Dynamic Resectorization of Airspace Boundaries between Adjacent Air Route Traffic Control Centers

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ABSTRACT

The objective of the study was to examine the impact of dynamic resectorization on air traffic controllers' performance, workload, situational awareness, and communications. The approach was to predefine regions of airspace that could be dynamically allocated to one Air Route Traffic Control Center (ARTCC) or the other depending upon the traffic situation. As a preliminary investigation, the scope of the study was limited to lateral boundary adjustments and specific heavy traffic and shifting weather situations that should benefit the most from dynamic resectorization. This paper describes a real-time human-in-the-loop simulation study designed to investigate a specific approach to implementing dynamic resectorization between two adjacent ARTCCs.

INTRODUCTION

Due to areas of severe weather, air turbulence, navigational, or communications equipment problems, it often becomes necessary to divert air traffic from their normal or preferred routes. Sometimes, sectors become so congested with traffic that aircraft must be diverted to avoid the sector. Allowing airspace users more flexibility in determining flight routes and the implementation of Free Flight proposals will further exacerbate these pressures over preferred routes or sectors (Planzer & Jenny, 1995; RTCA, 1995a, 1995b). The increased flight flexibility associated with Free Flight could lead to situations in which current airspace sector configurations no longer match traffic flows. To accommodate Free Flight, the sectorization of airspace will also need to be more flexible, especially if controllers maintain responsibility for safe separation. In an airspace with high traffic density, there is a higher probability for conflicts and increased controller workload. Airspace sectors that can be restructured to make use of the complete resources of the Air Traffic Control Specialists (ATCSs) have the potential to increase overall system safety, provide a more balanced workload for the controller, and reduce costly delays.

Current airspace structure is rigid and does not allow for dynamic resectorization of airspace boundaries. Dynamic resectorization is adaptive and can efficiently handle heavy traffic situations, shifting weather conditions, status changes in special use airspace, and user-preferred routes. Dynamic resectorization has the potential to reduce aircraft delays, decrease fuel consumption, and lower operating costs for the airline industry. The potential human factors benefits are to offset heavy controller workload and reduce coordination and communications. However, dynamic resectorization may be disruptive and could have negative consequences for controller situational awareness and performance. There are different approaches to implementing dynamic resectorization using current and future automation tools. Some methods may be more effective and less disruptive than others.

Dynamic resectorization represents a radical change from current, mostly static procedures that determine airspace boundaries. If dynamic resectorization is used to support increased flight flexibility, it still must provide controllers with the cues, information, and organization necessary to maintain situational awareness and aircraft safety. The key is ensuring that the dynamic resectorization process itself does not impair system effectiveness.

Purpose. The purpose of this study was to conduct a human factors evaluation of the potential impact of dynamic resectorization between adjacent ARTCCs on controllers using real-time ATC simulation. This study compared operations between a standard en route airspace with fixed boundaries to an en route airspace with dynamic boundaries. This should be viewed as an initial investigation of the dynamic resectorization concept and not as a comprehensive assessment.

METHOD

Two Human Factors Specialists and two ATCS Subject Matter Experts (SMEs) conducted the simulation in the Research Development and Human Factors Laboratory (RDHFL) at the FAA William J. Hughes Technical Center. A team of trained simulation pilots operated aircraft using simple keyboard commands and communicated with the controllers using ATC phraseology.

Participants. Twelve current, non-supervisory, full performance level ATCSs participated in this simulation study. Participants were required to have self-reported corrected vision of at least 20/30. They ranged from 31 to 56 years of age (mean=44.3) with an average of 15.4

years of ARTCC experience. Participants filled out an Informed Consent form explaining their participation in this study was strictly voluntary and that their privacy was protected. We maintained strict adherence to all Federal, Union, and ethical guidelines throughout the study. Participants were allowed to withdraw at any time without penalty. The simulation evaluated the concept of dynamic resectorization and not individual controllers.

Equipment. The simulation equipment consisted of workstations with large high-resolution displays, a voice communications system, networked computer resources, and ATCoach (1996) simulation software. As part of the simulation materials, we printed and time ordered flight progress strips in a strip bay prior to the start of each scenario. We audio-video recorded the simulation and included a touchscreen for the Air Traffic Workload Input Technique (ATWIT) (Stein, 1985) in the system.

Airspace. The research team developed a generic ARTCC (Genera Center; ZGN) airspace for this simulation using the ATCoach (1996) simulation model that closely replicates the en route environment. Generic airspace has several advantages relative to modeling an actual airspace in simulations. Using a generic airspace, researchers can select a cross-section of controllers from different Air Traffic facilities and quickly train them to operate within the airspace. ZGN consists of easily remembered fix names and simplified operating procedures. We divided ZGN into two separate ARTCC configurations (North ARTCC and South ARTCC) to simulate an inter-facility operation. We gave an airspace briefing to each participant, which described ZGN and pertinent standard operating procedures, sector layouts, and jet routes. In this briefing, we also described the areas of responsibility during dynamic resectorization.

Traffic Scenarios. Participants controlled traffic in two different experimental conditions. In the first condition, they employed dynamic resectorization between the two ARTCC configurations. The second condition involved current operating procedures for controlling and directing traffic between ARTCC facilities and served as a baseline for comparison. There were four scenarios for each condition. Two of the scenarios consisted of rather heavy traffic, and two were a combination of moderate traffic and a severe weather system. Each scenario was 60 minutes in duration and consisted of a mix of jet aircraft operating in instrument flight rules conditions. All scenarios started without any initial aircraft on the radar display. Then, aircraft steadily appeared, creating a buildup. This level of traffic was maintained for the duration. Each controller experienced all scenarios from each position (four from one ARTCC the first day and four from the other ARTCC the following day. In all scenarios, controllers directed traffic according to current ATC procedures (with the exception of procedural changes associated with dynamic resectorization).

Design. To evaluate situations that might have an impact on the controller operating in a dynamic airspace, we decided to limit our investigation to two independent variables: Airspace Type and Traffic Situation. The experimental design can be summarized as a 2 x 2 within-subjects design with the factors of Airspace Type (fixed or dynamic) and Traffic Situation (high density or weather). The scenarios were designed so that the North ARTCC (ZNO) always had the problem (high-density traffic or severe weather), and resectorization with the South ARTCC (ZSO) was the solution. We intended the resectorization to be a resolution to the traffic situation in ZNO without significantly impacting operations in ZSO.

Independent Variables. We examined these variables in terms of two conditions over eight scenarios:

1. High-Density Traffic Scenarios
   a. Baseline Fixed Boundaries with High-Density Traffic – This condition employed current 7110.65M ATC procedures for controlling traffic. It consisted of a large volume of aircraft, with a considerable amount transferring north from ZSO through ZNO (see Figure 1a).
   b. Dynamic Resectorization with High-Density Traffic –This condition included the same traffic flow as in the Baseline. It started with the baseline airspace configuration. At 17 minutes into the scenario, the airspace was resectorized as shown in Figure 1b to distribute the taskload more evenly.
2. Weather Scenarios
   a. Baseline Fixed Boundaries with Weather –This condition employed current 7110.65M ATC procedures for controlling traffic (see Figure 1a). This scenario consisted of a moderate volume of aircraft that is accompanied by severe weather located in ZNO (see Figure 2a).
   b. Dynamic Resectorization with Weather – This condition included the same traffic volume and flow as in the Baseline Weather scenario. The scenario started with the baseline airspace configuration. At 17 minutes into the scenario, the airspace was resectorized as

shown in Figure 2b to allow the ZNO controller to have more airspace available to reroute aircraft around the weather.

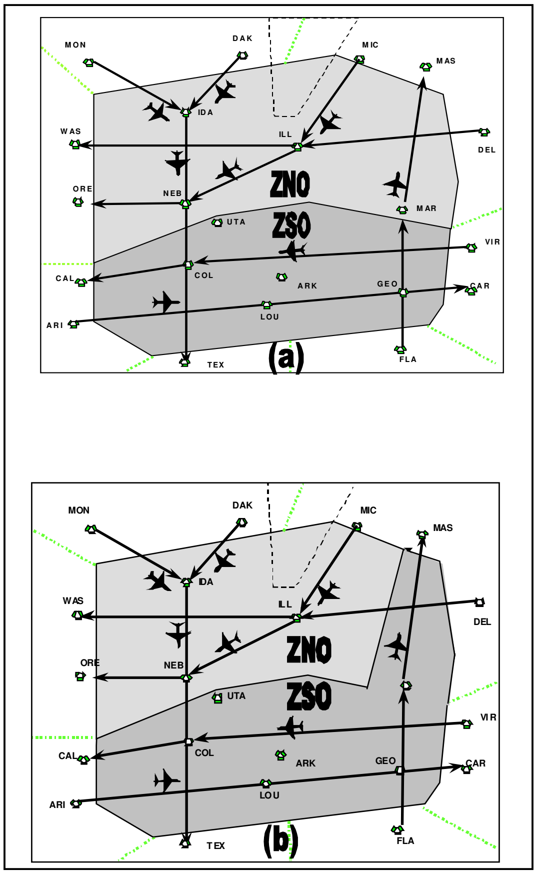
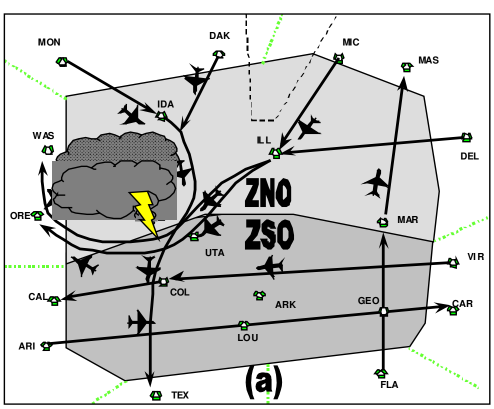


Figure 1. High-Density Traffic Scenarios. (a) Airspace boundaries for baseline scenario. (b) Airspace boundaries for resectorization scenario after resectorization has been completed.



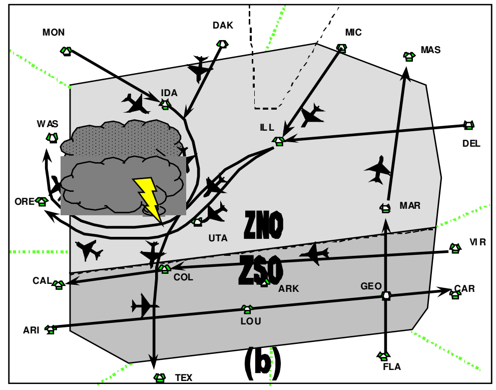


Figure 2. Weather Scenarios. (a) Airspace boundaries for baseline scenario. (b) Airspace boundaries for resectorization scenario after resectorization has been completed.

Dependent Variables. The automated data collection system of the RDHFL produces a large set of objective system effectiveness measures that are typically examined in ATC simulation research (Buckley, DeBaryshe, Hitchner, & Kohn, 1983). Table 1 lists selected measures separated into three categories: safety, capacity, and efficiency.

Table 1. System Effectiveness Measures

1 - SAFETY
NCNF – Frequency of aircraft conflicts
2 - CAPACITY
NCOMP – Number of flights completed
3 - EFFICIENCY
NPTT – Frequency of A/G communications
DPTT – Duration of A/G communications
DIST – Distance flown for all flights
NALT – Frequency of altitude changes
NHDG – Frequency of heading changes
NSPD – Frequency of airspeed changes

Additionally, our two ATCS SMEs observed controllers for over-the-shoulder (OTS) ratings of performance during each scenario. The SMEs used an observation form specifically designed for use in ATC human factors research (Sollenberger, Stein, & Gromelski, 1997).

We sampled controller workload in real time during each scenario using the ATWIT, a subjective rating method that provides an unobtrusive and reliable means for collecting self-report ratings of controller workload as they control traffic (Stein, 1985). A touchscreen was used to present a workload rating scale and record participant responses. The controllers indicated their current workload by pressing one of the touchscreen buttons labeled from 1 (low) to 10 (high). The touchscreen was programmed to request controller input every 5 minutes by emitting several beeps and presenting the rating scale. Participants had 20 seconds to respond. If they did not respond within that 20 seconds, the maximum workload rating of 10 was recorder. After each scenario, participants completed a Post-Scenario Questionnaire and the NASA Task Load Index (TLX) subjective mental workload scale was also administered (Hart & Staveland, 1988).

RESULTS

We used Analysis of Variance (ANOVA) to determine the effects of resectorization on the dependent measures collected in the simulation. We conducted a 2 x 2, Airspace Type (fixed or dynamic) by Traffic Situation (high-density or weather) repeated measures ANOVA, which was collapsed across both the North and South ARTCCs. In the present study, significant main effects for Traffic Situation are not very meaningful because the weather and high-density scenarios were considerably different from one another. Rather, we were interested in main effects for Airspace Type and the interactions between Airspace Type and Traffic Situation. Tables summarize the results of the simple main effects analyses conducted on the significant interactions. Graphs present the means of the experimental conditions in more detail for selected dependent measures.

System Effectiveness Measures. The efficiency indicators, frequency (NLL) and duration of land line (DLL) communications, showed significant interactions for Airspace Type and Traffic Situation. Figure 3 and Figure 4 illustrate these relationships.

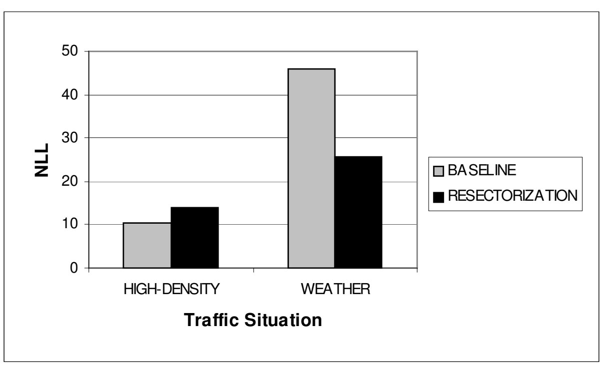


Figure 3. Airspace type by traffic situation interaction for frequency of land line communications.

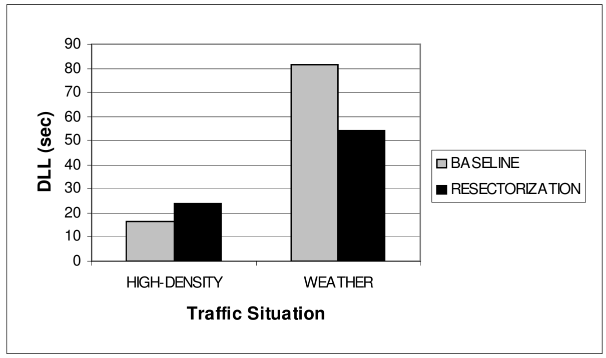


Figure 4. Airspace type by traffic situation interaction for duration of land line communications.

Controllers utilized the land line for coordination of traffic between ZNO and ZSO. Analysis of simple main effects for these interactions revealed that for the high-density traffic situation, dynamic resectorization required more land line communications than the baseline. For the weather situation, the reverse was true. The baseline scenario required considerably more coordination than the dynamic resectorization scenario. The same pattern was found for the duration of land line communications. Table 2 and Table 3 show the results of the analysis of simple main effects.

Table 2. Mean NLL and *F* Statistics Obtained from the Analysis of Simple Main Effects

High Density			Weather		
Base	Resect.	F-Value	Base	Resect.	F-Value
10.33	13.96	15.01**	45.88	25.79	92.53**

$^*p < .05$; $^{**}p < .01$

Table 3. Mean DLL and *F* Statistics Obtained from the Analysis of Simple Main Effects

High Density			Weather		
Base	Resect.	F-Value	Base	Resect.	F-Value
16.25	23.83	5.99*	81.54	54.08	6.79*

$^*p < .05$; $^{**}p < .01$

Workload. We computed an unweighted total subjective workload score with a range of zero to 120 for each participant by summing the responses on the six subscales of the NASA-TLX. A two-way ANOVA performed on these scores revealed a significant main effect for Airspace Type [$F\ (1,11) = 38.77$, $p < 0.01$]. Participants rated both scenarios as more workload intensive when they were controlling traffic in the baseline airspace configuration. This suggests that they perceived a positive impact as a function of resectorization on their workload when they thought about it after the runs. However, there was no significant interaction between Airspace Type and Traffic Situation for these scores. The mean TLX scores are presented in Figure 5.

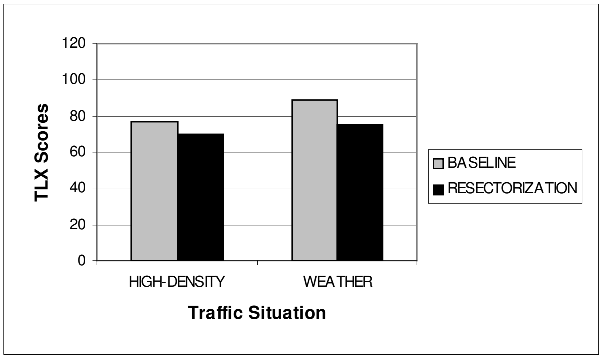


Figure 5. Mean NASA TLX scores.

In contrast to the TLX, ATWIT reflects workload estimates in real time. Figure 6 illustrates the ATWIT ratings as a function of Airspace Type and Traffic Situation. A two-way ANOVA revealed a significant interaction between these variables. Table 4 shows the results of the analysis of simple main effects.

Table 4. Mean ATWIT Ratings and *F* Statistics Obtained from the Analysis of Simple Main Effects

High Density			Weather		
Base	Resect.	F-Value	Base	Resect.	F-Value
5.14	5.03	0.33	5.90	5.22	9.89**

*$p < .05$; **$p < .01$

The *F* statistics indicate a significant decrease in controller workload for the weather scenario when dynamic resectorization was employed. For the high-density traffic situation when dynamic resectorization occurred, there was a slight, though non-significant, decrease in controller workload. In real time, differences still existed, but were not quite as clear.

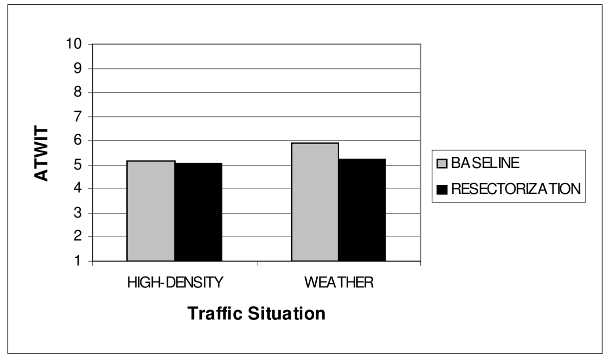


Figure 6. Airspace type by traffic situation interaction for ATWIT ratings.

Post-Scenario Questionnaire Ratings. Upon completion of each scenario a questionnaire was given to each participant in which they were asked to rate [on a scale of 1 (low) to 10 (high)] themselves on a variety of aspects of controller performance. A two-way ANOVA was performed on these self-ratings. One interesting finding worth mentioning has to do with their ratings of situational awareness. A significant main effect was obtained for Airspace Type [$F(1,11) = 5.68$, $p < .05$]. Participants rated their overall situational awareness higher when they were working traffic in dynamic airspace regardless of traffic situation. Figure 7 illustrates this main effect.

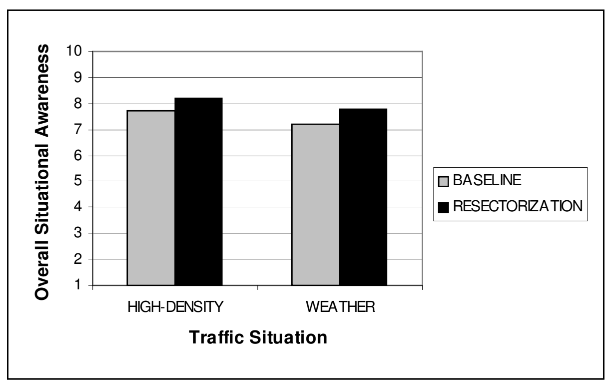


Figure 7. Mean Post-Scenario Questionnaire ratings of situational awareness.

DISCUSSION AND CONCLUSIONS

The present study investigated the concept of dynamic resectorization on controller performance, workload, and situational awareness. Our approach was to create ideal conditions (high-density and weather) for dynamic resectorization between two adjacent ARTCCs. In both cases, the problem traffic situation was created in ZNO, and a resectorization of airspace with ZSO was the solution.

The results indicated a significant difference in land line communications between the baseline and resectorization conditions for high-density scenarios. However, more land line communications were expected in the resectorization scenario because of the few aircraft (between 3 and 5 depending upon controller style) that were present in the portion of airspace that was being resectorized and required coordination. For weather scenarios a significant difference was also found. Controllers made a great deal fewer land line communications during the resectorization condition. This occurred because in the baseline condition ZNO controllers had to point out each aircraft that was deviating around the thunderstorms. Each point-out required a land line communication with the ZSO controller. This coordination was eliminated in the resectorization condition because the ZNO controller acquired a portion of ZSO, therefore reducing land line communication.

In general, the controllers thought that resectorization had positive benefits for them. Controllers expressed the belief that resectorization reduced their workload. However, participant perception did vary somewhat from real-time ATWIT to post hoc NASA TLX ratings. When controllers had time to think about the impact of resectorization, their views were somewhat more positive then when they were still working traffic. The NASA TLX data revealed significant decreases in subjective workload while operating in the resectorization condition for both high density and weather scenarios. ATWIT ratings indicated that resectorization did not affect workload in the high-density scenarios. However, controller ATWIT ratings were lower in the weather scenarios.

Overall, the objective and subjective data collected during this experiment support the fact that resectorization did not interfere with performance. In addition, the post-scenario estimates of workload declined in the scenarios in which dynamic resectorization was implemented. Most importantly, the results from this study indicated that if resectorization is accomplished in a timely manner, it does not negatively impact the controller whatsoever. Of course, the research team in the present study investigated a specific type of resectorization using predefined regions of airspace in conditions that were designed to be optimal for resectorization to take place. More research is needed investigating different traffic situations and different resectorization techniques.

A complete technical report on this study can be found in Hadley, Sollenberger, D'Arcy, and Bassett (2000).

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