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The Area Flow Multi-Sector Planner: A Fast-Time Study of MSP Coordination Activities

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Abstract—The FAA is investigating changes in the working procedures for the en route air traffic controller. These investigations have resulted in the development of the Multi-Sector Planner (MSP) concept, where the MSP is a planning controller providing strategic planning to multiple radar controllers for a specific area of responsibility. A real-time simulation (RTS) of two different MSP concepts was conducted in 2006 [1] and upon analysis of the results as well as other research efforts [2], it was determined that the MSP acting in an *Area Flow Manager* role showed the most promise in relation to the mid-term objectives, and that the next phase of the analysis should consider coordination activities for multiple MSP controllers over a wider area. This report summarizes the findings of that analysis.

Keywords; Strategic Flow Optimization; Capacity management; MSP; Multi-Sector Planner; Agent-based distributed fast-time simulation.

I. THE AREA FLOW MSP CONCEPT

The *Area Flow Manager* MSP is an MSP who is not involved in tactical separation operations and is only concerned with the planning and execution of strategic flow initiatives [1]. Using decision support tools with the automated exchange of results, the MSP manages sector traffic levels by balancing load among multiple sectors in the region of responsibility. The Area Flow MSP is also required to look outside the region of responsibility and coordinate with adjacent MSPs to assure appropriate flow balancing during peak traffic periods.

As part of a layered strategic planning solution, the Area Flow MSP has responsibility for a set of contiguous sectors within an ATC center. The MSP is responsible for balancing the demand in those sectors to avoid traffic levels reaching or exceeding a declared limit, based on predicted 4D trajectory data for traffic approaching the sector. For this study, the demand limit for each sector was determined by the Monitor Alert Parameter (MAP), a peak instantaneous traffic count [3]; however other measures suitable for predicting sector or controller capacity limits such as complexity, capacity or controller workload should work as well or better.

Demand balancing is achieved by identifying potential overloads, selecting suitable flights that contribute to those overloads and proposing strategic re-routes (in the lateral and/or vertical plane) through the use of a trial planning tool in order to keep the predicted load within the declared thresholds.

The MSP would have the possibility to propose trial plans for flights from the first entry in the MSP information window, until transfer of control to his or her own radar team. However, in reality it is likely that the MSP would probably consider alternative trajectories within a shorter time-frame, for example from 20-minutes or so prior to the MSA entry until hand-off.

Once a trial plan is proposed for a given flight or flights, it would be necessary to coordinate any changes that impact a sector outside of the current MSA, including the sector that would be responsible for implementing the proposed trial plan. To do this, the MSP would need to coordinate with neighboring MSPs who would accept or reject any proposed trajectory change on behalf of their own sector teams and on the basis of their own projected traffic loads.

Inter-MSP coordination will be done through electronic MSP-MSP message exchange where proposed trial plans would be published between impacted MSPs for acceptance or rejection. Once a given trial plan is accepted, the MSP would publish that plan to the relevant radar team for implementation and uplink to the flight-deck. Thus, working together over a wide area, multiple MSPs would manage traffic demand in collaboration with one another for the entire airspace system.

If a trial-plan is rejected, or the start of change in the trial plan is passed without it being implemented, the associated trial plan would be cancelled and the flight would continue on its original track. In this case, the originating MSP would have to look for alternative solutions to address the overload problem.

The Area Flow Manager Multi-Sector Planning concept aims therefore to provide the means to increase ATC productivity and improve traffic flow through medium-term (e.g. up to 40 minutes in advance of entry to the MSA) strategic solutions. In this role, MSPs manage sector traffic levels by balancing load among multiple sectors in the region of responsibility and in coordination with adjacent areas.

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II. MODELING APPROACH

A. Simulation Toolkit

The simulation has been carried out using a set of inter-operable fast-time simulation modeling tools, components and agents that are available in the ISA Software Next Generation ATM Concept Validation Toolkit. This provides a versatile collaborative modeling platform to allow models of different ATM stakeholders (e.g. Radar teams, MSP, Operators etc.) to work together to manage the traffic demand and capacity through the exchange of accurate and timely ATM system data in support of collaborative ATM planning processes. The platform is based on fully 4D-Trajectory based management concepts and provides key features and enablers including:

- System Wide Information Management (SWIM)
- Collaborative planning and balancing of demand/capacity
- User-oriented problem solving
- 4D trajectory management

For this study, modeling agents used included:

- Major airports (3) in the region – modeled to high fidelity using the RAMS Plus Airport and Terminal Area modeling tools and including all runway, arrival and departure procedures
- All ATC Sectors and Controllers for the three ATC Centers – using RAMS Plus Airspace and Controller models
- 50 Multi-Sector Planners – using the CHILL/MSP agent model, each responsible for up to 4 ATC sectors across three centers
- Common ATM Information State Space (CAISS) – providing the modeling support for System Wide Information Management
- Sim-C Event Notification System (SENS) – supporting message exchange

The CHILL/MSP Area Flow agent model is a new model that has been designed and implemented to work within the SIM-C platform to provide a model supporting the role and responsibilities of the MSP.

Each independent MSP agent was allocated to two or more sectors (typically 3) which make up the MSP area of responsibility (MSA). The information window (time frame) in which the MSP can work is set using some of the modeling parameters where each flight that is predicted to enter one or more sectors in the MSA is added as a Predicted Flight (PF) at a defined time offset. Demand capacity assessment is carried out on a continual basis until the PF actually enters the MSA or until a flight is diverted or modified by something elsewhere in the system such that it will no longer enter the MSA.

B. Scenarios

Three adjacent en route centers were selected for this study: Fort Worth Center (ZFW), Kansas City Center (ZKC) and Memphis Center (ZME). These centers were chosen because the real-time simulation [1] considered sectors north of Dallas-Fort Worth, and because these three adjacent centers contain substantial inter-center boundaries for a study of MSP coordination. Adjacent centers were defined with ATC behaviors (such as conflict detection and resolution) but were used as “ghost” or dummy sectors for MSP – these ghost sectors always accepted MSP coordinations and requests to uplink a re-routed trial plan.

The analysis was performed using three traffic samples representing peak traffic loads per center for 2007, 2007 plus 20% and 2007 plus 40%, corresponding to forecasted traffic loads for 2013 and 2018 respectively [4]. These samples are referred to as Baseline, Plus20 and Plus40 in this document. Each sample was run with ATC behaviors only (NoMSP) and with ATC plus the MSP agent (MSP).

The sectors in the three center area were grouped into suitable Multi-Sector Areas and each MSA was allocated to a Multi-Sector Planner, which was responsible for demand balancing for the Radar teams in the MSA.

III. MSP EXAMPLE

Figure 1 presents an example of the impact of MSP demand balancing activities. The figure shows peak 15-minute traffic counts in a busy sector over the peak 12 hours of the largest traffic sample (Plus40, corresponding approximately to forecast loads for 2018). The orange line shows the peak traffic in the Plus40 NoMSP scenario and the blue line shows the peak with MSP intervention. The MAP value is shown with a dashed red line for comparison: the MSP's objective is to keep the peak traffic count *below* this value.

As Figure 1 shows, the MSP was able to solve or significantly reduce the traffic count and overload duration for all but two of the overloaded periods. Note also that there were several periods below the MAP when the sector traffic count was higher with MSP than with NoMSP: the MSP for this sector accepted additional flights from adjacent sectors during periods when the sector was not overloaded, illustrating the importance of collaborative cooperation among MSPs.

The largest overload remaining in this example (20:45 to 21:15), which was *not* present in the NoMSP scenario, may have been caused by aircraft with extended durations in the sector (possibly due to conflict resolution), other prediction uncertainties, or MSP attempts to reroute flights which were rejected by neighboring MSPs. This overload occurred during the most overloaded hour in all of the scenarios. Thirty-nine sectors exceeded the MAP between 20:00 and 21:00 and 36 sectors during the following hour. If an MSP attempted to find reroutes to reduce an overload and these reroutes required coordination with other MSPs, the reroutes may have been rejected due to other overloaded sectors nearby.

IV. MSP RESULTS

The MSP agent was able to substantially reduce the number of individual minutes above the MAP as well as periods of longer duration. Figure 2 shows the total number of overload minutes and periods of 6 minutes or longer for all scenarios. The figure also shows dramatic increases in the time periods

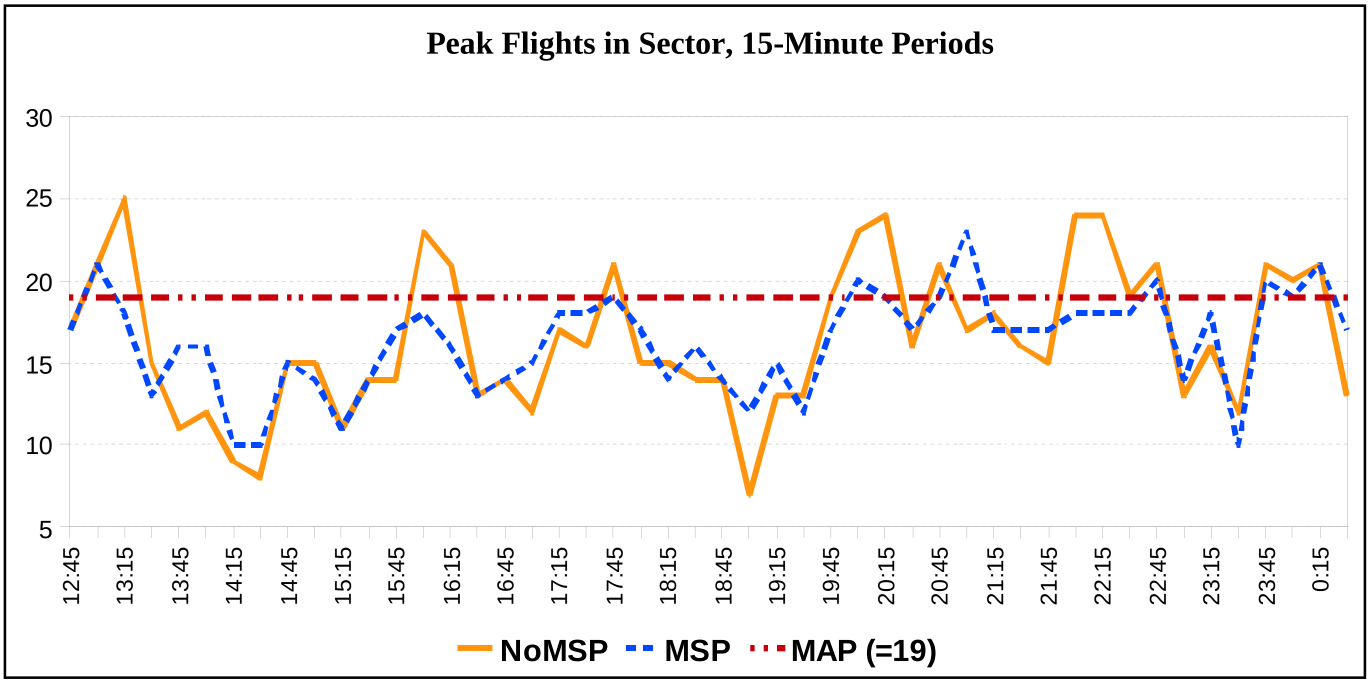

Figure 1. Example of MSP Activities

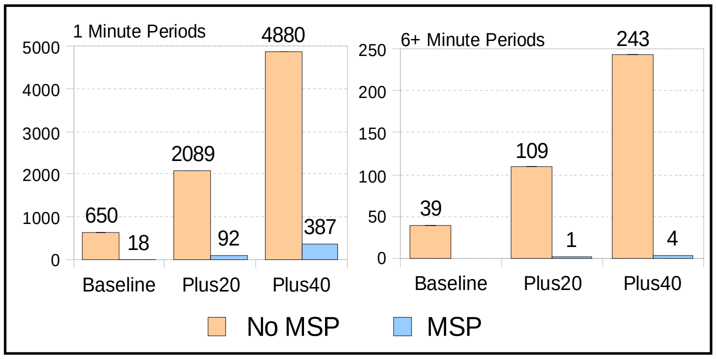

Figure 2. Number of Time Periods Above the MAP

exceeding the MAP from each traffic sample to the next. The Baseline sample contained only 12% more aircraft than the initial ETMS sample, yet the number of minutes exceeding the MAP increased by 310%. The increase from the Baseline to Plus20 was a further 321% and from Plus20 to Plus40, 234%.

Upon examination of the change in the peak percentage of MAP after MSP intervention, we found that 51% of 15-minute periods across all sectors showed a change in this peak. (The MAP value minus 1 is considered to be 100% of sector capacity for each 15 minute period.) Half of these or 25.1% of the total showed a reduction in peak percentage of MAP (by 16.8% on average), while the remaining 25.7% increased their peak MAP by 9.6% on average. Thus the average *benefit* of MSP activities (in reducing the peak traffic count) was greater than the average *penalty* to nearby sectors (those accepting the excess traffic).

Figure 3 overleaf shows more traditional "TFM"-style color-coded grid illustrating the impact of MSP actions over the peak 12 hours, for all sectors experiencing at least one overloaded period during the Plus40 NoMSP scenario. Periods with a peak percentage of MAP from 80% to 99.9% are shown in yellow to reflect the high, but not excessive, traffic loads.

V. TRIAL PLANNING AND COORDINATION

The following terms are used to distinguish the MSP actors:

- **Initiating MSP**: the MSP who, having identified a predicted overload period, is attempting to reroute aircraft out of the impacted sector.
- **Uplink sector or MSP**: the sector and MSP responsible for the sector in which the start of a trajectory change occurs, often an upstream sector. This is the MSP whose sector team will be required to communicate with the aircraft if the trajectory change is accepted.
- **Other MSPs**: all other MSPs that the initiating MSP may have to coordinate with.

A. Rerouting Trial Plans

To minimize the number of flights needing to be rerouted, the MSP agent chose flights for rerouting by identifying candidate aircraft whose predicted sector crossing times coincided with the most minutes of predicted overload. Once this initial selection was made, the MSP verified that the flight was indeed available to be rerouted, i.e. there were no other trial planning or coordination activities pending for the flight and it was not currently being rerouted by another MSP or a tactical controller.

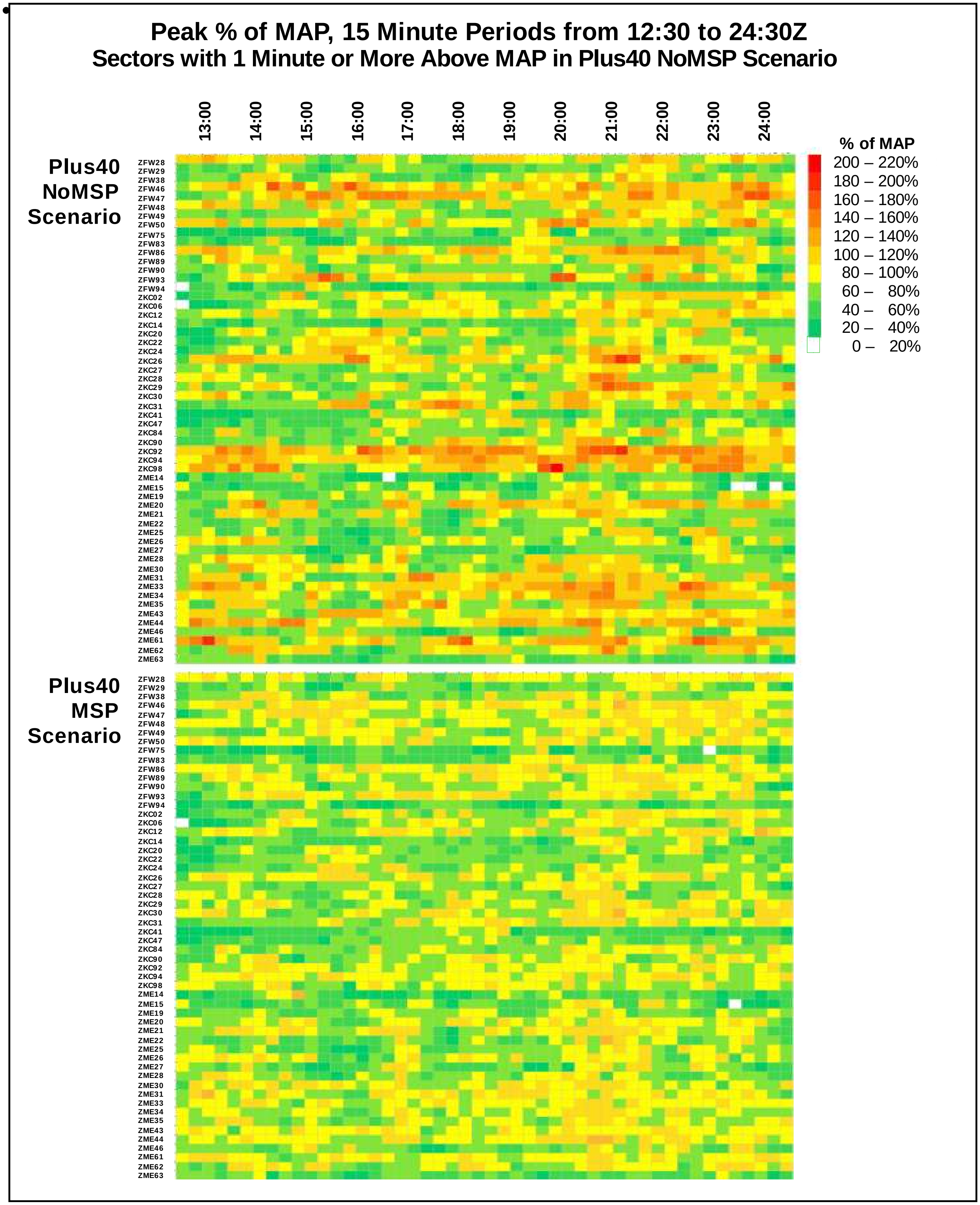

Figure 3. Peak Percent of MAP

The next step in the rerouting process was to create the proposed trial plan containing a reroute around, or reducing the flight's duration within, the overloaded sector. The MSP agent provides three types of reroutes:

- **"Local playbook" reroutes** were developed to assist the MSP tool with rerouting major flows within each sector. For simulation purposes, these reroutes were intended to provide the MSP agent with a few localized reroutes with a smaller impact on the user than the strictly geometric avoidance of a sector. These reroutes provide the best "simulation" of the typical reroutes that an MSP may be likely to provide. These were called "local playbook" rules because, as with the national playbook, we would anticipate that the MSPs working an MSA would develop a set of typical reroutes designed for the traffic flows in the local area.

- **Geometric reroutes** find the shortest path around the overloaded sector by computing a path around the boundary on both sides (i.e., to the north and to the south) and choosing the shortest of these. These reroutes begin and end at a navaid at some distance from the boundary, to avoid sharp turns around the sector corners.

- **Vertical reroutes** were attempted if both of the above reroute types were unsuccessful. A flight might be rerouted vertically (up to a maximum of +/- 4,000 feet from its cruise altitude) if this was sufficient to avoid the overloaded sector and if the aircraft performance permitted the change (the new cruise altitude was not too high and the aircraft is capable of climbing or descending quickly enough to avoid the sector.) Additionally flights could be level capped or given early descent for aircraft operating at airports in the local region.

B. *Coordination Rules*

Once a trial plan was successfully calculated, the MSP agent determined whether or not the trial plan required coordination with other nearby MSPs. The MSP was required to coordinate with another MSP in these cases:

- If the start of the proposed change in the flight's trajectory occurred in a sector outside the MSA. This is the typical case, for example, when a proposed reroute began in an upstream sector.

- If the trial plan entered a new sector which the original flight path did not enter. If the sector entry time was within 40 minutes of the beginning of the trajectory change and the predicted duration inside the sector was longer than 2 minutes, then the initiating MSP was required to coordinate with the MSP responsible for that sector.

Coordination was not required for sectors that an aircraft was already scheduled to enter, including when the new flight trajectory altered the sector entry or exit times or altitudes.

Coordination was also not required if there was no active MSP responsible for a sector. In this study MSPs were modelled only within the three center area. Whenever a trajectory change began outside of this area, the trial plan was first coordinated with any impacted MSPs, and if accepted then the reroute was simply transmitted to the relevant "ghost" sector for uplink to the aircraft.

Finally, coordination was not required if the entire change in the trajectory occurred within the initiating MSA.

VI. COORDINATION RESULTS

A. *No Coordination Required*

In this study, coordination was not required for 26% of all uplinked trial plans, on average across the three MSP scenarios. Fifty-six percent of these or 14.6% of all committed trial plans were uplinked by a sector outside of the three center area. In an environment where MSPs are active across all centers, these trial plans would in fact require coordination since the initiating MSP was in a different center from the uplink MSP.

B. *Coordination Required*

As described above, proposed trial plans required coordination with other MSPs when the trajectory change began in a sector outside the initiating MSA and/or whenever the revised trajectory entered a sector that was not previously crossed by that aircraft. In these cases, the initiating MSP would publish the TP to the uplink MSA, first, and then to any other MSPs responsible for new sectors in the flight's path. Figure 4 shows the proportions of the number of other MSPs that the initiating MSP was required to coordinate with, for each proposed trial plan.

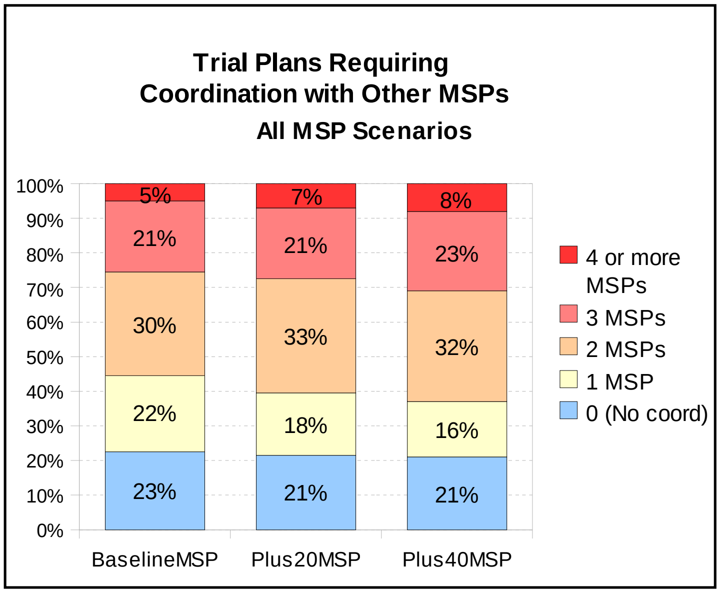

Figure 4. Trial Plans Requiring Coordination

Note that the apparent trend shown in Figure 4, where a higher percentage of trial plans required one or more coordinations in the Plus20 and Plus40 scenarios in comparison to the baseline, is an effect of our rerouting techniques. As the scenarios became busier, our simulated MSPs had to attempt more reroutes and more of those reroutes were geometric or vertical, thus increasing the number of new sectors crossed and the number of coordinations required. This is unlikely to occur in an operational environment where a human MSP would use more sensible reroutes.

C. *Trial Plan Rejection*

When trial plan coordination with other MSP(s) was required, a cancellation or rejection any of the other MSPs would cancel the trial plan. In these cases the initiating MSP was informed of the cancellation and, if time permitted, would attempt to find another candidate aircraft to reroute around the overloaded sector. The following subsections describe the reasons for trial plan cancellation/rejection, in descending order of frequency in the busiest scenario.

1) Sector Busy

Trial plans were rejected when they were expected to enter a new sector (not previously in the flight's path) which, with the addition of the new trial plan, was predicted to be at or above the MAP for at least one 2-minute period during the flight's traversal. This included the ‘uplink sector’ where the change in the proposed TP began.

Figure 5 shows the distribution of the time difference between the start of the trajectory change and the predicted entry time into an overloaded sector, for every trial plan rejected due to excess demand. Approximately half (50.6%) of the rejections due to busy sector were based upon predicted traffic load up to 20 minutes in advance, while the remainder were based upon longer lookahead times where we would typically expect higher rates of prediction error. In an operational environment, it may not be feasible to require trial plan coordinations this far in advance, unless there is a reasonable level of confidence in sector entry and dwell time predictions.

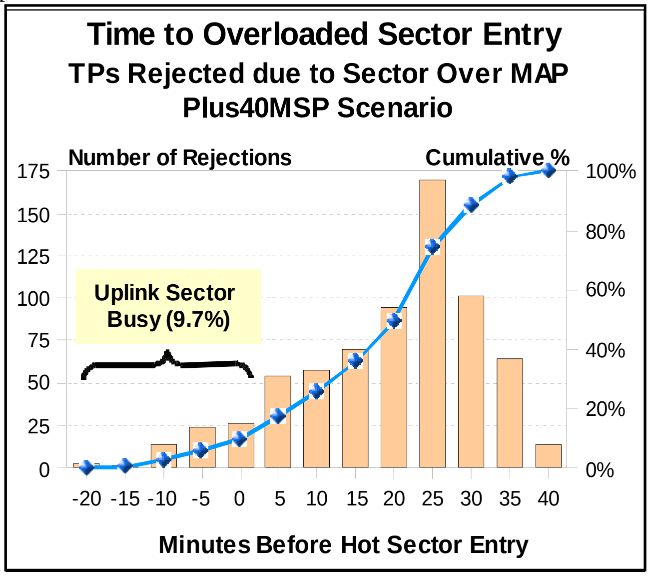

Figure 5

2) Timeouts

In the simulation, random event generation with elapsed time was used to model coordination timeouts and trial plan timeouts. Timeout rates for both types of timeouts combined ranged between 3% and 5% across all MSP scenarios.

3) MSP Busy

In the absence of clearly defined tasks and estimated task times for use in a workload model for the Area Flow MSP, we used two indicators to identify periods when an MSP may be too busy managing his or her own MSA to promptly consider coordination requests from other MSPs:

- Number of Flights to Reroute. This is an estimate of the number of flights remaining to be rerouted for all overload periods in all MSA sectors.
- Number of Pending Trial Plans. The total number of pending trial plans which have been proposed but not yet uplinked. The MSP will need to monitor this list since a trial plan cancellation may create the need for additional reroutes.

An MSP was considered to be too busy when the sum of these two indicators was above 50. This value was not based on any empirical evidence, rather after a number of tests were carried out, we felt that the value calibrated at this figure produced a reasonable rejection rate (1.1% in the Baseline, 1.5% in Plus20, and 7.9% in Plus40) due to the MSP being too busy to manage a TP request. It is clear that, following additional RTS simulations, it may be of interest to develop an MSP workload model or other measure to predict MSP overload, but at this stage it was considered outside the scope of the initial assessment.

This MSP "taskload" indicator was not intended to provide a realistic workload metric for the MSP but it has served to suggest that the balance of workload for an MSP should be considered when or if operational MSAs are designed. Our simulated MSAs were designed by focusing primarily on the direction and nature of the traffic flows in adjacent sectors without considering the overall traffic density or peak time periods. We inadvertently created 3 (out of 50) MSAs which experienced high traffic loads in 2-3 sectors simultaneously. Although the final results for these MSAs were still quite good despite the "MSP Busy" rejections, we would recommend taking both traffic density and flows into account when designing MSAs.

4) ATC Update

In a few cases, the R-side or tactical controller (simulated via RAMS Plus) modified a flight while an MSP trial planning and coordination process was underway for the same flight. Tactical updates, including local airport departure delays, spatial conflict resolution for separation management and SUA avoidance maneuvers, always took priority over MSP actions.

In these situations, the tactical model simply notified the MSP agent of the new 4D trajectory and any ongoing MSP trial planning/coordination activities were cancelled.

D. Summary of Coordination Results

As shown in Figure 6 summarizing the coordination results for the three MSP scenarios, the acceptance rate for all coordinated trial plans decreased from 88.9% in the Baseline to 83.3% in Plus20 and 70.5% in Plus40. Nearly all of the reduction in the acceptance rate for future traffic scenarios was due to increased levels of "MSPBusy" and "SectorBusy" rejections in the two future scenarios.

The model included the 3 MSP centers along with feeder or "ghost" sectors from the 7 centers adjacent to the study area. As discussed previously, these external centers did not have active MSPs and always accepted coordinations from any MSP.

Fifty-five percent (55.4%) of all uplinked trial plans were uplinked by an MSP within the same initiating center, on average across all 3 MSP scenarios. ZKC uplinked the most of it's own internal trial plans (62.6%), with ZFW next at 50.9% and ZME at 48.5%. Of course, these percentages will vary depending upon the direction and location of traffic flows, the general "shape" of the center and the proximity of the overloaded sector to the center boundary. But the message is clear: inter-center cooperation and facilitated coordination between facilities is vital for the MSP concept.

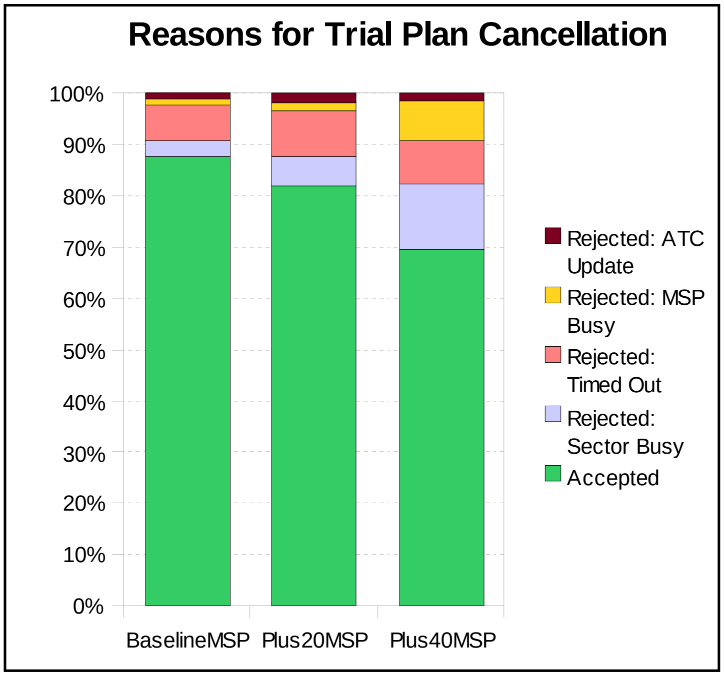

Figure 6.

VII. NEXT STEPS

A further real-time study will be held at NASA Ames in 2009 with the objective of refining inter-MSP coordination procedures, which will subsequently be fed back into a systemwide FTS analysis using the CHILL/MSP platform.

Additional research will include analysis of when and how data-link capabilities might be available, to potentially allow the MSP to uplink certain reroutes directly to the flight deck or to the airline operator for collaborative reroute planning.

Research is continuing on the development of the FAA Area Flow MSP concept and associated decision-support tools.

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Ian Crook has over 17 years experience in computing, specializing in the application of leading edge technologies to user oriented software systems. Specific skills include the use of Object Oriented methods, Artificial Intelligence, Discrete Event Simulation and Distributed Object Architectures. Having spent his formative years working in the aviation manufacturing industry, specializing in the development of onboard aircraft control software, Ian spent five years developing telecommunication systems, before returning to the aviation industry in 1991. Since then, Ian has specialized in the design of ATM-oriented simulation systems.

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