AN EVALUATION OF TWO MULTI-SECTOR PLANNER CONCEPTS: MULTI-D AND AREA FLOW

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Abstract

Several developments in the technology supporting air traffic management (ATM), such as digital data communication and improved positioning accuracy, have enabled consideration of new organizational and functional operations. One such consideration is a modification of the standard air traffic control team configuration to include a "multi-sector planner" (MSP) position. This MSP position has been investigated in several research and field studies, both in the U.S. and in Europe. The feasibility and effectiveness of two of these concepts were investigated in the current study. One concept, termed "Multi-D", took the traditional role of a data-controller but provided these types of services to several radar controllers instead of one. In the second configuration, termed "Area Flow", the MSP coordinated with neighboring MSP areas and attempted to manage the overall traffic flows and actively balanced sector traffic levels within their area of responsibility. The experiment consisted of a pair of one-week human-in-the-loop studies, in which each MSP concept (i.e. Multi-D and Area Flow) was tested separately with a different 5-person team. A baseline condition, which assumed traditional radar and data-controller teams with access to advanced decision support tools (DSTs) and automation, was also run each week to provide comparison data.

Overall, data suggest feasibility of both concepts, with many similarities and some differences. Both configurations emphasize strategic traffic management and neither safety nor efficiency appeared to be adversely affected. Workload data supported an assumption that a single MSP can cover multiple sector positions with a better overall workload distribution. The coordination data revealed that both Multi-D and Area Flow delegated a significant portion of their rerouting tasks to the upstream sectors since strategic traffic planning needed to occur well before the test sectors. The viability of requesting these reroutes to the upstream sectors needs to be verified in future studies.

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Introduction

Air traffic control in the en route airspace environment in the United States has traditionally been performed by a team configuration. This team divides duties so that one controller (the radar-controller, or "R-side") has primary responsibility for observing the radar screen (DSR) and exercising control by communicating with the flight crew by voice-radio contact. The second controller (radar-associate, data controller, or "D-side") on the team has primary responsibility to manage flight progress strips and to serve as a "strategic" aid to the radar controller. Several developments in the technology supporting air traffic management (ATM), such as digital data communication, improved positioning accuracy, conflict prediction, and sector complexity assessment, have enabled consideration of the continued efficacy of the standard team concept. New organizational and functional operations are being considered in response to increased traffic demand while the controller workforce transitions to a system with more automation and decision support tools. One concept under consideration modifies the standard team configuration to include a "multi-sector planner" (MSP).

The MSP position has been investigated in several research and field studies [1,2,3,4,5,6]. In the United States, consideration of a MSP position was undertaken to determine what advantages could be reaped from improved information availability in the National Airspace System (NAS) as part of the operational evolution plan [1,7]. Eurocontrol proposed three high level MSP concepts: concept A, termed traffic and complexity management; concept B, termed sector control with multi sector planning; and concept C, termed multi sector 4D control [8]. Human-in-the-loop evaluation results indicated an overall reduction in common situation awareness (not only for MSP condition but also with the stripless environment with traditional R-side/D-side). Also Radar controllers reported a lack of assistance and missed redundancy of another set of eyes over their actions.

Among the different MSP configurations, two configurations were investigated to determine their feasibility and effectiveness. One configuration, termed "Multi-D", took the traditional role of a data-controller but provided these types of services to several radar controllers (three R-sides were assigned to be the responsibility of one Multi-D in this experiment). As in current operations, the R-sides had the responsibility for managing the sector operations for the individual sectors, including aircraft separation and traffic flows. The Multi-D position supported the R-side by managing traffic flows within the multi-sector area and providing medium-term conflict resolutions, as well as assuming normal data-controller duties with automation assistance. The Multi-D position was envisioned as a controller who is co-located in the same facility as the radar controllers.

In the second configuration, the MSP served functions often associated with "traffic flow" management, coordinating with external MSP areas and attempting to manage sector traffic levels in a proactive process of balancing loads among the three sectors in their area of responsibility as well as with external areas. This position was termed "Area Flow planner". Unlike Multi-D, Area Flow did not resolve medium-term conflicts. Area Flow planner was envisioned as a new position who may not be co-located with the R-side controllers.

The two concepts were tested in a pair of one-week human-in-the-loop studies, in which each MSP concept (i.e. Multi-D and Area Flow) was tested separately with a different 5-person team. The details of the simulation study are described in the following sections.

Method

Participants

Participants were six radar control area supervisors and four Traffic Management Unit (TMU) supervisors from various Air Route Traffic Control Centers (ARTCCs). One of the area supervisors was also a member of the research team. The participants were divided into two groups of five and assigned to one of the two MSP configurations. One group was assigned to the Multi-D configuration during the first week and the second group was assigned to the Area Flow configuration in the second week. All aircraft in the simulation were flown by pseudo-pilots.

Airspace

The simulation airspace was a modified Dallas-Fort Worth Center (ZFW) airspace (Figure 1). Controller participants worked the three high-altitude sectors – Wichita Falls (SPS), Ardmore (ADM), and Decod (DECOD). In this study, all three sectors were expanded to increase sector size and complexity. Three retired controllers worked Ghost positions to handle the surrounding traffic.

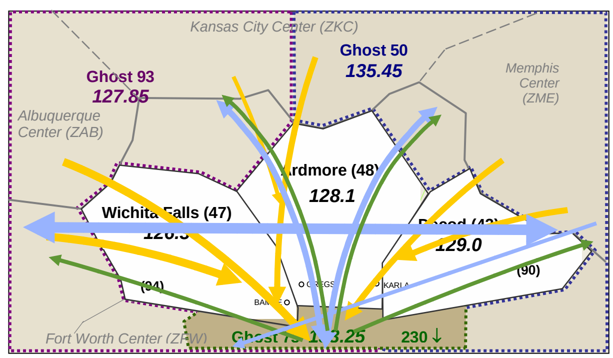


Figure 1. Simulated airspace

The traffic patterns consisted of a mixture of arrival, departure, and overflight traffic. There was significant level of arrival traffic in all three sectors – arrivals transitioned Wichita Falls from the northwest, Ardmore from the north, and Decod from the northeast. The sectors were treated as "generic", which meant that the traffic pattern deviated significantly from current day traffic at ZFW. The traffic was generated using Trajectory-Centered Simulator (TCSim) and an in-house scenario generator [9].

Experiment Design

The experiment consisted of two one-week studies with different participants that tested either the Multi-D or the Area Flow configuration. The experiment was a 2x2 design, varying either the condition (Baseline vs. MSP) or the traffic pattern (high traffic with no weather vs. moderate traffic with weather). Data collection began after 1 ½ days of training. Each condition was run twice, totaling eight runs per week. The Baseline condition was run with advanced tools but no change in the team structure. In this study, two of the three sectors (i.e. Ardmore and Wichita Falls) were operated with traditional R and D pairs while Decod sector only had the R-side controller.

The Baseline D-side controllers worked the MSP and the ghost MSP positions during the MSP simulation runs. The Multi-D position, which was envisioned as a controller position, was located in the same room as the R-side but positioned so that his/her displays were not readily visible by the R-side controllers. Since the Multi-D was not positioned next to the R-sides, verbal coordination was only possible via the ground-ground voice communication system, or by walking to the R-Side controllers. In contrast, the Area Flow position was envisioned to be strictly strategic and did not involve tactical air traffic control. Therefore the Area Flow position was located in a different room from the R-side controllers. For both Multi-D and Area Flow configurations, the ghost MSP position was in a separate room from the MSP.

Two types of traffic scenarios were tested in each condition – scenarios with a significant weather disturbance and scenarios with a high traffic density. With these manipulations the experimental design was a within subjects design as each of the teams was assigned to one of the two MSP configurations and then exposed to the Baseline and the experimental condition. The presentation of the experimental conditions within each of the two groups was counterbalanced to offset the learning effects.

The study had nested purposes. The first was to determine, given a suite of tools and procedures, if the operational concept in either of its two forms would be feasible in US operations. To answer this question, the experiment compared the performance of the MSP concepts against a baseline procedural concept that included the advanced tools of a future ATM, but no change in the roles, responsibilities and team structure. The second purpose was to attempt to identify the relative strengths of the two forms of the operational concepts being examined. The two implementations of the MSP concept (Multi-D & Area Flow) were tested against a set of traffic and environmental conditions to make some inferences for each concept.

Tool Capability

The study was conducted using a simulation platform called Multi Aircraft Control System (MACS), which was built in-house at NASA Ames for research purposes [9]. MACS provides the environment for rapid prototyping and evaluation of current and future air/ground operations for the NAS. For the MSP study, a subset of the existing suite of capabilities was used. These capabilities are described briefly in the following sections.

R-side

The controller decision support tools (DSTs) were integrated into a high-fidelity emulation of the Display System Replacement (DSR) controller workstation (Figure 2). This DSR emulator is highly configurable to mimic both DSR workstations in the field today and future DSR workstations equipped with advanced DSTs.

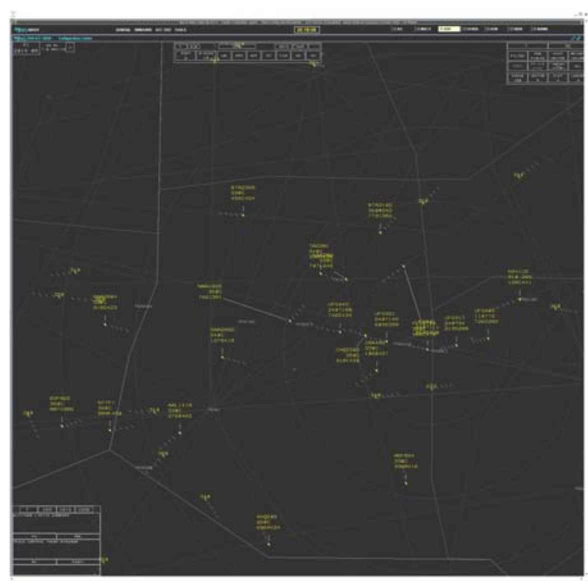


Figure 2. MACS-based DSR emulation

To maximize the benefits of advanced air and ground-side DSTs, they were integrated with

Controller Pilot Data Link Communication (CPDLC) and the Flight Management System (FMS). This integration allows the controllers and the pilots to exchange 4D trajectory information quickly and with low workload. Many of the capabilities described below, e.g. automatic transfer of communication, altitude and route trial plan, etc., were integrated with CPDLC to enable them to be uplinked to the flight crews as a loadable clearance. The controller data link interface was modeled after CPDLC Build I used in Miami Center (ZMA). Its features include data block symbology, automated transfer-of-communication (TOC), and a data link message status list [10]. The data link for auto-TOC links the frequency change automatically to the aircraft handoff process, significantly reducing the overall controller workload.

Another key automation support was trial planning of routes and altitudes integrated with data link. The controller can modify the 4D flight path using trial planning capabilities to either stretch or shortcut the path or change the aircraft's cruise altitude. The trial plan capability is accessed by clicking on a trial planning portal (right arrow) on the data block (Figure 3).

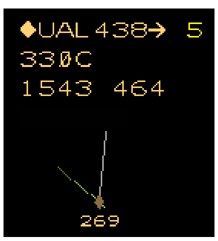


Figure 3. DSR data tag with trial planning portal (arrow) and predicted conflict in 5 minutes

Another ground-side automation aid was a trajectory based conflict-probe. Conflict information is displayed as minutes to separation loss in the first line of the data block. Clicking on the time to separation loss highlights the aircraft targets and displays the flight paths and the predicted conflict location (Figure 4). Once a conflict is identified, trial planning can be used to create a new lateral route, a new altitude, or both. Conflict probing is active for the trial planned route/altitude as well as the current route, so the controller can create a conflict-free path before sending it as a clearance via data link.

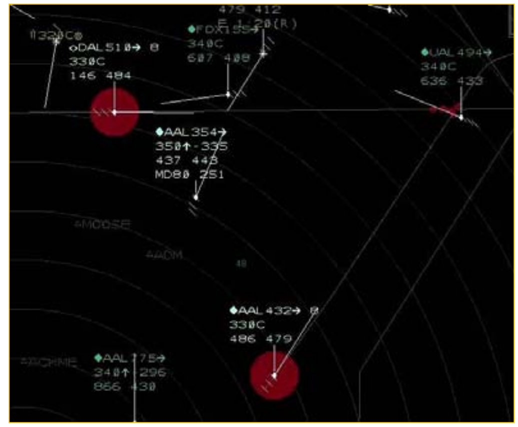


Figure 4. Conflict probe display

D-side

In this study, D-side positions were not provided with an interface that mimicked current day D-side systems. Instead, they were given the same displays and functionalities as the R-sides, which included the advanced automation support, plus electronic flight strips. Participant feedback indicated that they were comfortable with this arrangement for providing D-side support.

Multi-D and Area Flow

Several instantiations of MSP positions have been prototyped. The MACS implementation of the MSP position is similar to a controller position zoomed out to view multiple sectors with many automated functions to support the operations. New functions to support MSP operations include ground-to-ground data link for coordination of trajectory changes and interactive traffic load tables/graphs to predict sector loads (Figure 5). The prototyped system assesses the sector loads by predicting the number of aircraft that will be present in the sectors of interest and displays the counts in a table and a graphical format. The indication changes color whenever a predicted load exceeds a pre-set value similar to a monitor alert parameter (MAP). The value can be adjusted for additional complexities like weather. When the MSP recognizes excessive sector load s/he can determine the specific flights that are contributing to this load by selecting the cells within the load table or a vertical bar in the load graphs. This highlights all aircraft that are contributing to the load with rectangular boxes around the data tag on the traffic display.

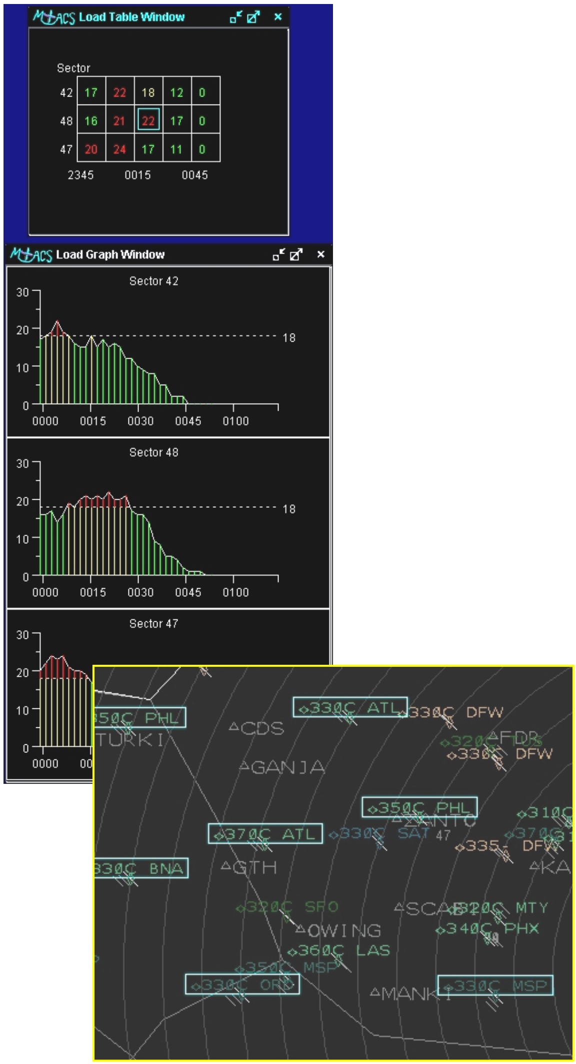


Figure 5. Sector load graphs and table

Automation tools provided to the Multi-D were: a traffic situation display that spanned across three sectors, conflict probe capability with 15-minute look-ahead time along the aircraft's 4D trajectory, route/altitude trial plan capability, ground-to-ground and ground-to-air data link, sector load graphs and table, electronic flight strips, and a "quick look" capability. The Area Flow position had most of the same tools as Multi-D, except a conflict probe on active routes, ground-to-air data link capability, and handoff controls.

MSP Roles and Responsibilities

Multi-D

This position was designed to allow one radar associate to serve as the data controller for multiple radar controllers. The position provides the capability to perform flight data entries, accept and initiate handoffs, and to data link trajectory changes to the sector controller positions and/or to the aircraft. However, the Multi-D in general did not have the same traffic awareness as the traditional D-side because s/he had to monitor multiple sectors, was not able to monitor all radio transmissions, could not listen or talk to the R-side as easily, and could not interpret the individual R-Sides' body language as well as if he or she were in close proximity. Therefore, the Multi-D was not able to help with all the handoffs, or flight data entries even though s/he had the tools to do these tasks.

The main tasks that this position could fulfill were medium-term conflict detection and resolution, and to reduce the sector complexity on the R-Side. Multi-D accomplished this by trial planning solutions to conflicts, weather avoidance, or other traffic situations, then communicating those solutions to the respective R-side for approval and execution. Trial plans were coordinated among the controllers using a ground-to-ground data link capability that was developed for this purpose. Using sector load graphs and tables (Figure 5) to predict when a specific sector's traffic levels would reach critical levels, the Multi-D initiated various route modifications to reduce the traffic complexity in that sector. A conflict list and conflict information on the datablock were used to detect medium-term conflicts that needed to be resolved.

Area Flow

This position was designed to manage the sector loading for a specific airspace area. Interactive load graphs allow the operator to view predicted sector counts and identify aircraft contributing to a particular load. Conflict probing was available for trial plans and specific flights could be color coded at the Area Flow position according to different criteria (e.g., direction of flight, destination, altitude, etc.). A typical goal of the Area Flow planner was to reroute as few aircraft as possible while maintaining the sector aircraft count below the MAP and effectively rerouting aircraft around weather cells. To facilitate identification of the aircraft that would impact multiple sectors, the load table was designed to select a combination of sectors to display aircraft that traversed through all of the selected sectors.

Before rerouting the flights the Area Flow planner had to make sure that the new routes would be acceptable to all affected regions. Two adjacent Area Flow planners communicated verbally, adjusted the plan, and decided who would implement the reroutes. Either area flow planner were able to construct new trajectories using the trial planning functions as described before and send the coordination requests to the R-sides.

Results and Discussion

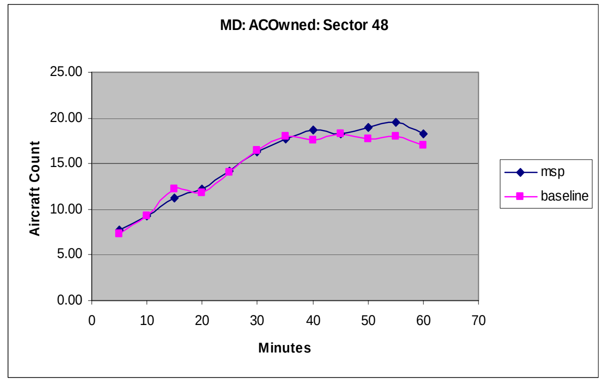
The feasibility and operational benefits of the two MSP concepts were investigated first by comparing within-subject performance data – i.e. performance of subject participants operating under each MSP concept was compared against the performance of the same participants in the Baseline condition. These within-subject analyses examined the relative benefits and shortcomings of each MSP concept compared to a more traditional R and D controller team without potential confounds due to individual differences.

The metrics used for analyses consisted of objective metrics (e.g. aircraft count, separation loss), subjective feedback (e.g. participant ratings), and observer notes (e.g. number and types of verbal coordination). A Java-based tool called DProc was used to visualize, integrate, transform, and analyze the data collected in this study [11].

Aircraft Count

The Area Flow planner (but not Multi-D) was actively rerouting aircraft to reduce the aircraft count below the MAP. The aircraft count data revealed a significant reduction below MAP for the Area Flow but not the Multi-D condition. Figure 6, which shows the average aircraft count for combined weather and high traffic/no weather scenarios, illustrates this point for Ardmore sector (sector 48).

The aircraft count in the Baseline condition (purple line) looks quite similar for the Multi-D and Area Flow teams. While the Multi-D condition produced aircraft counts that were quite similar to the Baseline, the peak aircraft count in the Area Flow condition was well below the MAP values, which were preset at different values for weather and high traffic scenarios. The data clearly shows that the Area Flow planners were able to effectively manage the traffic load in each sector and thereby able to manage the R-side controllers' workload. Multi-D also tried to manage the R-side's workload by reducing the overall traffic complexity, but the data suggest that their strategies did not significantly reduce the number of aircraft traveling through the sector.



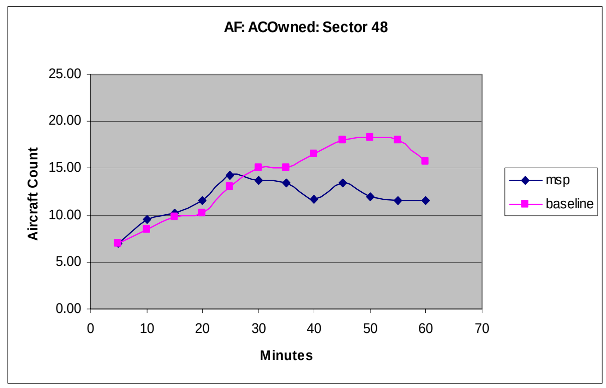


Figure 6. Aircraft count for Multi-D (MD) and Area Flow (AF) evaluations

Strategic Traffic Management

Overall results suggest that one of the key benefits of these MSP concepts is a more strategic traffic management due to the MSP position working the traffic more globally and managing multiple sectors simultaneously. However, the actual benefit mechanisms seemed to differ between Multi-D and Area Flow concepts, likely due to differences in their roles and responsibilities.

For instance, the Multi-D controller was tasked to resolve medium-term conflicts across three sectors, which resulted in fewer late conflict resolutions compared to the Baseline condition.

However, this result only held true for the high traffic/no weather condition, suggesting that medium-term conflict resolutions were less effective during weather scenarios. Figure 7 shows the total number of conflicts (across 2 runs per cell) that were resolved with less than 5 minutes to separation loss. Although 5 minutes is well within the normal tactical maneuvering that is done today, controllers with advanced 4D trajectory trial planning tools in this study resolved conflicts much earlier in most situations. A χ^2 independence test for Multi-D runs shows a significant interaction between the type of scenarios (weather vs. high traffic) and the operational conditions (Baseline vs. MSP). $\chi_1^2 = 6.6$, $p < 0.01$. In contrast, the Area Flow planner, who did not resolve any existing conflicts but ensured that any new route modifications were conflict-free, showed only a slight but non-significant benefit in conflict resolution. $\chi_1^2 = 1.2$, $p > 0.2$. Other comparisons (e.g. weather vs. no weather, interaction effects, etc.) were also not significant.

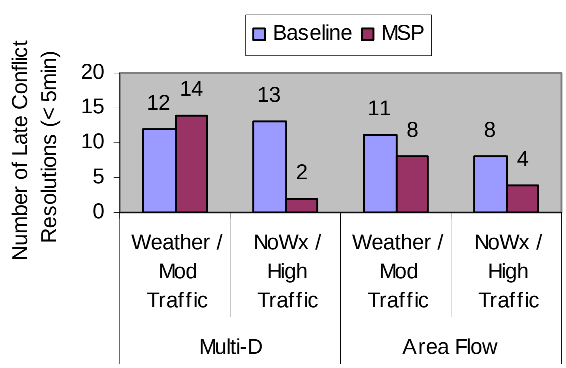


Figure 7. Total number of late conflict resolutions (< 5min) for Multi-D and Area Flow

Another metric that illustrates strategic traffic management is the number of tactical maneuvers. Table 1 shows an aggregate number of altitude, vectors, and direct-to commands issued verbally in the Area Flow week of the study. These verbal clearances were generally issued whenever the controllers needed a quicker response than can be achieved via data link. The aggregate of the tactical maneuvers across sectors shows significantly fewer tactical verbal clearances under Area Flow/MSP condition (Area Flow = 47, Baseline = 88; $\chi_1^2 = 12.4$, $p < 0.001$. A χ_1^2 independence test also showed marginal interaction between conditions, suggesting that the Area Flow planner reduced the tactical maneuvers used by the R-sides in weather scenarios. $\chi_1^2 = 2.92$, $p < 0.09$. In contrast, the Multi-D condition had the same number of tactical maneuvers as the Baseline (not shown).

Table 1. Number of verbal clearances (cruise altitude, vectors, and direct-to) in Area Flow

	Condition	Scenario		
		Weather / Mod Traffic	No Wx / High Traffic	Total
Area Flow	Baseline	65	23	88**
	MSP	28	19	47**
	Total	93**	42**	135

** Results are significant at p < 0.001.

Finally, both the Multi-D and Area Flow seemed to help the R-sides to maneuver aircraft effectively around the weather, as the number that penetrated through the weather cells reduced significantly under MSP operations (see Figure 8; Multi-D: $\chi_1^2 = 4.3$, $p < 0.04$; Area Flow: $\chi_1^2 = 4.8$, $p < 0.03$). MSPs may have reduced the controllers' workload by either directly helping them to reroute around weather or by taking over some other tasks so that the controllers could have more time to work the weather problem. Although the actual number of penetrations differed significantly between Multi-D and Area Flow weeks, it is difficult to infer any conceptual advantages since the results were most likely due to individual differences.

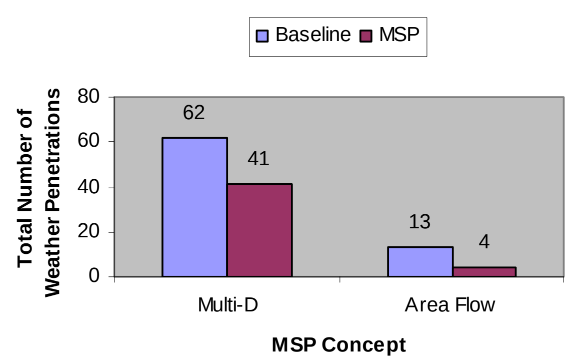


Figure 8. Weather penetrations for Ardmore sector: Multi-D vs. Area Flow

Efficiency

Both Multi-D and Area Flow operations had minimal effect on the overall efficacy of the route trajectories. Figure 9 illustrates the average difference between MSP and Baseline Estimated Time of Arrivals (ETAs) at the destination airport. Negative value denotes earlier ETAs under the MSP conditions compared to Baseline.

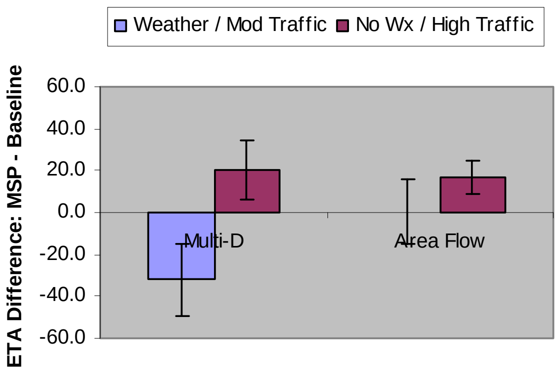


Figure 9. Difference in Estimated Time of Arrival (ETA): MSP – Baseline
(Error bar = +/- 1 standard error)

Examination of the traffic delays in the weather scenarios showed no differences under Area Flow operations (D = 0.1; $t_{218} = 0.008$, $p > 0.9$) and potentially slight reduction in delays under Multi-D operations (D = -32.0; $t_{203} = -1.86$, $p < 0.07$). In high traffic scenarios, there was surprisingly small amount of increase in overall delays under MSP operations. The delays were expected to be higher since both MSP operators actively rerouted aircraft along less efficient paths to reduce the traffic count and complexity in the test sectors. Although the increase in delays were similar for both Multi-D (D = 20.3) and Area Flow (D = 16.7), the increase was only marginally significant for the Multi-D ($t_{247} = -1.46$, $p < 0.15$) while being significant for the Area Flow ($t_{254} = 2.20$, $p < 0.03$).

Interestingly, participants rated both Multi-D and Area Flow operations to be more efficient than the Baseline. Their comments revealed that their definition of efficiency was broader than just delays – for example, MSP operations were thought to be more efficient since “key strategic moves by the MSP would remedy problems in multiple sectors”. This and other similar comments suggest that controllers considered strategic traffic management as one of the keys to efficient operations.

Safety

It has been noted in several European studies of an MSP concept similar in structure to the Multi-D operations in our study that there was a subjective concern expressed by the controllers at the loss of a person-to-person back-up to identify and avoid conflict [4,6]. In this study, the number of operational errors/separation violations did not suggest any change in objective safety between the concepts or between the concepts and the Baseline operations. For Multi-D, the number of separation violations were equal to the Baseline condition (one violation each in Baseline and Multi-D runs) and for Area Flow, there were fewer separation violations compared to Baseline (one violation for Baseline; none for Area Flow).

From a subjective perspective, the R-side controllers thought the Multi-D operations were as safe as the Baseline while the Multi-D controllers thought that the safety was slightly compromised due a reduction in situation awareness compared to D-side. For Area Flow, both R-side controllers and Area Flow planners thought that the Area Flow operations were safer than the Baseline operations. It is worth noting that the controllers felt that operations were generally safe overall, though the MSPs reported that they did not (and could not) maintain situational awareness of all the sectors’ traffic in traditional terms.

Workload Distribution

The analyses of the participant workload suggested that in the Multi-D configuration, the radar-controllers’ workload was essentially unchanged between conditions (i.e. Multi-D vs. Baseline), suggesting that a single Multi-D controller was as effective in aiding the radar-controllers as were the two data-controllers in the Baseline condition (avg. R-side Baseline = 3.21; avg. R-side MD = 3.16). However, they achieved this goal in different ways, as the Multi-D helped radar-controllers mostly by reducing traffic complexity in the sectors with traffic flow initiatives, while Baseline data-controllers helped their respective radar-controllers via point-outs, handoffs, etc. As expected, the Multi-D workload was significantly higher (M = 3.6) than the D-side workload (M = 2.34) since one Multi-D was providing support for three sectors. Univariate ANOVA analysis of condition (Baseline vs. MSP) by role (D/Multi-D vs. R) showed a significant interaction. F=6.05, df=1, $p<0.02$.

As illustrated in Figure 10, the level of workload for Multi-D and R-sides were comparable, providing a better distribution of workload across positions than the Baseline, in which D-side controllers with advanced automation had significantly lower workload than the R-side controllers.

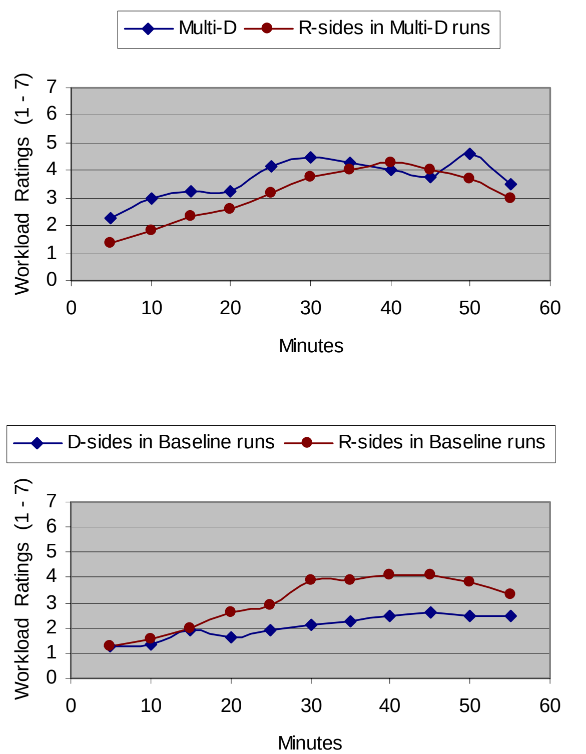


Figure 10. Workload assessment for Multi-D/MSP runs (top) and Baseline runs (bottom)

Similarly, the Area Flow planner had very little overall effect on the R-side workload (avg. R-side Baseline = 2.41; avg. R-side Area Flow = 2.29). The workload for the Area Flow planner mainly consisted of coordinating with the adjacent Area Flow planner to manage the traffic flow far away from the impacted sectors, resulting in frequent verbal coordination between them but only few verbal coordination activities with the radar-controllers. Similar to Multi-D, the Area Flow workload was significantly higher (M = 2.31) than the D-side workload (M = 1.81). Univariate ANOVA analysis of condition (Baseline vs. MSP) by role (D/Area Flow vs. R) showed a significant interaction. F=4.18, df = 1, $p<0.05$. A mean workload rating of 2.43 is below the median of the scale (which is 4) indicating that participants found workload generally manageable under all conditions. Although these ratings were generally lower than Multi-D ratings, the differences are likely due to individual differences. Similar to Multi-D, the distribution of workload between Area Flow and R-sides was better than Baseline (see Figure 11).

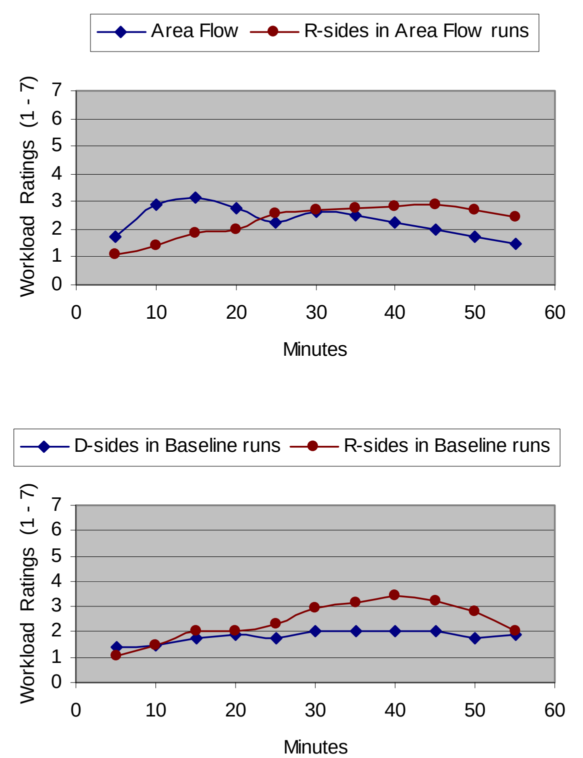


Figure 11. Workload assessment for Area Flow/MSP runs (top) and Baseline runs (bottom)

Communication and Coordination

An examination of the MSP communication/ coordination suggest an expected shift from frequent exchange between R-side and D-side controllers in baseline conditions to less frequent exchange between MSP and R-sides. In the MSP condition, there was an additional coordination process with the adjacent MSPs. Analyses of the route coordination between participants suggest that, in general, Multi-D and Area Flow had fewer coordination compared to D-sides in Baseline. However, the "ghost" Multi-D and Area Flow had equal or greater number of coordination than their counterparts, suggesting that a portion of the coordination efforts were "passed on" to the upstream sectors. The feasibility of such operations, when the upstream sectors also have full traffic levels, needs to be addressed in future studies. Overall, the trial plan duration for Multi-D and Area Flow ranged from 37 – 47 sec per trial plan and the total number of trial plans (sent and cancelled) ranged from 18 – 28 per 60 minutes, suggesting that the MSP workload was reasonable for both MSP configurations.

When asked about the coordination and communication efforts, both Multi-D controllers responded that although the amount of communication in the Multi-D position was less than in the Baseline D, the coordination itself was more difficult. Similar to the Multi-D controllers, Area Flow planners also found the coordination efforts to be more difficult than in the Baseline D. Interestingly, Area Flow planners also thought that they communicated more often than when they were D-side controllers in the Baseline condition.

It appeared during the study that communication strategies did not have time to evolve to a stable and predictable structure within the time of the experiment. Longitudinal studies of controller coordination and communication with a larger number of participants is recommended in order to better understand the impact of the changes of roles and responsibilities represented by the MSP operational concept.

Concept Acceptability

Like the studies reported by Herr, Teichmann, et al. [6], the opinions of the controllers was "guardedly positive". The overall acceptability of the MSP concepts was rated by the participants using the controller acceptability rating scale (CARS) [12]. For the Multi-D configuration, R-side controllers gave high acceptability ratings to both their Baseline and Multi-D runs. The ratings were between 8 and 9, which meant that the R-side position was acceptable and minimal work-arounds were needed to meet desired performance effectiveness. Multi-D participants gave lower ratings overall for the positions that they staffed. They rated the both the D-side and Multi-D positions as 6.0 and 6.6, respectively, which suggested that adequate performance was achieved with considerable work-arounds needed to adequately manage the traffic.

For the Area Flow configuration, the participants rated their positions as slightly less acceptable than the Baseline configuration. The Area Flow position was rated with an average of 7.8 – a CARS rating of 7 described concept acceptability as "minor, but annoying deficiencies", which meant that desired traffic management required moderate work-arounds. Although the overall ratings were favorable to the Area Flow configuration, data suggest that the Multi-D configuration showed better acceptability in comparison to their respective Baseline ratings.

As is going to be the case in systems transition, authority and responsibility will need to be tuned through experience. One issue that favors consideration of the Area Flow concept as an appropriate development direction is its rather clear difference from current roles and responsibilities. For the Multi-D concept, there was a clear tension between the radar controllers and Multi-D with respect to the final authority in a sector. Multi-Ds thought that they had a greater authority to re-direct aircraft based on a larger picture of the traffic situation while the radar-controllers thought that, as a data-controller, Multi-D should maintain a similar level of authority as current day data-controllers.

Radar-controllers in particular emphasized the need for all team members to understand the role of the Multi-D within the team and for procedures to be clearly defined to integrate this role. They also commented that Multi-D's role to dynamically assist multiple sectors when more than one sector is busy will be difficult. Overall, they saw the benefit of MSP's ability to identify dynamic route structures around weather although the Multi-D participants were concerned about trust in the position since the Multi-D position was further removed from R-side which bred less trust. Multi-D participants also had problems with situation awareness because they were forced to focus heavily on one area at the expense of another during heavy traffic situations.

In contrast, Area Flow planners had a broader perspective and made decisions that were often managed outside the area of the sectors known to the R-sides through coordination with adjacent MSPs (though the processes of this coordination will have to be the focus of future analysis and experimentation.). As such, their actions were not subject to review by the R-Side controller. This was a rather more extensive change of roles than the Multi-D. R-sides expressed some confusion as to their responsibility or authority to intervene and modify the Area Flow's plan. This issue was also cited in European studies and analyses of information requirements. It is worth noting, that this confusion, as to the basis for modification of a plan provided by a planner (either human or automation) with a broader and presumably more globally optimal plan is a fundamental issue in the development and implementation of more advanced Next Generation Air Transportation System (NGATS).

The participants also commented that the acceptability of the Area Flow concept predicated on having proper tools to assess and execute traffic flow initiatives, such as accurate departure information, shortcut functions to re-route multiple aircraft along a similar route, and better traffic complexity indicators. As noted in the discussion of communication and coordination, the Area Flow tools did not provide conflict detection (as that was not their intended role). However, Area Flow controllers often used the route planning tool to investigate potential conflicts.

Conclusion

The study proved the feasibility of the concept of a Multi-Sector Planner position in en route operations. The study differentiated different mechanisms whereby safety, efficiency, and redistribution of workload can be achieved with two operational instantiations of the MSP concept. While not intended to definitively distinguish between the two operational concepts, the results have suggested a distinction between Area Flow and Multi-D operations.

The operational integration differences between the Area Flow and Multi-D operations do suggest that Area Flow provides a more consistent path for future development aligned with Operational Evolution Plan (OEP) and NGATS development. The change of roles to a planner, and the strategy of reduction of possible conflicts to reduce reliance on tactical response from the D-side provides for a clearer interaction and authority process for the controllers. The Area Flow operations also allows for a more flexible control station configuration as the Area Flow operations did require the Area Flow to be physically co-located with the Radar-controllers in the operations.

The Area Flow operation also could be aided by tools that are consistent with planned NGATS and OEP development, through integration of information and planning for more strategic rerouting. So, given no clear operational cost to Area Flow development, that operational concept is more consistent with future airspace operations development.

In pursuit of operational refinement of the Area Flow concept, it is necessary that several significant areas of research be pursued. We have not yet researched the impact of interactions among several MSPs who have areas of responsibility that require active management and coordination while they are also being asked to assist other adjacent MSPs in there area flow. We also have not undertaken a systematic analysis of the roles, responsibilities and procedures required to integrate the operation of multiple Area Flow MSPs with the larger Center control and flow requirements. This then extends to the coordination of center requirements with NAS level requirements.

Another area of research is to identify what tools might be required for the Area Flow in their control of traffic in their specific areas and for the yet to be defined coordination requirements with other MSPs. The level of automation and the type of decisions aids that could be used to support MSP operations should be explored. These analyses and simulations are recommended to advance the development of an Area Flow configuration in the context of ongoing NGATS technical developments.

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