adjust their altitude filter limits, display terminal maps, and the range setting on their DSR displays.

c. The en route controllers may issue holds for incoming aircraft to reduce workload while they handle the TRACON aircraft. When they initiate a hold, the controller must make a hold entry that records the time the hold began and indicates when the pilot should expect a further clearance. In the HCS, these are the Hold (QH) and (HM) commands.

d. The en route controllers will need to carefully implement en route separation. Controllers will need to communicate more frequently with pilots and make more accompanying data entries.

e. Because the TRACON aircraft are separated according to terminal standards (3 nm, 1000 ft) prior to the outage, the en route controllers initially may have numerous conflict alerts. The controllers will suppress these alerts until they achieve to en route separation standards (5 nm and 1000 ft). In the HCS, these are the Suppress Conflict Alert Pair (CO) and Group Suppression (SG) commands.

f. The en route and terminal controllers will frequently coordinate over the landline.

g. If needed and available, the en route supervisor may assign a D- or A-side controller to the affected sectors. Alternately, the supervisor may split affected en route sectors to spread the traffic across more controllers.

h. The en route controllers may need to obtain new beacon codes for aircraft because en route aircraft may have duplicate codes to those assigned by the TRACON. In the HCS, this is the Code Modification (QB) command.

3.2.1 Potential Differences from Routine Operations

The largest differences from routine operations will occur shortly after the radar outage while the en route controllers are taking over the TRACON airspace and establishing en route separation. The differences would last until the TRACON radar comes back online, arrivals are rerouted to other airports before entering the ARTCC, or the Traffic Management Unit (TMU) institutes a program to keep aircraft on the ground at their departure points. In any case, the duration of the effect will be medium or long.

The primary metric for this situation is the time required after the radar outage until en route separation is achieved for all aircraft. This measure would include the time needed to recognize the problem, notify the supervisor and other controllers, and reroute or resequence traffic to achieve proper separation. A related metric is the number of altitude, speed, and heading changes used to obtain the en route separation.

Table 2 presents measurable potential differences between this special situation and routine operations.

Table 2. Potential Effects Resulting from Radar Outage at TRACON

Construct	Metric	Possible Direction & Magnitude
Safety Risk	**Standard metrics**	**Large increase over routine operations**
	Number of conflict alerts	Increase because aircraft are initially separated at terminal standards and must be transitioned to en route standards
Efficiency	**Standard metrics**	**Large decrease over routine operations**
	Number of aircraft in holding pattern	Increase
	Average duration of holds	Increase

Table 2. Potential Effects Resulting from Radar Outage at TRACON (continued)

Construct	Metric	Possible Direction & Magnitude
Efficiency (cont.)	Number of altitude, speed, & heading changes.	Increase because controllers must transition from terminal standards to en route standards
	Number of route changes issued	Increase only if outage and resulting drop in efficiency lasts long enough that aircraft must be sent to alternate destinations for fuel reasons.
	Elapsed time from the radar outage until en route separation is achieved for all aircraft.	N/A – Metric does not directly compare to routine operations
Workload	**Standard metrics**	**Large increase over routine operations**
	Number of hold commands	Increase
	Number of altitude, speed, and heading commands	Increase
	Number of display control commands (e.g., range, off-center, brightness)	Increase
	Number of map selection commands	Increase
	Number of altitude filter commands	Increase
	Number of suppress conflict alert commands	Increase
	Number of beacon code commands	Increase
	Number of route commands	Increase only if outage and resulting drop in efficiency lasts long enough that aircraft must be sent to alternate destinations for fuel reasons.
	Number of ground-ground communications	Increase
	Number of air-ground communications	Increase

3.2.2 Considerations for Testing

A human-in-the-loop simulation of a radar outage at a TRACON is straightforward. We would select en route sectors that feed traffic directly to the TRACON for the simulation. In some en route traffic simulations, aircraft drop from the simulation once they leave the en route airspace, but this would not be possible here. The traffic scenario would need to simulate traffic all the way to the ground, even if the en route radar can no longer see the aircraft. A supervisor would be needed to simulate the supervisory aspects of the situation. Ghost sector controllers would be necessary to play the role of the affected TRACON positions. Given the complexity of the coordination, TRACON controllers who understand the airspace would best staff these ghost sectors. En route controllers do not normally display the short-range radar data, so we would not need to simulate a short-range radar feed. Obtaining TRACON controllers to serve as ghost controllers increases the complexity and cost of the simulation.

3.3 Radar Outage: Nonradar Control

Description: "Radar goes out in the sector and nonradar control must be used."

Because multiple radars cover most busy en route airspace, losing one long-range radar normally has low operational impact. If the primary radar goes out, the HCS mosaic target presentation automatically displays target positions based on the secondary radars following a specified hierarchy. If any radar data are available, controllers continue to work traffic using radar procedures and separation standards. In this scenario, however, the controller must adopt nonradar procedures, which would occur only in sectors where there is no radar redundancy or where multiple simultaneous outages occur that disable both the primary and secondary radars.

There are many areas in the NAS without radar coverage, and nonradar procedures are well established. Controllers who regularly staff nonradar airspace or airspace with surveillance gaps are accustomed to working nonradar procedures. However, a radar outage in airspace that is normally covered by radar can be serious because airspace with good radar coverage typically has a higher volume than nonradar airspace. In addition, controllers who normally do not staff nonradar airspace may be less experienced or current with nonradar procedures. Our SMEs characterized this situation as creating a small increase in safety risk, a moderate decrease in efficiency, and a moderate increase in workload.

To move from radar to nonradar procedures, a controller typically would take the following actions.

a. An indication of the outage appears on the displays. In DSR, this is a large red "X." The affected en route controllers will immediately notify the supervisor and other affected controllers.

b. The controllers will immediately begin to implement nonradar procedures, including obtaining position and altitude reports from pilots. In HCS, these are the Progress Report (PR) and the Reported Altitude (QR) commands.

c. The controllers will coordinate with adjacent sectors and facilities over the landline using the information on their printed flight strips.

d. URET is not approved for separation assurance, even in these circumstances, but it still contains useful information that controllers may need as they establish nonradar separation. The controllers might use the URET Aircraft List and Graphic Plan

Display to assist in determining last known positions, altitudes, headings, or routes. As the data in URET become older, the information becomes less and less useful, and controllers will rely exclusively on nonradar procedures and reported positions.

e. The controllers may briefly place aircraft in hold while they establish nonradar procedures. When controllers initiate a hold, they must make a hold entry that records the time the hold began and indicates when the pilot should expect a further clearance.

f. Once established on nonradar procedures, the controllers will require regular position reports from aircraft.

g. Other sectors or facilities that still have radar may be able to see some of the affected traffic. Those sectors will normally try to reduce workload at the affected sectors by accepting their handoffs. To do this, they will need to obtain the flight plan information from the controllers by coordinating over the landline.

h. The controllers will try to reduce the number of handoffs they accept, especially until nonradar separation is firmly established.

i. Once flight plan information has been sent to adjacent sectors, the controllers will handoff as many aircraft as possible to reduce their own workload.

3.3.1 Potential Differences from Routine Operations

Most of the potential differences between this situation and normal en route operations occur during the period when the controllers are establishing nonradar operations. Once established, the effects are primarily on efficiency because the controllers will not handle as many aircraft but will handle them safely and at a moderate workload level.

The primary metric for this situation is the time required after the radar outage until nonradar separation is achieved for all aircraft. This measure includes the time needed to recognize the problem, notify the supervisor and other controllers, and reroute or resequence traffic to achieve proper separation. A related metric is the number of altitude, speed, and heading changes used to obtain the en route separation.

Table 3 presents measurable potential differences between this special situation and routine operations.

Table 3. Potential Effects of Radar Outage: Nonradar Control

Construct	Metric	Possible Direction & Magnitude
Safety Risk	**Standard metrics**	**Small increase over routine operations**
Efficiency	**Standard metrics**	**Moderate decrease over routine operations**

Table 3. Potential Effects of Radar Outage: Nonradar Control (continued)

Construct	Metric	Possible Direction & Magnitude
Efficiency (cont.)	Number of aircraft in holding pattern	Increase in short term until nonradar is established
	Average duration of hold	Increase in short term until nonradar is established
	Number of altitude, speed, & heading changes	Increase in short term until nonradar is established
	Number of aircraft under control	Decrease as controllers handoff to adjacent sectors or facilities
	Elapsed time from the radar outage until nonradar control is established for all aircraft.	N/A – Metric does not directly compare to routine operations
Workload	**Standard metrics**	**Moderate increase over routine operations**
	Number of uses of URET Aircraft List	Increase in short term until data become too outdated
	Number of uses of URET Graphic Plan Display	Increase in short term until data become too outdated
	Number of initiate handoff commands	Increase until affected sectors are cleared
	Number of accept handoff commands	Decrease until radar is available again
	Number of hold commands	Increase in short term until nonradar is established
	Number of altitude, speed, and heading commands	Increase in short term until nonradar is established
	Number of progress report commands	Increase

Table 3. Potential Effects of Radar Outage: Nonradar Control (continued)

Workload (cont.)	Number of reported altitude commands	Increase
	Number of ground-ground communications	Increase in short term until nonradar is established
	Number of air-ground communications	Increase

3.3.2 Considerations for Testing

A human-in-the-loop simulation of a radar outage at the ARTCC is somewhat complex. We would disable the Target Generation Facility (TGF) component that simulates the selected radar at the chosen time. This will propagate errors and discrepancies up through the system, eventually resulting in radar outage messages at the controllers' displays and activation of the HCS mosaic presentation. To conduct a more rigorous simulation, we should select sectors without radar redundancy or could simulate multiple radar failures. In the latter case, we would have to develop a situation such as severe weather to explain why multiple redundant radars would fail at roughly the same time. In addition, pseudopilots playing the role of the affected pilots may not be accustomed to making position reports and may need additional training.

3.4 Flight Data Processing Outage at an Adjacent Facility

Description: "There is a Host failure at an adjacent facility, and your facility must absorb some of the traffic."

In the legacy system, FDP is handled by the HCS; in ERAM, the ERAM FDP module will handle these functions. In the current NAS, FDP computers are taken offline routinely for service by Technical Operations personnel. However, they normally coordinate these outages well in advance and schedule them for times with the least potential impact to operations. When scheduled and properly coordinated, an FDP outage causes only minimal disruption to the NAS.

On the other hand, losing FDP functionality unexpectedly can be a difficult situation. Aircraft callsigns and flight plans are no longer available or updated. Alerting algorithms, such as conflict alert and minimum safe altitude, no longer operate. Controllers must rely on their flight strips and controllers at adjacent facilities for assistance. The affected ARTCC will quickly slow down or reroute traffic to reduce the chance for error and keep workload manageable. The affected ARTCC will try to handoff as many aircraft as possible to adjacent facilities. Controllers at adjacent facilities will see their workload increase as they put their own aircraft into hold and reroute traffic away from the affected facility. Our SMEs characterized this situation as creating a small increase in safety risk, a moderate decrease in efficiency, and a moderate increase in workload.

To address the FDP outage at an adjacent facility situation, controllers typically take the following actions.

a. Controllers receive information over the landline about the HCS failure from controllers at the affected facility or from their own supervisor. If a controller is the first to learn about the failure, he or she must notify the supervisor immediately.
b. The supervisor notifies the TMU at the ARTCC.
c. The controllers staffing sectors that receive traffic directly from the affected facility will stop accepting handoffs from unaffected sectors and facilities and accept handoffs only from the affected facility.
d. The controllers select new display maps to include as much of the affected airspace as possible.
e. The supervisor may remap some VSCS frequencies, and the controllers will activate them at their workstations.
f. The controllers try to radar-identify targets from the affected facility that they can see but for whom no flight plan exists. Even with an FDP outage, controllers can still see limited data blocks with beacon codes and altitudes. The controllers will make landline calls to the affected facility to obtain flight plan and route information. The controllers also may make radio transmissions to obtain the information directly from pilots. They enter the information into the HCS as it becomes available.
g. The TMU tries to slow down the incoming flows to the affected facility.
h. At the sectors feeding the affected ARTCC, the controllers would begin holding aircraft at the boundary so as not to increase traffic volume in the affected facility. The controllers will issue necessary clearances to keep holding aircraft separated.
i. If the hold lasts a long time, the controllers will begin issuing new routes to the holding aircraft.

3.4.1 Potential Differences from Routine Operations

Because this situation may last for a long time, any measured differences will also have a long duration. In some cases, the differences will change as the traffic situation changes.

The primary metric for this situation is the time required after the FDP outage until all aircraft are again under active control. This measure would include the time needed to recognize the problem, notify the supervisor and other controllers, and reroute or resequence traffic to achieve proper separation. A related metric is the amount of manual coordination necessary between the affected and unaffected facilities in the form of communications and flight plan transfers. Table 4 presents measurable potential differences between this special situation and routine operations.

Table 4. Potential Effects of Flight Data Processing Outage at Adjacent Facility

Construct	Metric	Possible Direction & Magnitude
Safety Risk	**Standard metrics**	**Small increase over routine operations**
Efficiency	**Standard metrics**	**Moderate decrease over routine operations**
	Number of aircraft in holding pattern	Increase
	Average duration of holding pattern	Increase
	Number of altitude, speed, & heading changes	Increase
	Number of route changes	Increase if situation lasts a long time
	Number of aircraft under control	Increase in short run as controller takes handoffs from affected facility; decrease in long run as aircraft are rerouted around the affected facility.
	Elapsed time from the FDP outage until all aircraft from the affected facility are again under active control.	N/A – Metric does not directly compare to routine operations
Workload	**Standard metrics**	**Moderate increase over routine operations**
	Number of start track commands	Increase in short run until all flights from affected facility are under active control
	Number of accept handoff commands to unaffected facility from affected facility	Increase in short run until all flights from affected facility are under active control

Table 4. Potential Effects of Flight Data Processing Outage at Adjacent Facility (continued)

Construct	Metric	Possible Direction & Magnitude
Workload (cont.)	Number of accept handoff commands to unaffected facility from unaffected sectors or unaffected facilities	Decrease
	Number of hold commands	Increase
	Number of altitude, speed, and heading commands	Increase
	Number of flight plan readout commands	Increase in short run until all flights from affected facility are under active control
	Number of beacon code commands	Increase in short run until all flights from affected facility are under active control
	Number of route amendment commands	Increase (if outage lasts for a long time)
	Number of ground-ground communications	Increase
	Number of air-ground communications	Increase

3.4.2 Considerations for Testing

A human-in-the-loop simulation of an FDP outage at an adjacent ARTCC is complex. The TGF component that accepts interfacility flight plans and generates interfacility handoffs to the affected facility would be disabled at the appropriate time. The errors and unaccepted handoffs would propagate to the unaffected facility, and the controllers would shortly notice the problem. Because of the complex coordination between the controllers and the affected facility, experienced controllers should staff ghost sectors. A supervisor and perhaps a TMU specialist should be available during the simulation to provide realism for those aspects of the situation.

3.5 Special Use Airspace: Intruder

Description: "TFRs and Combat Air Patrols (CAPs) are in place because of the Super Bowl. A visual flight rules (VFR) aircraft with no flight plan enters the restricted zone."

This is a critical situation where FAA controllers serve mainly as support to national defense organizations. When the intruder is detected, special procedures are started by the Department of Defense (DoD) involving prescribed actions at specific times. Actions by the FAA will not normally affect the execution of the DoD procedures. The controller will track the intruder and try to contact it. However, if the specified time passes, DoD will scramble jets or helicopters for an intercept, and the controller will need to coordinate with DoD or law enforcement. Most importantly, controllers need to move other aircraft out of the way. Our SMEs characterized the situation as creating a small increase in safety risk, a small decrease in efficiency, and a small increase in workload.

Each of these situations varies but, in general, controllers will take the following actions.

a. The en route controller informs the supervisor and other necessary parties.
b. The supervisor may add controllers or change airspace configurations to take workload off the affected controller.
c. The controller may make a blind broadcast to the intruder.
d. If the intruder responds, the controller will start a track on the aircraft and "suggest" a heading to leave the restricted area.
e. If the specified time passes without a response and interceptor aircraft are scrambled, the controller may need to move other aircraft out of their flight path and away from the restricted area. The controller will not normally create flight plans for the intercepting aircraft.
f. As needed, the controller will vector the interceptors toward the intruder.
g. The controller will track the intruder until it lands on its own or is escorted out of the TFR area by the interceptors.

3.5.1 Potential Differences from Routine Operations

This situation lasts until the intruder leaves the restricted airspace or it is resolved in some other manner. Once the interceptor aircraft arrive and escort the intruder away, normal operations should resume quickly. Table 5 presents measurable potential differences between this special situation and routine operations.

Table 5. Potential Effects of Special Use Airspace: Intruder

Construct	Metric	Possible Direction & Magnitude
Safety Risk	**Standard metrics**	**Small increase over routine operations due to the unpredictability of the situation and movements of the CAP aircraft.**
Efficiency	**Standard metrics**	**Small decrease over routine operations**
	Number of altitude, speed, & heading changes	Increase for aircraft near restricted area or in CAP flight path
	Number of route changes	Increase for aircraft near restricted area or in CAP flight path
	Number of aircraft under control	Decrease as controller vectors aircraft away from the area in response to a CAP action
Workload	**Standard metrics**	**Small increase over routine operations**
	Number of altitude, speed, and heading commands	Increase for aircraft near restricted area or in CAP flight path
	Number of route commands	Increase for aircraft near restricted area or in CAP flight path
	Number of ground-ground communications	Increase
	Number of air-ground communications	Increase

3.5.2 Considerations for Testing

Realistically simulating this situation is very complex. We would have to construct appropriate TFR maps ahead of time and loaded them into the automation systems. In the field, the local facility would construct them. The TGF maintains aircraft models for VFR and military aircraft, and they can be added to the scenario at the appropriate times. However, ensuring that the procedures and communications are realistic requires carefully working with FAA-procedure SMEs and possibly representatives from DoD or law enforcement. In addition, the pseudopilots playing the roles of the intruder and the interceptor aircraft need special training and scripts with specific pseudopilot actions to take at specific times. Extensive shakedown and testing of this situation would be necessary.

3.6 Special Use Airspace: Dynamic Temporary Flight Restrictions

Description: "Moving TFRs and CAPs are in place because of a presidential motorcade on the ground. Constraints (e.g., altitude) vary depending on the affected areas. One of the areas surrounds a major airport that remains open to commercial flights."

Scheduled carriers normally are permitted to use these TFR areas, but general aviation (GA) aircraft are not. If GA aircraft approach the TFR, controllers will need to keep them away by issuing clearances and reroutes. Our SMEs characterized this situation as creating a small increase in safety risk, a large decrease in efficiency, and a small increase in workload.

To address this situation, controllers will normally take the following actions.

a. Controllers will configure the radar display to include information about the TFR. This will involve displaying a prepared map or using the annotation tool in the DSR to create the area.

b. If GA aircraft approach the TFR, controllers will contact the aircraft and issue new routes and change flight plans.

3.6.1 Potential Differences from Routine Operations

As with the intruder situation, the duration of the situation depends on what occurs with regard to the motorcade. If the motorcade is delayed for a long time, the effect of the situation on operations will be extended for the necessary duration. Once the TFR is over, normal operations can resume fairly quickly. Table 6 presents measurable potential differences between this special situation and routine operations.

Table 6. Potential Effects of Special Use Airspace: Dynamic Temporary Flight Restriction

Construct	Metric	Possible Direction & Magnitude
Safety Risk	**Standard Metrics**	**Small increase over routine operations because of the potential interaction with inexperienced GA pilots**
Efficiency	**Standard Metrics**	**Large decrease over routine operations**
	Number of altitude, speed, & heading changes	Increase for aircraft that must be vectored away from the TFR; decrease overall due to fewer aircraft in sector
	Number of route changes	Increase for aircraft that must be vectored away from the TFR; decrease overall due to fewer aircraft in sector
	Number of aircraft under control	Decrease
Workload	**Standard metrics**	**Small increase**
	Number of altitude, speed, and heading commands	Increase for aircraft that must be vectored away from the TFR; decrease overall due to fewer aircraft in sector
	Number of route amendment commands	Increase for aircraft that must be vectored away from the TFR; decrease overall due to fewer aircraft in sector
	Number of uses of annotation tools	Increase as the TFR area moves
	Number of air-ground communications	Increase for aircraft that must be vectored away from the TFR; decrease overall due to fewer aircraft in sector

3.6.2 Considerations for Testing

If planned and coordinated ahead of time, a situation like this has low operational impact. However, if the TFRs change dynamically, the situation can become much more complex for controllers. For a rigorous simulation, the situation could change from its pre-coordinated route or schedule. This would add complexity without sacrificing realism. For example, the motorcade could be significantly behind schedule so that controllers must divert or place in hold GA aircraft that are already en route to the airport.

Unlike the intruder situation, realistically simulating this situation is not difficult. We would develop a script that contains the actions of the motorcade with corresponding times. A supervisor would be responsible for portraying the events as they unfold. No special scenario development or pseudopilot training is necessary. We would provide some shakedown and testing of this situation to ensure that the supervisor is comfortable following the script and does not reveal what happens next to the controllers in the simulation.

3.7 Severe Weather: Deviations

Description: "Severe weather conditions have arisen very quickly making it necessary for traffic in your sector and an adjacent sector to divert through a narrow corridor in your sector."

Each severe weather situation is different so there is no fixed order of controller actions. In any case, as the controllers work the traffic, certain actions will become more frequent as the traffic pattern adjusts in response to the dynamic weather situation. Our SMEs characterized this situation as having a moderate increase in safety risk, a large decrease in efficiency, and a large increase in workload.

Controllers commonly take the following actions to address a severe weather situation like this.

a. The controller will likely rely more heavily on vertical separation because the open corridor is narrow. As a result, the controller will issue more altitude clearances.

b. The controller will frequently coordinate with adjacent sectors and facilities, including initiating and approving point outs.

c. Because the corridor is located in the controller's sector, the controller will be accepting more handoffs from adjacent sectors who have rerouted their traffic.

d. The controller may use the URET Aircraft List to obtain flight plan information from other sectors or facilities.

e. The controllers will make route amendments to reflect changes in flight path for each aircraft. As they become busier, updating the flight plan will decrease in priority. The D-side controller will be very busy making entries.

f. The controller may use the DSR annotation tools to reflect pilot reports of the weather as they come in or to mark the areas that pilots are flying if the controller gives them discretion to deviate as necessary. In addition, if they are filing formal pilot reports, the controller must record these by hand and give them to the supervisor.

g. The controller may use URET Wind Grid Display to examine the wind situation.

h. The controller may be receiving and reading information in the DSR sent by the TMU regarding the weather. In the HCS, controllers may also use the Weather Request (WR) command.

3.7.1 Potential Differences from Routine Operations

The duration of the situation is completely dependent on the behavior of the weather. As the weather clears, traffic will begin to return to normal, but the effects of deviations can last until all the deviated aircraft are back on their normal routes. Table 7 presents measurable potential differences between this special situation and routine operations.

Table 7. Potential Effects of Severe Weather: Deviations

Construct	Metric	Possible Direction & Magnitude
Safety Risk	**Standard metrics**	**Moderate increase over routine operations**
Efficiency	**Standard metrics**	**Large decrease over routine operations**
	Number of altitude, speed, & heading changes	Increase
	Number of route changes	Increase
	Number of aircraft under control	Increase while the corridor through the weather is located in the sector; decrease once TMU or other facilities begin to reroute traffic before they reach the sector
Workload	**Standard metrics**	**Large increase over routine operations**
	Number of altitude, speed, and heading commands	Increase
	Number of route commands	Increase
	Number of air-ground communications	Increase
	Number of ground-ground communications	Increase

Table 7. Potential Effects of Severe Weather: Deviations (continued)

Construct	Metric	Possible Direction & Magnitude
Workload (cont.)	Number of uses of URET Aircraft list	Increase
	Number of uses of URET Wind Grid Display	Increase
	Number of point out commands	Increase
	Number of accept handoff commands	Increase
	Number of route readout commands	Increase
	Number of uses of annotation tools	Increase
	Number of weather request commands	Increase

3.7.2 Considerations for Testing

Realistic simulations of severe weather situations are complex. We must collect a sample of recorded weather data and replay it through the TGF or other simulator. Modifications to the data may be necessary to move the weather to the desired location and to have the desired characteristics and timing. We must adapt traffic scenarios to follow the weather. Pseudopilots need considerable experience to make their own decisions about how to deviate around the weather according to the controller's instructions. For example, the controller may allow the pilot to deviate "as necessary up to 20 degrees left." The pseudopilots are relying on the simulated weather also and need to realistically maneuver the aircraft. We may need to simulate additional weather systems, such as the Weather and Radar Processor, to provide realism for controllers and sufficient information to support the pseudopilots. Ahlstrom & Della Rocco (2003) began developing metrics to measure controller performance with regard to weather that we could explore for inclusion here.

3.8 Severe Weather: Playbook Action

Description: "Due to serious weather, the TMU has implemented a Playbook action affecting your sector and other centers in the country. You must initiate major reroutes through your airspace."

Reroutes are a routine part of en route ATC and the commands associated with reroutes will be covered during day-in-the-life scenarios. However, implementing a Playbook action can affect hundreds or even thousands of flights. In most cases, these reroutes are issued made by the airlines through their dispatch office. However, in some cases, a controller must directly issue reroutes for the traffic in his or her sector over the radio, known as a “red route[1].” If a controller has many red routes, the controller’s workload will increase. Our SMEs characterized this situation as creating a small increase in safety risk, a small decrease in efficiency, and a large increase in workload.

In general, controllers take the following actions to respond to a new Playbook action.

a. The reroute will normally appear highlighted in URET or on the printed flight strip as a red route. In this case, the reroute is already in the system, but the controller still needs to issue it to the pilot.

b. The controller may use the URET Aircraft List or Graphic Plan Display to ensure that the new route does not create potential conflicts.

c. The controller will issue the reroute to the pilot by making a radio transmission.

d. The controller will use a strip marking or the URET Aircraft List checkbox function to indicate when a reroute has been successfully issued.

e. If the controller cannot enter the reroute into the HCS automatically, it will not appear as a red route. In this case, the supervisor will manually provide it to the controller. The controller must enter the reroute into the HCS for each affected aircraft. Then the controller must issue it manually to each pilot over the radio.

f. Controllers will use ground-ground communications and the fourth line in the datablock for heading, speed, and free form text to coordinate with other sectors and facilities that will be receiving the rerouted traffic. In the HCS, the fourth line of the data block can be amended using the Full Datablock Heading, Speed, and Free Form Text (QS) command or by using the corresponding flyout menu on the DSR.

3.8.1 Potential Differences from Routine Operations

The duration of the situation is completely dependent on the behavior of the weather. As the weather clears, traffic will begin to return to normal but the effects of major reroutes can last until all the rerouted aircraft arrive at their destinations and TMU begins issuing normal routes again. Table 8 presents measurable potential differences between this special situation and routine operations.

[1] The term red route originated with earlier flight strip printers, which coded the reroutes in red ink. In the current en route system, red routes are coded with reverse video.

Table 8. Severe Weather: Playbook Action

Construct	Metric	Possible Direction & Magnitude
Safety Risk	**Standard metrics**	**Small increase over routine operations**
Efficiency	**Standard metrics**	**Small decrease over routine operations**
	Number of route changes	Increase
	Number of aircraft under control	Depends on the relationship between the sector and the Playbook action. Some sectors will experience an increase in traffic as more traffic are routed to them. Other sectors will experience a corresponding decrease.
Workload	**Standard metrics**	**Large increase over routine operations**
	Number of route commands	Increase
	Number of route readout commands	Increase
	Number of air-ground communications	Increase
	Number of ground-ground communications	Increase
	Number of uses of URET Aircraft list, especially checkbox feature	Increase
	Number of uses of URET Trial Plan tools	Increase
	Number of full datablock speed, heading, and free form text amendments	Increase

3.8.2 Considerations for Testing

This situation can be simulated easily. The reroutes would be prepared before the simulation, and the supervisor would provide them to the controllers at a selected time. For a realistic simulation of red routes, the reroutes would need to be entered into the system enough in advance to cause the red routes to appear on the flight strips and in URET. We would need to work with TMU SMEs to select Playbook actions that are appropriate and identify sectors that are affected by the action.

3.9 Traffic Congestion

Description: "Traffic from your sector into an adjacent sector is heavy. The adjacent sector reports that it cannot accept any more aircraft, effective immediately."

Our SMEs characterized this situation as initially creating no increase in workload, no decrease in efficiency, and no increase in safety risk. As the duration of the congestion increases, however, the safety risk remains may increase slightly but the workload and efficiency impact both can become moderate to large.

To handle a situation such as this, en route controllers will typically take the following actions.

a. The controller will begin holding aircraft immediately and start coordinating with adjacent sectors. The controller may record expect-further-clearance information on the flight strip, in the remarks field using the Amendment (AM) command, or in the URET "Hotbox" free form text area.

b. The controller will coordinate regularly with the supervisor. Other sectors and the TMU might start easing the incoming flow to assist the controller and manage workload.

c. The controller will rely on altitude separation to keep aircraft in hold separated.

d. Eventually, the controller will stop accepting handoffs from adjacent sectors.

e. If a hold lasts longer than first anticipated, the controller must extend the holds by communicating with pilots at least 5 minutes prior to expiration.

f. If the congestion continues for a long time, pilots will request to be rerouted and the controller will make corresponding flight plan amendments.

3.9.1 Potential Differences from Routine Operations

As with weather, the duration of this situation is not fixed. Initially, the situation is not serious, but it quickly deteriorates as more aircraft are put in hold and more are rerouted. In the field, closing a sector for congestion would only last until the affected sector was cleared and then the TMU adjusted flows to ensure that another closure was not necessary. Table 9 presents measurable potential differences between this special situation and routine operations.

Table 9. Potential Effects of Traffic Congestion

Construct	Metric	Possible Direction & Magnitude
Safety Risk	**Standard metrics**	**No measurable change over routine operations initially; small or moderate increase at long durations**
Efficiency	**Standard metrics**	**No measurable change over routine operations initially; moderate or large increase at long durations**
	Number of aircraft in holding pattern	Increase
	Average duration of holding pattern	Increase
	Number of route changes	Increase if situation has a long duration
	Number of aircraft under control	Increase in the short run as aircraft enter sector but are not handed off; level off or decrease as TMU responds to the situation and aircraft are rerouted.
Workload	**Standard metrics**	**No measurable change over routine operations initially; moderate to large increase at long durations**
	Number of hold commands	Increase
	Number of altitude, speed, and heading commands	Increase
	Number of entries to the remarks field	Increase
	Number of uses of URET Hotbox (free form text)	Increase

Table 9. Potential Effects of Traffic Congestion (coninued)

Construct	Metric	Possible Direction & Magnitude
Workload (cont.)	Number of route amendment commands	Increase if situation has a long duration
	Number of air-ground communications	Increase
	Number of ground-ground communications	Increase

3.9.2 Considerations for Testing

This situation is simple to simulate, especially the initial event and the immediate response. As the situation continues, however, the traffic scenario will need to change to simulate the actions of the TMU to reroute traffic away from the congested area. This will require consultation with TMU SMEs to develop realistic timing and characteristics for the slowdown of traffic. In addition, experienced controllers should staff ghost sectors due to the complexity of the coordination between the controllers and the closed sector.

3.10 In-flight Emergency

Description: "An aircraft has reported a loss of electrical and hydraulic power and is descending rapidly and unpredictably through your sector."

Though a single in-flight emergency is obviously dangerous for the aircraft and stressful for the pilots and controllers involved, the effect on overall ATC operations is not large. Our SMEs characterized this situation as creating a small to moderate increase in safety risk, no measurable change to a small decrease in efficiency, and a small to moderate increase in workload. To handle this situation, controllers typically take the following actions.

a. The controller will try to obtain the callsign, aircraft type, and nature of emergency from the pilot.

b. The controller may use the fourth line in the datablock to designate an aircraft in emergency. This can be accomplished using the QS command in the HCS or the corresponding flyout menu in the DSR.

c. The controller will enter altitude information for the affected aircraft as much as possible. This may be from reported altitudes from the pilot.

d. The controller will coordinate with adjacent sectors, particularly those below, typically using point outs.

e. The controller will direct the aircraft to the nearest suitable airport. The controller may make airport information entries to identify the best location.

3.10.1 Potential Differences from Routine Operations

This situation will only last until the aircraft is safely on the ground. Depending on location and altitude, this can take 10-30 minutes. Once the aircraft has landed, normal operations resume quickly. Table 10 presents measurable potential differences between this special situation and routine operations.

Table 10. Potential Effects of In-flight Emergency

Construct	Metric	Possible Direction & Magnitude
Safety Risk	**Standard Metrics**	**Small or moderate increase over routine operations**
Efficiency	**Standard Metrics**	**No measurable change or small decrease over routine operations**
	Number of aircraft in holding pattern	Increase
	Average duration of holding pattern	Increase
	Number of route changes	Increase if situation has a long duration
	Number of aircraft under control	Increase in the short run as aircraft enter sector but are not handed off; level off or decrease as TMU responds to the situation and aircraft are rerouted.
Workload	**Standard metrics**	**Small or moderate increase over routine operations**
	Number of altitude commands, especially reported altitude	Increase
	Number of airport information commands	Increase
	Number of point out commands	Increase

Table 10. Potential Effects of In-flight Emergency (continued)

Construct	Metric	Possible Direction & Magnitude
Workload (cont.)	Number of air-ground communications	Increase
	Number of ground-ground communications	Increase

3.10.2 Considerations for Testing

Because we do not normally simulate in-flight emergencies, the TGF pseudopilots would need training to realistically simulate emergency radio communications. In addition, we will have to carefully construct the traffic scenario and aircraft behavior to be realistic. We might need to obtain a flight profile for an aircraft in a similar emergency situation, perhaps in consultation with the Civil Aerospace Medical Institute, and hard code the aircraft flight path into the traffic scenario. This would allow the pseudopilot to concentrate on making realistic communications at the scripted times rather than creating realistic emergency maneuvers. Obviously, substantial testing and shakedown would be necessary.

3.11 Onboard Medical Emergency

Description: "A departing commercial aircraft has reported a medical emergency onboard and requests to land at the nearest available airport. The aircraft must dump fuel before landing."

Again, though this is a serious situation for the people involved, its effect on overall en route operations is minor. Our SMEs characterized this situation as creating no measurable change in safety risk, no measurable change to a small decrease in efficiency, and a small to moderate increase in workload. To handle this situation, en route controllers will typically take the following steps.

a. The controller will look for a suitable airport. If the controller normally works high altitude sectors, he or she may not be knowledgeable of the characteristics of all airports along the route of flight.

b. The controller will coordinate with sectors below, typically using point outs.

c. The controller will notify the supervisor and the TMU, as needed.

d. The controller will make point outs and coordinate with adjacent sectors while the pilot is dumping fuel.

e. The controller will make altitude and flight plan amendments for the aircraft.

f. The controller will coordinate with the airport authority regarding the medical emergency, as needed.

3.11.1 Potential Differences from Routine Operations

This situation will only last until the aircraft is safely on the ground. Depending on location, altitude, and the amount of fuel needing to be dumped, this can take 10-30 minutes. Once the aircraft has landed, normal operations resume quickly. Table 11 presents measurable potential differences between this special situation and routine operations.

Table 11. Potential Effects of Onboard Medical Emergency

Construct	Metric	Possible Direction & Magnitude
Safety	**Standard metrics**	**No measurable change over routine operations**
Efficiency	**Standard metrics**	**No measurable change to a small decrease over routine operations**
Workload	**Standard metrics**	**Small or moderate increase over routine operations**
	Number of airport information commands	Increase
	Number of point out commands	Increase
	Number of air-ground communications	Increase
	Number of ground-ground communications	Increase

3.11.2 Considerations for Testing

Because we do not normally simulate onboard medical emergencies, the TGF pseudopilots would need training to realistically simulate radio communications for this situation. Because the approach and landing for the aircraft would follow standard procedures and clearances, additional training or scenario scripting would not be necessary.

4. Discussion and Next Steps

The effectiveness of an en route ATC system cannot be thoroughly tested using only routine situations. The information presented provides a set of important operational situations and characterizes them in terms of measurable potential differences from routine operations. Comparing how well the legacy en route system and ERAM support these special situations can assure the FAA that ERAM will effectively support controllers in many operational contexts.

The majority of the controller commands discussed previously appear in the 30 most frequently used commands identified in our earlier report (Allendoerfer et al., 2006), with the following exceptions.

1. Emergency Airport Display (AI)
2. Reported Altitude (QR)
3. Hold (QH)
4. Suppress Conflict Alert (CO) and Group Suppression (SG)
5. Entry of remarks into flight plan using Amendment (AM) command
6. URET Aircraft List Checkbox
7. URET Hotbox (free form text)
8. URET Trial Plan
9. URET Graphic Plan View
10. URET Wind Grid Display
11. DSR Annotation tools

We recommend that these commands be treated equivalently to the 30 most frequently used commands during testing because of these commands' importance in special situations. Though they are not commonly used during routine operations, they are necessary during certain less common but operationally important situations.

<u>4.1 Comparing Systems</u>

Critical Operational Issue 1 for ERAM says

> *Does ERAM support ATC operations, using current ATC procedures and methods to provide safe, orderly, and expeditious flow of traffic, with at least the same effectiveness as the current system?* (FAA, 2003)

To answer this question, as part of formal DS testing, we propose running human-in-the-loop simulations for routine situations and for some of special situations discussed here, as dictated by resource constraints. During the simulations of the special situations, we will collect data while controllers respond to the situation using the legacy system and repeat the simulation using ERAM. To be considered at least as effective as the legacy system, the results obtained for ERAM must be equivalent or better than the results obtained for the legacy system. If the legacy system and ERAM are equivalent for a situation, the results would show changes in the relevant metrics of the same direction and magnitude for both systems. If there are differences between the systems on the relevant metrics, we will determine if the differences represent improvements or reductions in system effectiveness or if the differences resulted from experimental confounds.

The situations discussed in this report are not designed to highlight known differences between the legacy system and ERAM. Those differences will be discussed in the third report in this series. Rather, the situations described here provide a cross section of events that occur in the NAS that place the system and the controllers closer to their limits. We do not believe that it would be sufficient to test only routine situations or situations where a known difference between the legacy system and ERAM exists. The rigorous and thorough test program that we advocate tests both systems across a range of operational situations, including some that are intentionally difficult for the system and controllers to handle. Doing so would allow us to determine if there are unanticipated differences between the systems. Testing as many different situations as possible would give the FAA confidence that ERAM supports ATC operations with at least the same effectiveness as the legacy system across the wide range of conditions that controllers encounter operationally.

4.2 Mapping ERAM Changes

ERAM makes a number of changes to the legacy system. Some of these changes are directly related to the controller user interface (UI) and have a clear potential to affect how controllers use the system. Other ERAM changes are not specifically targeted at the UI but may have latent effects on controllers. In the next phase of this project, we will conduct an analysis to identify areas where changes in ERAM can be anticipated to affect how controllers use and interact with the system. We will include these areas in our subsequent test plans and activities.

Examples of ERAM changes that we anticipate will have some effect on controllers include the following.

- ERAM will use Areas of Interest (AOIs) to expand the flight database for each ARTCC. AOIs may reduce the amount of time controllers spend manually transferring flight plan data between facilities because a larger number of flight plans from adjacent facilities will be available. This ERAM change may affect how controllers respond to special situations like the FDP Outage at Adjacent Facility situation described in Section 3.4.
- ERAM will incorporate new tracker algorithms. Other members of the AMTWG are examining the ERAM tracker from the accuracy and performance standpoints. However, as occurred on the Standard Terminal Automation Replacement System deployment, changes in tracker algorithms, if obvious to controllers, can affect controllers' acceptance of and trust in the new system. Identification of situations where controllers might notice differences in ERAM due to its tracker algorithm should be identified early and included in ERAM testing and training.
- ERAM will contain a new approach toward system redundancy and backup. This change is not targeted at the UI but may affect how controllers respond to equipment outages. This ERAM change may affect how controllers respond to special situations like the FDP Outage at Adjacent Facility situation described in Section 3.4.

4.3 Usage Characteristics

Using the list of 30 most frequently used commands from the first report (Allendoerfer et al., 2006) plus the important-but-infrequent commands identified in Section 4, we will conduct detailed analyses to determine usage characteristics for each. Usage characteristics include examining some of the sample analyses reported here but also examining each function at a more detailed level, such as the time to complete an action, the number of keystrokes or mouse clicks required, the time spent looking at the keyboard or screen, and the error rate. We will base the usage characteristic analysis on data already collected from ZDC and other ARTCCs. The analysis will also include observations and measurements made in the Intergration and Interoperability Facility for critical functions that are not found in the day-in-the-life recordings.

4.4 Additional Facilities

All the analyses reported here are based on discussions with controllers from two ARTCCs. A more definitive analysis would include interviews with SMEs from a larger number of facilities and, at best, all of them.

4.5 Baseline Simulation Test Plan

The best method for directly comparing controller usage of the legacy system and ERAM is to conduct a baseline simulation on both platforms. In the baseline simulations, we will present controllers with selected traffic situations and ask them to respond to the same situations using both systems. The same metrics will be calculated for both systems and direct comparisons can be made with a minimum of confounding variables. Discussion of the baseline methodology can be found in the *Air Traffic Control Baseline Methodology Guide* (Allendoerfer & Galushka, 1999) and the reports of baseline simulations conducted for the PVD (Galushka et al, 1995) and the DSR (Allendoerfer et al., 2000).

If the changes in ERAM result in changes in how controllers interact with the system, these differences should appear in the baseline metrics. For example, if the ERAM single flight database eliminates the need to manually transfer flight plans between facilities, this benefit could appear as a reduction in the number of flight plan entries surrounding an outage.

If changes in ERAM result in changes in other aspects of controllers' tasks, such as operational efficiency, these differences should appear in other baseline metrics. These metrics include measures of air traffic safety, efficiency, and workload (Allendoerfer & Galushka, 1999). For example, if an ERAM change reduces controller data entry workload, which, in turn, results in controllers being able to handle more traffic, baseline metrics such as the number of aircraft handled or the average time in the sector may show improvements.

In preparation for the baseline simulations, we will write a test plan that outlines the situations to be simulated, metrics that will be captured, and other methodological details. The descriptions of the simulated situations will outline requirements for traffic volume and characteristics (e.g., number of aircraft, number of intersecting trajectories) and operational events (e.g., emergencies, outages) that will occur in several scenarios that drive the simulation platform. The simulated situations will allow controllers to exercise all selected functions, and we will design it to elicit latent effects of other ERAM changes, if any. We will develop and shakedown the scenarios as part of preparations for the simulations.

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Acronyms & Abbreviations

A-position	Assistant Position
A-side	Assistant Side
AMTWG	Automation Metrics Test Working Group
AOI	Areas of Interest
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
CAP	Combat Air Patrols
COI	Critical Operational Issues
CPT	Conflict Probe Tool
D-position	Data Position
D-side	Data Side
DoD	Department of Defense
DS	Display System
DSR	Display System Replacement
ERAM	En Route Automation Modernization
FAA	Federal Aviation Administration
FDP	Flight Data Processing
GA	general aviation
HCS	Host Computer System
NAS	National Airspace System
PVD	Plan View Display
QP	Point Out Command?
SDP	Surveillance Data Processing
SME	Subject-Matter Expert
TFR	Temporary Flight Restrictions
TGF	Target Generation Facility
TMU	Traffic Management Unit
TRACON	Terminal Radar Control
UI	User Interface
URET	User Request Evaluation Tool
VFR	visual flight rules
VSCS	Voice Switching and Control System
ZDC	Washington ARTCC

Appendix A

Interview Form

HOST/DSR/URET Critical Interaction Analysis Survey Form

The NAS Human Factors Group recently analyzed the frequency with which controllers access HOST/DSR/URET functions using actual data obtained from an ARTCC over an 11-hour period. While this information is useful, it does not tell us about the importance of a function, particularly during somewhat uncommon, but serious events. Some functions may be used relatively infrequently, but are nevertheless extremely important when certain situations arise.

Instructions:

1) For each of the events described below, please provide ratings as to the extent to which your workload and efficiency are affected, and the extent to which the situation presents a safety risk. For all events, assume that the traffic level is moderate to heavy. Use the following scales to make your ratings.

   Workload: (include all aspects of workload – mental, physical, temporal demand, etc.)

   ① No effect on workload.

   ② Slight increase in workload.

   ③ Moderate increase in workload.

   ④ Large increase in workload.

   Efficiency:

   ① No effect on efficiency.

   ② Slight decrease in efficiency.

   ③ Moderate decrease in efficiency.

   ④ Large decrease in efficiency.

   Safety/Risk:

   ① No risk to safety even if appropriate actions can not be taken immediately.

   ② Small risk to safety if appropriate actions can not be taken immediately.

   ③ Moderate risk to safety if appropriate actions can not be taken immediately.

   ④ High risk to safety if appropriate actions can not be taken immediately.

2) Then list and rank order the most critical functions needed to manage activities at your workstation during each event and describe your use of those functions in those situations.

	Event	Ratings	Most Critical Functions and Description of Their Purpose
1.	**Display Outage** The display goes out at your workstation. You need to move to another position and bring up another workstation.	Workload: ① ② ③ ④ Efficiency: ① ② ③ ④ Risk: ① ② ③ ④	1. ____ 2. ____ 3. ____ 4. ____ 5. ____ Others:
2.	**Radar Outage 1** The radar goes out at the TRACON and your center must now manage the aircraft within that airspace.	Workload: ① ② ③ ④ Efficiency: ① ② ③ ④ Risk: ① ② ③ ④	1. ____ 2. ____ 3. ____ 4. ____ 5. ____ Others:
3.	**Radar Outage 2** Radar goes out in the sector and non-radar control must be used.	Workload: ① ② ③ ④ Efficiency: ① ② ③ ④ Risk: ① ② ③ ④	1. ____ 2. ____ 3. ____ 4. ____ 5. ____ Others:
4.	**HOSTOutage** There is a HOST failure at	Workload: ① ② ③ ④	1. ____ 2. ____

	Event	Ratings	Most Critical Functions and Description of Their Purpose
	an adjacent facility and your facility must absorb some of the traffic.	Efficiency: ① ② ③ ④ Risk: ① ② ③ ④	3. ____ 4. ____ 5. ____ Others:
5.	**Special Use Airspace / Restrictions 1** Restrictions (Temporary Flight Restrictions – TFRs and combat air patrols - CAPs) are in place because of the SuperBowl. A VFR aircraft with no flight plan enters the restricted zone.	Workload: ① ② ③ ④ Efficiency: ① ② ③ ④ Risk: ① ② ③ ④	1. ____ 2. ____ 3. ____ 4. ____ 5. ____ Others:
6.	**Special Use Airspace / Restrictions 2** Moving TFRs and CAPs are in place because of a presidential motorcade on the ground below. Constraints (e.g., altitude) vary depending on the affected areas. One of the areas surrounds a major airport that remains open to commercial flights.	Workload: ① ② ③ ④ Efficiency: ① ② ③ ④ Risk: ① ② ③ ④	1. ____ 2. ____ 3. ____ 4. ____ 5. ____ Others:

	Event	Ratings	Most Critical Functions and Description of Their Purpose
7.	**Severe Weather 1** Severe weather conditions have arisen very quickly making it necessary for traffic in your sector and an adjacent sector to divert through a narrow corridor in your sector.	Workload: ① ② ③ ④ Efficiency: ① ② ③ ④ Risk: ① ② ③ ④	1. ________ 2. ________ 3. ________ 4. ________ 5. ________ Others:
8.	**Severe Weather 2** Due to serious weather the TMU has implemented a playbook action affecting your sector and other centers in the country. You must initiate major reroutes through your airspace.	Workload: ① ② ③ ④ Efficiency: ① ② ③ ④ Risk: ① ② ③ ④	1. ________ 2. ________ 3. ________ 4. ________ 5. ________ Others:
9.	**Congestion** Traffic from your sector into an adjacent sector is heavy. The adjacent sector reports that it can not accept any more aircraft effective immediately.	Workload: ① ② ③ ④ Efficiency: ① ② ③ ④ Risk: ① ② ③ ④	1. ________ 2. ________ 3. ________ 4. ________ 5. ________ Others:

	Event	Ratings	Most Critical Functions and Description of Their Purpose
10.	**Emergency 1** An aircraft has reported a loss of electrical and hydraulic power and is descending rapidly and unpredictably through your sector.	Workload: ① ② ③ ④ Efficiency: ① ② ③ ④ Risk: ① ② ③ ④	1. ____ 2. ____ 3. ____ 4. ____ 5. ____ Others:
11.	**Emergency 2** A departing commercial aircraft has reported a medical emergency onboard and requests to land at the nearest available airport. The aircraft must dump fuel before landing.	Workload: ① ② ③ ④ Efficiency: ① ② ③ ④ Risk: ① ② ③ ④	1. ____ 2. ____ 3. ____ 4. ____ 5. ____ Others:

Appendix B

Standard Metrics for Human-in-the-Loop Baseline Simulations

Standard Human-in-the-Loop Baseline Metrics

The metrics listed below are adapted from the *Air Traffic Control Baseline Methodology Guide* (Allendoerfer & Galushka, 1999). Formal definitions of these metrics can be found in that document along with advice on successful collection and analysis of these data. The *Methodology Guide* incorporates earlier en route baseline studies (Allendoerfer, Galushka, & Mogford, 2000; Galushka, Frederick, Mogford, & Krois, 1995) and other research in metrics of controller performance (Hadley, Guttman, & Stringer, 1999).

Key
R = Radar Controller
D = Data Controller
SME = Subject Matter Expert
ATWIT = Air Traffic Workload Input Technique

Safety Risk

- Number of Operational Errors
- Number of Conflict Alerts
- Number of Halo Initiations
- Descriptions of Other Safety Critical Issues (e.g., reports from participants or SMEs)

Efficiency & Performance

- Number of Aircraft Under Control
- Average Time in Sector
- Number of Altitude, Speed, and Heading Changes
- Post-Run Questionnaire Ratings
  - Quality of ATC services from a controller point of view-R
  - Quality of ATC services from a controller point of view-D
  - Quality of ATC services from a pilot point of view-R
  - Quality of ATC services from a pilot point of view-D
- SME Over-the-Should Rating Form Items
  - Maintaining Safe and Efficient Traffic Flow-R
  - Maintaining Safe and Efficient Traffic Flow-D
  - Maintaining Attention and Situation Awareness-R
  - Maintaining Attention and Situation Awareness-D
  - Prioritizing-R
  - Prioritizing-D
  - Providing Control Information-R
  - Providing Control Information-D
  - Technical Knowledge-R
  - Technical Knowledge-D
  - Communicating-R
  - Communicating-D

Workload/Taskload

- Number of Data Block Offset Actions
- Number of Overall Data Entries- R
- Number of Overall Data Entries-D
- Number of Data Entry Errors-R
- Number of Data Entry Errors-D
- ATWIT Workload-R
- ATWIT Workload-D
- Number of Air-Ground Communications (also called Communication Taskload)
- Number of Ground-Ground Communications (also called Coordination Taskload)
- Post-Run Questionnaire Ratings
    - Post-Run Workload-R
    - Post-Run Workload-D