ABSTRACT

This study evaluates a new sector design called Dynamic Airspace Super Sectors (DASS). DASS may be thought of as a network of one-directional, high density highways in the sky, like thin ribbons of airspace stretching over the U.S. and connecting major airports. DASS is a simplification of airspace structure that may decrease Air Traffic Controller (ATC) workload and allow higher densities of aircraft to be safely monitored. DASS would also potentially reduce delay for aircraft using DASS. The team used these two factors, workload and delay, to measure the effectiveness of the DASS Alternatives. This study uses Total Airport and Airspace Modeler (TAAM) and Arena simulation environments to simulate two aspects of the design alternatives: the effect of varying the number of entrance/exit points to DASS, first, on traffic outside and second, on traffic inside of DASS.

1 PROBLEM DESCRIPTION

Dynamic Airspace Super Sectors (DASS) will address the en route traffic problem by addressing a major limiting factor of the air traffic system: the mental workload of Air Traffic Controllers (ATCs).

The en route traffic problem is caused by many factors including increasing demand for air travel and the current sector structure. The demand for air travel is growing, in part, due to its economic affordability. It will be difficult in the coming years for the National Airspace System (NAS) to meet the demand. Increasing congestion will impair the domestic economy and, more importantly, safety if changes are not made.

The limitation in this case is often the amount of mental workload that an ATC can handle, and the amount of this workload depends on the airspace structure and sector design. Today, sectors are designed to keep ATC workload in a sector down to a manageable level. This is becoming difficult with the current airspace structure. For example, because of congestion in the Northeast Corridor, sectors are kept small to reduce sector load, however, sectors cannot become much smaller without making the system more inefficient. Furthermore, the current sector design is outdated. Many sector boundaries have remained the same, while traffic patterns and volumes have changed over the years.

The current airspace structure (see Figure 1) is a limiting factor in the ability to increase the capacity of the NAS. Often, because of high workload in a sector, ATCs enforce much higher miles in trail (MIT) restrictions than is required (e.g., 30 MIT vs. 5 MIT). Sometimes, aircraft are rerouted or even denied access into a sector, because of congestion. Without a way to decrease sector workload, only marginal increases in the capacity of the NAS can be expected. ATC workload is directly related to the Situational Awareness of ATCs, that is, the perception and understanding that ATCs have of the air traffic situation they are monitoring. A major redesign of the current sector system is needed in order to improve their Situational Awareness.

DASS proposes to simplify airspace structure by radically redesigning sectors, in order to improve the Situational Awareness of ATCs, thus reducing their workload and increasing the number of aircraft that can be safely handled. At the same time, DASS will meet the needs of increasing air travel demand.
2 VALUE HIERARCHY

The following criteria with weights, which will be used to measure our design alternatives, were developed with the help of our sponsor, Karl Grundmann.

The criteria are a set of stakeholder objectives; the first level of objectives is shown in **Figure 2**. Safety is the most important issue because any compromise in safety could possibly result in the loss of many lives. Increasing accidents would also deter passengers from flying, thus having an economic impact. While performance and cost are both important criteria, a system that is safe and that performs at a high level can justify a higher cost. However, a less expensive system that endangers lives and causes passengers to be late will never be used, no matter how low the cost.

\[
U_0 = (.5)U_S + (.09)U_A + (.075)U_{WL} + (.075)U_G + (.06)U_D + (.2)U_C
\]

Where, \( U_0 \) = total utility
\( U_S \) = safety utility
\( U_A \) = availability utility
\( U_D \) = delay utility
\( U_G \) = capacity utility
\( U_{WL} \) = workload utility

While all these criteria are important in evaluating the DASS designs, many of them are outside of the scope of the study. Safety is very difficult to quantify and measure. Availability of such a large system with so many components is also very difficult to measure. Because of this, we assumed that safety and availability were assured for all alternatives. Cost of the system was assessed but weighing it against the anticipated benefits was problematic, because many of the benefits, such as saved time, were difficult to attach a price. Our simulations were primarily concerned with workload and delay, but also explored some issues with capacity. Because the only concrete metrics that we had were workload and delay, we based our evaluations solely on those two. Given more time and resources a more complete utility analysis may have been possible.

3 CONCEPT OF OPERATIONS

3.1 Goals of the DASS System

DASS system aims to increase ATC Situational Awareness, thereby minimizing ATC mental workload at critical sectors to allow air traffic growth at equal or greater safety and efficiency. In addition, DASS aims to reduce delay and cancellations and make possible more predictable flights.

3.2 General Concept

The DASS system is a structured network of elongated sectors, which can be imagined as thin ribbons of airspace, stretching over the United States and connecting major airports. They are akin to an Interstate Highway System in the sky. Each ribbon is one-directional, has one primary lane, and will carry high volumes of traffic. The DASS ribbons are “dynamic” in that they move in order to adapt to changing weather patterns and jet flows. They are “super” in that they transcend, or go beyond, the boundaries of standard sectors.

DASS sectors are a special segregated airspace, separated from the congestion around them. **Figure 3** shows how DASS would overcome the problem of rerouting by providing a ribbon-like sector that may cut through several standard sectors. The DASS sectors would be treated as dynamic Special Use Airspace. Non-DASS ATCs would assure that no non-DASS aircraft enter DASS.
The DASS system would also provide vertical structure to air traffic. Aircraft flying along the main section of a DASS ribbon would all fly at the same altitude. Part of the ascend and descend may also be part of the ribbon depending on the DASS design.

One concept of the design of this system that reduces ATC workload and makes reduced separation standards possible is self-separation. That is, aircraft within DASS would maintain safe separation without the aid of ATCs. Aircraft must meet important criteria before they will be able to use the DASS system. They must have the Required Communication, Navigation, and Surveillance Performance (RCNSP) capabilities.

### 3.3 Potential Benefits

By simplifying horizontal and vertical structure of airspace, the complexity of air traffic situations may be reduced. ATC Situational Awareness may be increased, and ATCs may safely be able to monitor more aircraft. Situational Awareness refers to the ATC’s ability to perceive, comprehend, and project the outcome of an air traffic situation. Reducing air traffic complexity will help with all three, and improved Situational Awareness will help ATCs make better decisions. This may decrease the mental workload of ATCs. Safety may increase, and ATCs may be able to monitor more aircraft at higher densities.

Furthermore, because of the simplified structure of the airspace and because aircraft will be self-separating, separation standards within DASS airspace may be reduced without degrading safety. This better usage of airspace will increase the capacity of the National Airspace System and help relieve congestion.

Because of the increased capacity and because aircraft in DASS would never be rerouted because of congestion, delays and cancellations may ultimately be reduced. To aircraft that are equipped, DASS offers an airspace that may give nearly optimal flight routes with very predictable flight times and little delay compared to current flights which are sometimes padded by one hour for an one and a half hour flight. Fuel saving and this increased predictability is vital to the satisfaction of DASS stakeholders, such as the passengers and airlines. For DASS to be successful, these benefits should exceed the cost for airlines to equip their aircraft with the RCNSP capabilities.

### 3.4 Costs

The cost of the system to the FAA is primarily Capital Costs, because most of the costs of the system are non-recurring. It is assumed that ATCs and Air Traffic Managers would be paid the same amount as prior to implementation of DASS. The Capital Costs is composed of System Engineering and Design Cost. For 50 engineers working for 2 years to complete the system engineering and design phase, the cost estimate was $26,000,000. The next major cost is Software Cost. The team used a metrics approach to find the number of man-hours to complete this part, which turned out to be 328 man-years. With 115 people working less than 3 years, the cost was $57,000,000. The final major cost was ATC Training Cost. For an estimated 400 ATC needed, the cost was $5,120,000. This gives a total Capital Cost of about $88,000,000.

The Capital Cost for Airlines depends on how they meet the requirements for equipment described below.

### 3.5 Requirements for Aircraft

Because of the critical importance of the RCNSP devices, the aircraft must have multiple, independent redundant systems to meet the requirements.

To briefly sum the RCNSP requirements:

- Aircraft must have independent and redundant devices to allow digital communication between DASS ATC and other DASS aircraft.
- Aircraft must be able to broadcast and receive data about its characteristics (such as position, speed, trajectory, altitude, flight number, aircraft ID) to aircraft within a 150 mile radius and to DASS ATC.
- Aircraft must have a GPS-based surveillance and navigation system.
- Aircraft must have an independent radar-based surveillance and navigation system.
- Aircraft must have a Collision Avoidance System (CAS)

### 3.6 Components of the DASS System

The DASS system has major four components:

- The network of DASS sectors,
- The management system,
- The DASS ATCs, and
- The maintenance personnel.
3.6.1 DASS Network

Consists of the network of dynamic ribbons that connect major airports, which will continually change because of shifting weather patterns and other irregularities. Two main elements make up the DASS network: the standard flow regions and the critical points. Standard Flows are the regions where aircraft fly without interruption. Critical Points are points where aircraft are allowed to enter and exit DASS. They may be located near major airports or they could be distributed in many places along the path of a DASS sector and can include multiple entry for one airport.

3.6.2 Management System

The Management System is composed of two parts: Software and Personnel. The software for the DASS system provides the definition of the DASS network, meaning, the location of all the DASS sectors at any given point in time. The software will be able to change the DASS network as necessary due to weather, favorable jet flows, restricted airspace, or any other anomalies. The software will shift the system without causing any of the DASS sectors to intersect.

The management personnel will be responsible for operating the software. They are also responsible for disseminating the information about the definition of the DASS network to ATCs across the continental U.S. and overlooking the whole system.

3.6.3 DASS Air Traffic Controllers

DASS ATC are responsible for controlling aircraft as they enter and exit DASS airspace at the Critical Points, monitoring the aircraft in the Standard Flows and around the DASS ribbons, and providing emergency support. DASS ATC are also responsible for providing specific information about the coordinates of DASS sectors to aircraft.

3.6.4 Maintenance Personnel

The Maintenance Personnel is responsible for maintaining the software of the system.

3.7 External Systems

External systems to the DASS system include:
- Pilots/Aircraft
- Non-DASS ATC

4 DESIGN ALTERNATIVES

There are two aspects of the design of the DASS system. The first is the ribbon geometry and the second is the network design. Because we were unable to test the ribbon geometry designs, here we present only one hypothesized ribbon. For the network designs, we were able to perform analysis using simulation.

4.1 Ribbon Geometry

After considering several options for the form of the DASS ribbon, the team determined one logical design concept which would be able to perform the functions required for the DASS system.

Because structure adds to the predictability of traffic within DASS and because aircraft will use self-separation, three mile separation is hypothesized to be possible. Thus, the ribbon dimensions were chosen in order to allow three mile horizontal separation between the aircraft within DASS and five mile horizontal separation and 1000 feet vertical separation between aircraft inside DASS and aircraft outside of DASS. These dimensions are still subject to review. Figure 4 shows the cross-section of the hypothesized ribbon.

Aircraft within DASS are governed by special DASS flight rules. An important concept of this design is that it allows aircraft traveling at different speeds to pass each other while remaining in the ribbon, thus minimizing the possibility of delays caused by a slow aircraft. Aircraft will be able to fly side by side three miles apart (on the left and right crosses) until the passing maneuver is complete, after which the aircraft would return to the center of the ribbon (center cross). Because wake vortex generally propagates downwards, merging occurs from the sides of the ribbon. Aircraft inside the ribbon shift to the left or the right away from the merging aircraft. After the merging maneuver is complete, the aircraft would return to the center of the ribbon.

4.2 Network Design

The simulations we performed all deal the number and location of Critical Points (entrances and exits) in the system. One design feature relating to critical points is the number of entrances that each city has to the DASS ribbon: 1 entrance, 2 entrances, or 3 entrances for a city. The second design alternatives deals with the network configuration. There are three major network design alternatives:
Alternative 0 is the current sector system. This is to leave the Air Traffic Management system as it is. Currently, sectors are designed to minimize the number of handoffs between ATCs and keep sector workload down to a manageable level. ATCs play an involved role in controlling aircraft as they fly through and between the current sectors. Refer to Figure 1 above for a layout of the current sector system.

Alternative 1 is called the City Pair alternative. In this design, DASS sectors stretch from city to city without intermediate points for entry and exit. This is the simplest DASS alternative. It is essentially direct routing from New York to Chicago with a set cruising altitude. We must first see the effects of this design before studying Alternative 2.

Alternative 2 is called the Multiple Cities alternative. This is similar to Alternative 1, except there will be intermediate points of entry and exit for cities between the two end points of a ribbon. An example of a network for this alternative is shown in Figure 5.

In this example network, the ribbons connecting New York and San Francisco would have intermediate entrances near Denver, Salt Lake City, Chicago, and Cleveland. Philadelphia may also use the same ribbon to go west.

5 SIMULATION

Our group produced two simultaneous computer simulations of the DASS system. This study uses Total Airport and Airspace Modeler (TAAM) and ARENA simulation environments. We will be using TAAM to examine the effects of placing two one-way ribbons in opposing directions between two densely populated cites to examine how it will affect the surrounding air traffic situation. Arena will be used to more closely examine the queuing delays at the entry points to and inside the ribbons. We chose two cities, New York and Chicago, because of the high volume of flights and extreme congestion in that area.

In TAAM and Arena, we modeled both the City Pair Alternative for a ribbon from New York (NYC) to Chicago and the Multiple Cities Alternative with added traffic to and from Philadelphia, Cleveland, and the ‘West’, meaning, Denver, Oakland, Portland, Seattle, San Francisco, San Jose, and Salt Lake City. All DASS traffic flies along the path of the ribbon between NYC and Chicago, which is the study area (Figure 5). NYC is composed of the airports: Kennedy Intl, La Guardia, and Newark Intl. Chicago is composed of Chicago O’Hare Intl and Chicago-Midway. The TAAM simulation

In TAAM, we also compared these Alternatives with the Baseline Alternative (Current System). In Arena, a model of the Baseline is not possible, however, we were able to explore the effect of changing the number of entrances for a city. In Arena, we simulated only one way from NYC to Chicago.

5.1 Total Airport and Airspace Modeler (TAAM)

5.1.1 Objective

TAAM is a high fidelity modeling tool with the capability of modeling airports in extremely high detail. It can also be used, however, to model en route airspace, and in our study, we took advantage of this capability. However, the TAAM model is designed for the current sector system. It is not designed to model our specialized DASS ribbons or the new function of DASS ATC.

Because of this, the objective of our simulation was to determine the effect of specialized routing, that is, forcing aircraft to fly along a path that resembles the DASS ribbon. Simulating all traffic flying through the study area, we measured the effect of this specialized routing on ATC workload, which was measured as TAAM normally measures it for the current sector system. The results of this study helps us determine whether it is worthwhile to investigate the DASS concept any further.

5.1.2 The Model

The team performed three simulations in TAAM. First, we first simulated the Baseline Current Sector System, by simulating all traffic over 4 Air Route Traffic Control Centers (ARTCCs): Chicago Center (ZAU), Cleveland Center (ZOB), New York Center (ZNY), and Indianapolis Center (ZID). See Figure 6. We limited the study to sectors above 25,000 feet (FL250), because this is where the DASS sector will be located. All flights fly through this section of airspace, including airports outside of this section, were taken into account. Because the study focus was restricted to only en route airspace, airports were treated as “sink and source;” they simply outputted aircraft at the de-
parture time of the flight and disposed of them when they reached the destination. Thus, holding patterns and delays because of congested terminal and ground traffic were not factors.

The second simulation run was the City Pair Alternative, which was straight flights between NYC and Chicago flying along one path at one altitude (29,000 ft or FL290). We located the “ribbons” with opposing flows 15 miles apart. This is because we did not want workload to be affected by “head on” traffic.

In the third simulation run, we included Philadelphia and extended the ribbon from Chicago to San Francisco and Portland. Any traffic flying along this path to/from NYC and Philadelphia were included in the ribbon.

We chose the Miles-in-Trail (MIT) restriction for aircraft to be five miles, which is the current MIT for en route airspace. Ideally, the MIT for DASS aircraft would be reduced to three miles, because of the added predictability. Special Use Airspace was considered, but because there was only one restricted area between New York and Chicago, we did not include it in our model. We used the sector boundaries defined by Arash Yousefi, a graduate student at George Mason University.

Historical Enhanced Traffic Management System (ETMS) data for the entire day of Thursday, May 2, 2001 provided the departure times, flight routes, and aircraft type which were used as input data for the TAAM simulation. The routes represented actual flight routes through existing waypoints, not Great Circle or direct routing. Thus, we would be able to see a difference between the current system, which includes indirect routing, and the DASS alternatives with specialized routing, which more resemble direct routing with a forced cruising altitude. Also, this study used the individual aircraft models that already existed in the TAAM database.

The team used ideal weather and Visual Flight Rules (VFR). VFR are rules that govern the procedures for conducting flight under visual meteorological conditions (VMC). Requirements for visual conditions are normally 3 mile visibility and a 1000 foot cloud ceiling and ideal weather. We made this assumption for weather because, a system must first work under ideal conditions before being considered under imperfect conditions.

5.1.3 Workload Metrics

Many factors influence the measure of workload in TAAM. Total workload is the sum of four types of workload.

- **Horizontal Movement Workload** is a function of density (# aircraft in a sector) and residence time (time spent in a sector).
- **Conflict Detection and Resolution Workload** is based on type of conflicts and conflict severity.
- **Coordination Workload** is based on the number and type of coordination actions by ATCs.
- **Altitude Change Workload** is determined by the type of sector altitude clearance requests such as level off and commence climb.

A metric that is used for this analysis is the Complexity Index (CI), which is defined by Total workload divided by Total number of aircraft.

5.1.4 Results

We found both TAAM’s measure of workload and CI for the four Centers of interest. The workload shown in Table 1 is the sum of the hourly workloads for the course of one day. Workload has gone up between 7% to 109% from the Baseline to the Multiple Cities Alternative. This corresponds to the increase in number of aircraft per Center, which is the sum of the number of aircraft that pass through a sector during each hour for the course of the day (Table 2). Some of the increase is likely due to the channeling of extra aircraft through the centers.

The case of ZNY is interesting, because the number of aircraft more than doubles, which corresponds to the increase in workload. The hourly data (not shown) illustrates that number of aircraft and workload both go up for many of the individual sectors, even sectors where there was no workload before. The new paths of aircraft are causing aircraft to spend more time in ZNY sectors than they were before. While workload increases greatly, the CI for ZNY actually decreases significantly (Table 3). This indicates that while there may be more aircraft and they may spend more time in the Center, the complexity of the air traffic in the Center may actually have been decreased per aircraft,
which indicates that more aircraft may be able to be safely monitored.

These results show no straight answer to whether the DASS Alternatives are better than the Baseline. Even though CI is lowered, creating a specialized path through ZNY automatically causes more aircraft to be in this sector per hour, which means that it may actually be more difficult to increase the density of traffic there.

For the other three sectors, both workload and CI increase slightly. Again, specialized routing causes more aircraft to be in those Centers per hour, which seems to complicate workload and in this case, make the traffic situation more complex.

<table>
<thead>
<tr>
<th></th>
<th>ZAU</th>
<th>ZID</th>
<th>ZOB</th>
<th>ZNY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>21400</td>
<td>20300</td>
<td>22500</td>
<td>3500</td>
</tr>
<tr>
<td>City Pair</td>
<td>22200</td>
<td>22300</td>
<td>24800</td>
<td>6350</td>
</tr>
<tr>
<td>Multiple Cities</td>
<td>23000</td>
<td>21700</td>
<td>25200</td>
<td>7310</td>
</tr>
</tbody>
</table>

% Increase Baseline to Multiple Cities:
- Baseline: 7%
- City Pair: 7%
- Multiple Cities: 12%
- ZNY: 109%

Table 1: Workload per Center

<table>
<thead>
<tr>
<th></th>
<th>ZAU</th>
<th>ZID</th>
<th>ZOB</th>
<th>ZNY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>10133</td>
<td>8130</td>
<td>9514</td>
<td>1500</td>
</tr>
<tr>
<td>City Pair</td>
<td>10446</td>
<td>8880</td>
<td>10751</td>
<td>3007</td>
</tr>
<tr>
<td>Multiple Cities</td>
<td>10750</td>
<td>8718</td>
<td>10768</td>
<td>3562</td>
</tr>
</tbody>
</table>

% Increase Baseline to Multiple Cities:
- Baseline: 6%
- City Pair: 7%
- Multiple Cities: 13%
- ZNY: 137%

Table 2: Total Number of Aircraft per Sector

5.2 Arena Simulation

5.2.1 Objective

Arena is an event-based, stochastic simulation modeling software useful in constructing queuing problems. Where the TAAM simulation deals on the macro scale with aircraft within and without the DASS system, the Arena study is concerned on a micro scale only with our DASS designs and the effect of changing the number of critical points on internal delay. The goals of this simulation were to measure the queuing delays for the City Pair Alternative and the Multiple Cities Alternative, with 1, 2, and 3 entrances, and 1x and 2x the number of flights. In doing so, we hoped to determine the best alternative based on delay and capacity.

5.2.2 The Model

We modeled a two lane DASS ribbon. At the critical points, only one aircraft can enter at a time. At entrances, aircraft must maintain 3 Miles in Trail. Within the ribbon, passing is allowed, but aircraft in any lane aircraft must maintain three mile separation between the preceding and succeeding aircraft.

The aircraft were generated using Enhanced Traffic Management System (ETMS) data for Wednesday, May 2, 2001. Using flight data from the Bureau of Transportation Statistics, TransStats for the month of August 2001, the team looked at the aircraft types and the number of flights per aircraft type that fly from New York to Chicago. Using the Jeppesen FliteStar software, the team found the ascend and descend times for the study aircraft.

In the model, the speeds of the aircraft are assigned after the aircraft are generated. Based on the number of flights per aircraft type and using the economical cruising speeds from the International Directory of Civil Aircraft 1999/2000, the team used five speeds, distributed by percentage, to the generated aircraft.

The ribbon model is a sequence of process blocks. Each process box represents a 3 mile stretch of airspace. Our model contains 260 processes, which equates to a 780 mile ribbon stretching from about 150 miles west of NY to about 100 miles southwest of CHI. When an aircraft entity enters into a process it ‘seizes’ a resource, which in our model represents a lane of traffic. The process is then ‘delayed’ (delay is considered ‘wait time’ in Arena) to represent the amount of time the aircraft would need to travel 3 miles. Upon exiting the process the resource is ‘released’ and another aircraft can then use that resource (or lane).

In the model, the speeds of the aircraft are assigned after the aircraft are generated. Based on the number of flights per aircraft type and using the economical cruising speeds from the International Directory of Civil Aircraft 1999/2000, the team used five speeds, distributed by percentage, to the generated aircraft.

The ribbon model is a sequence of process blocks. Each process box represents a 3 mile stretch of airspace. Our model contains 260 processes, which equates to a 780 mile ribbon stretching from about 150 miles west of NY to about 100 miles southwest of CHI. When an aircraft entity enters into a process it ‘seizes’ a resource, which in our model represents a lane of traffic. The process is then ‘delayed’ (delay is considered ‘wait time’ in Arena) to represent the amount of time the aircraft would need to travel 3 miles. Upon exiting the process the resource is ‘released’ and another aircraft can then use that resource (or lane).

In the model, the speeds of the aircraft are assigned after the aircraft are generated. Based on the number of flights per aircraft type and using the economical cruising speeds from the International Directory of Civil Aircraft 1999/2000, the team used five speeds, distributed by percentage, to the generated aircraft.

The ribbon model is a sequence of process blocks. Each process box represents a 3 mile stretch of airspace. Our model contains 260 processes, which equates to a 780 mile ribbon stretching from about 150 miles west of NY to about 100 miles southwest of CHI. When an aircraft entity enters into a process it ‘seizes’ a resource, which in our model represents a lane of traffic. The process is then ‘delayed’ (delay is considered ‘wait time’ in Arena) to represent the amount of time the aircraft would need to travel 3 miles. Upon exiting the process the resource is ‘released’ and another aircraft can then use that resource (or lane).

In the model, the speeds of the aircraft are assigned after the aircraft are generated. Based on the number of flights per aircraft type and using the economical cruising speeds from the International Directory of Civil Aircraft 1999/2000, the team used five speeds, distributed by percentage, to the generated aircraft.
amine the chokepoints inside the ribbon, based on which processes have the highest wait time, and allows us to examine the total overall wait time for each flight route (e.g., NY to Chicago, Philadelphia to West). Once we completed the models we were then able to conduct simulation runs and examine our system.

5.2.3 Results

This first thing we wanted to examine were the chokepoints within our ribbon. To do this we looked at the average wait time at each process and graphed the results (Figure 7). The spikes in the graph show us where we would have high levels of flight delay. Most of the peaks we see are expected, as they occur at the entrances for airports. There is, however, an abnormally high double spike in the middle of the graph. This double spike occurs right before the exit point for flights going to Chicago. If it were to be plotted on a map you would be able to see that the spikes occur in the middle of Cleveland Center near an FAA identified chokepoint. This double spike occurs in every model we have created. This leads the group to believe that flight scheduling is the cause for this double spike, although the group is currently examining the model to ensure the model is correct and not the cause of the double spike. The drop which occurs in the middle of the graph is where aircraft entities exit the ribbon for Chicago. The gradually increasing delay seems to indicate that delay accumulates and aircraft get slowed down by the aircraft ahead.

The second issue is the design of the number of entrances per city and the effect of this on delay. We obtained the following result for two entrances (See Figure 8). Overall delay is relatively the same, however there are two spikes for each city. The graph of three entrances looks similar. Because adding entrances adds complexity to the system, one entrance per city is recommended.

<table>
<thead>
<tr>
<th>Process Number</th>
<th>Time (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.005</td>
</tr>
<tr>
<td>2</td>
<td>0.01</td>
</tr>
<tr>
<td>3</td>
<td>0.015</td>
</tr>
<tr>
<td>4</td>
<td>0.02</td>
</tr>
<tr>
<td>5</td>
<td>0.025</td>
</tr>
<tr>
<td>6</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Figure 7: Wait Times for One Entrance Model. Left to Right = East Coast (NY) to West (Past CHI).

The third issue we wanted to examine is the overall capacity of our system. First we must determine the threshold for acceptable delay. Then we must look at the overall delay time for flights in the ribbon and ensure that it is below the threshold. After examining several options, including how the FAA calculates delay, our group has decided that 15 minutes is an acceptable threshold.

Since flights from New York City to Chicago are the longest flights that are completed in our simulation, we will be using that model to examine capacity. Table 4 shows our results from running 20 replications of flights from NY to CHI using 3 different models.

<table>
<thead>
<tr>
<th>Model</th>
<th>Avg WT</th>
<th>HW</th>
<th>Avg Max</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td>0.56</td>
<td>0.08</td>
<td>0.93</td>
<td>8.35</td>
</tr>
<tr>
<td>Network</td>
<td>0.87</td>
<td>0.08</td>
<td>1.20</td>
<td>8.66</td>
</tr>
<tr>
<td>2x Network</td>
<td>1.83</td>
<td>0.13</td>
<td>2.27</td>
<td>11.00</td>
</tr>
</tbody>
</table>

Table 4: Wait Times for flights from NY to CHI.

WT = Wait time, HW = Half-width

‘Direct’ is a model that has only flights going from NY to CHI. This is our City Pair Design Alternative. It is clear that having flights only from NY to CHI will take a large increase in delays before the ribbon reaches capacity. ‘Network’ includes flights from NY to the West and flights from PHL to CHI and the West. ‘2x Network’ is the same network but with 2x the original flight schedule, which was created by adding fictitious flights to the flight schedule 2 minutes after actual flights.

Looking at the table we see that the ribbon capacity is suitable for all runs. Even when we double the number of flights in our network the average maximum wait is only 2.27 minutes and the largest wait we observed from 20 replications (or 3240 flights) is an 11 minute wait, far below our pre-determined 15 minute wait time. Our results also show that flight times for DASS are quite predictable.
6 CONCLUSION

The DASS System may be a viable option for the future. It may be a stepping stone for moving in a new direction for Air Traffic Management, by providing incentive for airlines to equip their aircraft with advanced Communication, Navigation and Surveillance equipment.

The TAAM simulation showed that specialized routing by itself is probably not a good option, because of the increased number of aircraft and increased workload in each center. Complexity for one center may actually have gone down significantly, however this must be tempered with the knowledge that the other two factors shot up dramatically. This does not mean that DASS is not a good option. DASS aircraft would be separated from non-DASS aircraft, which may reduce workload.

The Arena simulation seemed to indicate that delay gradually accumulates in the DASS ribbon and aircraft get slowed down by aircraft ahead. For 1x and 2x traffic, 1 entrance per city is probably sufficient, and capacity within the ribbon does not seem to be an issue.

ACKNOWLEDGMENTS

We would like to thank our professor, George Donohue, for his guidance and Chris Wargo for his assistance. We would also like to thank Arash Yousefi and Sean Sprague for their help in performing the simulations. We would especially like to thank our sponsor, Karl Grundmann, for his help and assistance.

REFERENCES


AUTHOR BIOGRAPHIES

JOHN ALIPIO is a Systems Engineering Student at George Mason University with a concentration track in Highway Transportation Systems. He is a member of the Tau Beta Epsilon Engineering Honor Society and will graduate in Fall 2003. John may reached through email at <jalipio@gmu.edu>

PATRICIA CASTRO is a Systems Engineering Student at George Mason University. Patricia will be graduating in Fall 2003. She can be reached at <pcastro@gmu.edu>

HONG KAING is a senior at George Mason University who is enrolled in the Systems Engineering Program and will be graduating in May 2003. His specialization focuses on using Operations Research techniques to analyze the performance of systems. He recently fulfilled one of his life goals and got his first dog in April. A German Shepherd/Akita mix, his name is Pneumotos, meaning ‘spirit’ in Greek. Hong can be reached by e-mail at <hkaing@gmu.edu>

NOREEN SHAHID is a student in the Systems Engineering Department at George Mason University. Her specialization track is in systems performance and modeling. She is a member of various organizations, Society of Hispanic Professional Engineers (SHPE), Society of Women Engineers (SWE), and Alpha Omicron Pi Fraternity. She will be working for the MITRE Corporation as an intern this summer, and will be graduating in the Spring of 2004. She enjoys outdoor activities and sports. She may be contacted by email at <nshahid@gmu.edu>

OMAR SHERZAI is an undergraduate student at George Mason University majoring in Systems Engineering. Current degree concentration is Dynamic Systems Modeling and Performance. He can be contacted by email at <osherzai@gmu.edu>