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DYNAMIC AIRSPACE SUPER SECTORS (DASS) AS HIGH-DENSITY HIGHWAYS IN THE SKY FOR A NEW US AIR TRAFFIC MANAGEMENT SYSTEM

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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 and increase predictability of arrival times for aircraft using DASS. The team originally considered three design alternatives—the City Pair, the Common Route, and the baseline current sector system. The City Pair Alternative was eliminated early on because of suboptimal use of airspace due to low traffic volumes. Using a utility function, the Common Route and the Baseline were analyzed further both qualitatively and quantitatively with simulation. This study uses the Arena simulation environment to study one section of DASS ribbon between New York and Chicago. For this section the team determined the chokepoints within the ribbon and the capacity of the ribbon.

1 PROBLEM DESCRIPTION

This design problem is concerned only with en route airspace. En route traffic problems are a major contributor to overall delays, in particular, in the northeast corridor of the United States. Congestion in that area causes more delays to ripple throughout the rest of the National Airspace System (NAS). The demand for air travel is growing, and it will be difficult in the coming years for the NAS to meet the demand. Increasing congestion will impair the domestic economy and, more importantly, safety if changes are not made.

In managing en route airspace, the limitation 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 (**Figure 1**). Today, sectors are designed to keep air traffic controllers (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. The current sector design is also outdated. Many sector boundaries have remained the same, while traffic patterns and volumes have changed over the years.

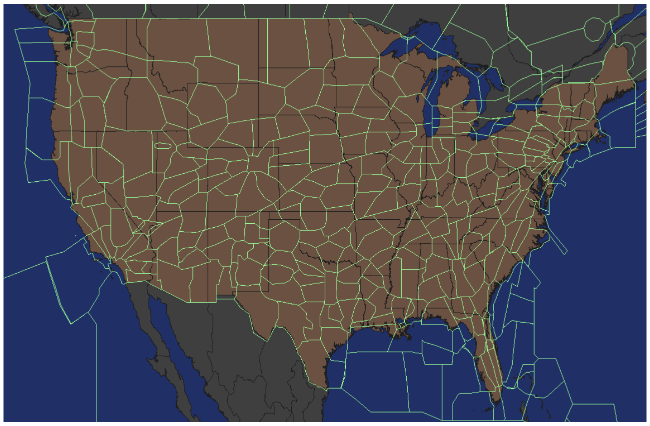

Figure 1: Sector Overlay

Often, because of high workload in a sector, ATC 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 ATC, that is, the perception of, understanding of, and ability to predict what will happen in the air traffic situation that ATC are monitoring. A major redesign of the current sector system is needed in order to improve their situational awareness.

ATC's understanding of aircraft behavior contributes to their situational awareness. Aircraft behavior can be understood as the following state vector developed by Tom G. Reynolds at Massachusetts Institute of Technology.

$$\text{Aircraft Behavior, } X(t)^{*} = \left\{ \begin{array}{c} \text{Position, } R(t) \\ \text{Velocity, } V(t) \\ \text{Acceleration, } A(t) \\ \text{Intent, } I(t) \end{array} \right\}$$

Due to current radar updates from 4 to 12 seconds, the position, as well as velocity and acceleration which are derived from position, have uncertainties. Uncertainty in aircraft behavior is a barrier to situational awareness.

Advanced communication, navigation, and surveillance (CNS) devices would decrease this uncertainty, however there is no viable paradigm in which these devices can work. One paradigm is one in which aircraft equip in order to decentralize control of flight routes from the ground to the cockpit, however this presents two implementation problems. First, airlines lack the incentive to equip, because of no immediate benefit until all aircraft equip. Second, aircraft behavior would be very difficult to understand for ATC, who must still play a role as monitors at a minimum.

Finally, aircraft behavior is a function of intent, which can be thought of as the flight path of an aircraft. Many aircraft have conflicting intent, and this leads to lower situational awareness and higher workload.

The problem can be summarized. High workload is limiting the ability of air traffic controllers to handle large numbers of aircraft, increasing congestion and delays throughout the system. Inefficiencies in the current sector system and uncertainty and complexity of aircraft behavior contribute to this.

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.

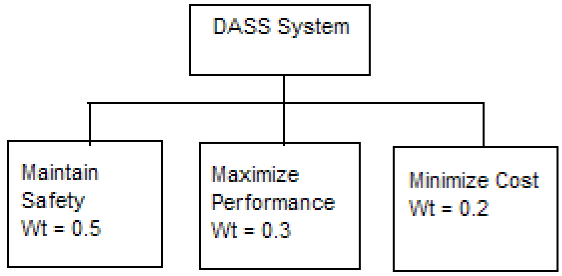

Figure 2: Value Hierarchy (First Level)
Weights add up to 1.

Maximize Performance is further broken down into:
Maximize Availability (Weight = 0.09)
Minimize ATC Workload (Weight = 0.075)
Maximize NAS Capacity (Weight = 0.075)
Minimize En Route Delays (Weight = 0.6)

Using these weights, the team defined a utility U_0 for each alternative:

$$U_0 = (.5)U_S + (.09)U_A + (.075)U_{WL} + (.075)U_G + (.06)U_D + (.2)U_C \tag{1}$$

Where, U_0 = total utility
U_S = safety utility
U_A = availability utility
U_{WL} = workload utility
U_G = capacity utility
U_D = delay utility
U_C = cost utility

Each utility has a value between 0 and 1, 1 being the best, 0 being the worst. Many of these utilities are difficult to measure quantitatively. We therefore took a qualitative approach and used Boolean values, 1 and 0, to rank one alternative better than another.

3 CONCEPT OF OPERATIONS

3.1 Goals of the DASS System

DASS plans to simplify airspace structure by radically redesigning sectors in order to improve the Situational

Awareness of ATC and minimize their workload at critical sectors. By doing this, DASS aims to allow air traffic growth at equal or greater safety and efficiency. In addition, DASS intends to reduce delays 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 airspace.

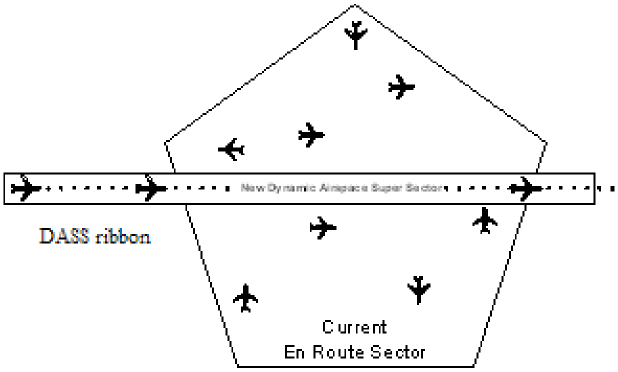

Figure 3: A Dynamic Airspace Super Sector

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 an 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 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 capabilities:

- 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)

3.5 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.

3.5.1 DASS Network

The 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 entrances for one airport.

3.5.2 Management System

The Management System is composed of three parts: the Software, the Interface, and the Personnel. The software for the DASS system provides the definition of the DASS network or the location of all the DASS sectors at any given time. The software will 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. This function will be automated and should have multiple redundancy to meet very high availability and reliability standards.

The interface is what management will use to interact with the software. Because this interface needs to conform with the current system interface, the display may remain the same with added features for display of and interaction with the DASS system.

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

3.5.3 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.

The DASS system shall use the current ATC interface as a base for its user interfaces. Added features will allow ATC (DASS and non-DASS) to see the location of DASS sectors. Depending on the definition of the display and varying abilities of ATC, the DASS ATC display will show the relevant vertical information (around 1000 to 5000 feet above and below ribbon) and the relevant horizontal information (around 10 miles to each side of the ribbon) and around a 150 mile length of ribbon. These numbers are initial estimates which reflect the cognitive limits of individual ATC and were attained after speaking with a former air traffic controller.

3.5.4 Maintenance Personnel

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

3.6 External Systems

External systems to the DASS system include:

3.6.1 Pilots/Aircraft

Aircraft are governed by DASS rules of self-separation once they enter DASS airspace. Furthermore, in order to enter DASS airspace, aircraft must have the RCNSP capabilities.

While in DASS airspace, aircraft are provided with the definition, or coordinates, of the DASS sector they are flying in. Aircraft must follow the path of these coordinates and maintain the correct altitude.

Aircraft will broadcast their aircraft data (aircraft ID, flight number, position, speed, altitude, trajectory, climbing, descending, turning) to other aircraft within DASS and to DASS ATC. Aircraft will also interact with DASS in cases of emergency. Although aircraft will usually be self-separating, aircraft must ultimately adhere to commands from ATC.

3.6.2 Non-DASS ATC

Non-DASS ATC will interact with DASS ATC when aircraft enter and exit DASS. When the aircraft enters DASS airspace, responsibility for the aircraft is transferred from non-DASS ATC to DASS ATC.

The DASS system will provide the coordinates of the DASS network to non-DASS ATC. Non-DASS ATC must then ensure that no aircraft will intersect the DASS sectors, which will be treated as a dynamic Special Use Airspace. Non-DASS ATC will also provide emergency support to aircraft that must exit irregularly from the DASS system.

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 performed qualitative and quantitative analysis.

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.

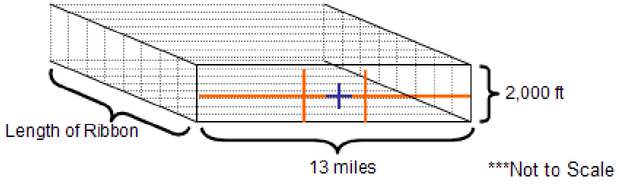

Figure 4: Ribbon Dimensions

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).

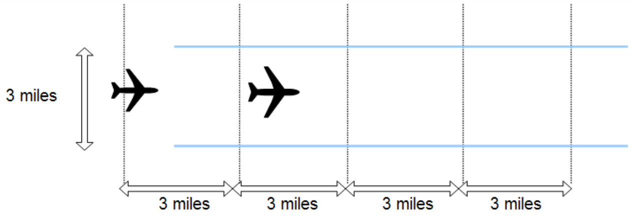

Figure 5: Before a passing maneuver

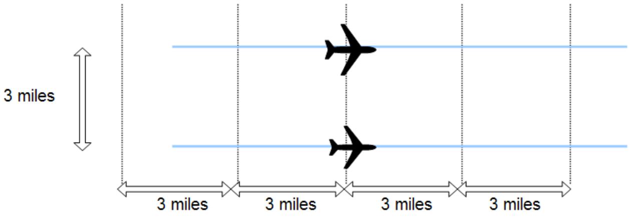

Figure 6: During a passing maneuver

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

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 between cities with a set cruising altitude. We must first see the effects of this design before studying Alternative 2.

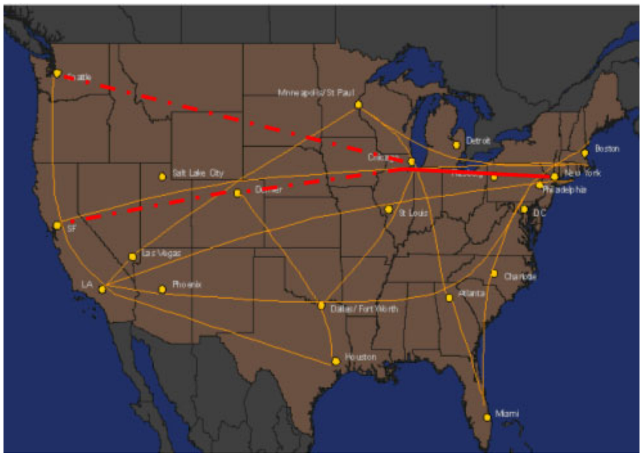

Figure 7: Example Common Route Network. (thin lines), Section of study (dark solid line), Extended ribbon for simulated Common Route Alternative (dashed lines).

Alternative 2 is called the Common Route 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 7.**

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. For our simulation, we considered the ribbon section between New York and Chicago.

5 UTILITIES ANALYSIS

5.1 Workload Utility

We analyzed workload qualitatively, however, we used a metric for workload developed by Arash Yousefi et al. from George Mason University which is meant for use with the software Total Airport and Airspace Modeler (TAAM). Total workload (TotalWL) is the sum of four types of workload:

$\text{TotalWL} = \sum WL_{HM} + WL_{CDR} + WL_{C} + WL_{AC}$, where

- WL_{HM} = Movement or basic workload.
Determined by # aircraft in a sector and residence time (amount of time an aircraft spends in a sector)
- WL_{CDR} = Conflict workload.
Based on type of conflict and conflict severity
- WL_{C} = Coordination workload.
Determined by type of coordination (voice call, clearance issue, inter-facility transfer, etc...)
- WL_{AC} = Altitude change workload.
Determined by type of sector altitude clearance requested

DASS changes basic workload. Because of the nature of DASS, more aircraft may be in a DASS sector at one time and for longer amounts of time than in the current sector system. This increase in basic workload is counteracted by the major reduction in conflict workload and coordination workload. Conflict workload will be very low, because aircraft would resolve their own conflicts. The number of conflicts would also be fewer because of the very simple air traffic flows. In addition, DASS would require little coordination by ATC except at critical areas (entry/exit), and because sectors are longer, there would be less handoffs. Altitude change workload may also be slightly less because all aircraft in DASS would fly at the same altitude. For this reason, we gave DASS a utility of 1 ($U_{WL(DASS)} = 1$) and the current sector system a utility of 0 ($U_{WL(Baseline)} = 0$).

5.2 Safety Utility

Some of the same things that affect workload affect safety, including the structure of airspace and the ease of understanding an air traffic situation. So as workload conditions improve, safety improves. Although aircraft would be more closely spaced, aircraft in DASS would have better accuracy in determining the position of surrounding aircraft due to the required CNS devices. Non-DASS ATC would also have to deal with an extra dynamic Special Use Airspace (SUA), but according to a former air traffic controller, if everyone (DASS and non-DASS ATC and pilots) knows it is there, an SUA is easier to deal with than individual aircraft. Therefore, we consider the DASS system safe. However, the current system can also be considered safe. We gave both $U_{S(DASS)} = 1$ and $U_{S(Baseline)} = 1$.

5.3 Capacity Utility

One of the reasons for the few en route violations of safe separation is the Miles in Trail (MIT) restrictions that ATC often place on aircraft forcing them to stay farther apart than is required. This leads to lower airspace capacity. In the DASS system, greater situational awareness leads to reduced separation standards, which allows more traffic growth. In our simulation, we also show that the capacity of a DASS ribbon from New York to Chicago is 4x the current flight load. Therefore, we gave $U_{G(DASS)} = 1$ and $U_{G(Baseline)} = 0$.

5.4 Delay Utility

We looked at flights from New York to Chicago. From official FAA schedule data (Enhanced Traffic Management System or ETMS data), the average flight time for a distribution of aircraft was 2 hours and 27 minutes. The idealized flight time is 2 hours and 10 minutes, which comes from an approximate 90 minute air time from the software Jeppesen FliteStar and an average 40 minute taxi time from a study by Andersson and Kari et al. There is a pad of 17 minutes. From our simulation, under ideal conditions, DASS aircraft had an en route delay of under a minute. Therefore, $U_{D(DASS)} = 1$ and $U_{D(Baseline)} = 0$.

5.5 Predictability, Ease of Implementation, and Cost

In the DASS system, aircraft must fly direct paths to their destination, therefore predictability would be greater and $U_{P(DASS)} = 1$ and $U_{P(Baseline)} = 0$.

For obvious reasons, $U_{I(DASS)} = 0$ and $U_{I(Baseline)} = 1$.

Cost is composed of development, implementation, and operational costs. The baseline is better in development and implementation costs, but because in both DASS and the current system, the FAA would be paying ATC and managers, the operational costs for both systems would be comparable. Therefore, $U_{C(DASS)} = 0.33$ and $U_{C(Baseline)} = 1$.

5.6 Utilities Conclusion

Plugging our values into the utility function, we get the overall utility of DASS $U_{DASS} = 0.833$ and the utility of the current sector system $U_{Baseline} = 0.774$. DASS surpasses the current system in performance. Although we do not explore it here, we may want to look at this in another way. We may want to look at cost separately to be able to weigh it against the benefits. The costs to the FAA are primarily capital costs, which are the system engineering and design cost, the software development cost, and the cost of training ATC. Similarly, the costs to airlines are mainly capital costs—the cost of equipping their aircraft with the required CNS devices and the cost of training pilots.

6 SIMULATION

The Arena simulation software will be used to 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. We will measure the capacity of the ribbon between those cities.

We modeled both the City Pair Alternative for a ribbon from New York (NY) to Chicago and the Common Route 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 same route between NY and Chicago, which is the study area (**Figure 5** above). NY is composed of the airports: Kennedy Intl, La Guardia, and Newark Intl. Chicago is composed of Chicago O'Hare Intl and Chicago-Midway. In Arena, a model of the Baseline is not possible. We simulated only one way from NY to Chicago.

6.1 Objective

Arena is an event based stochastic simulation model software package manufactured by Rockwell Software to model server/queue systems. Our Arena model is composed of two primary sub-models, airports (generators) and the actual DASS ribbon. Combining the two models together allowed the group to examine the queuing delays within the ribbon and allowed us to determine the chokepoints and overall capacity of the ribbon. We did this by changing the flight load (1x, 2x, 4x, 8x and 16x) for aircraft flying into our ribbon.

6.2 The Model

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

The aircraft were generated using actual historical data from the official FAA flight schedule (Enhanced Traffic Management System or 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 Chicago. 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' 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). There are two resources assigned to each process to represent the two lanes of traffic in our DASS ribbon. When both resources are taken, an aircraft must wait to enter that 3 mile stretch of the ribbon and a waiting time is recorded for that aircraft at the individual process. This allows us to examine 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, PHL to West).

A very important concept to understand in our ribbon model is the Miles in Trail (MIT) restriction. Air Traffic Service Providers enforce an MIT restriction in order to maintain a certain distance between aircraft. In our case, the MIT restriction was 3 miles. Within our ribbon, aircraft must maintain a 3 mile separation distance between other aircraft in their same lane. To model this we used the 3 mile processes described above in which only on aircraft can occupy (or 'seize') each lane in a 3 mile stretch of ribbon. If the lane is occupied, succeeding aircraft must wait. We enforced a similar MIT restriction at the entrances to the ribbon. For safety reasons, we wanted aircraft to approach the DASS ribbon in single file with 3 miles separating each aircraft, so that only one aircraft can enter the ribbon at a time. Thus we created a 3 mile process with only 1 lane. From now on, we will refer to this process or box as the MIT box. The wait times for this box are called the MIT values or MIT wait time.

The major airports in the following cities were used in our model: New York City, Philadelphia, Cleveland and Chicago. All flight coming from these cities and going to Chicago and the West (Denver, Oakland, Portland, Seattle, San Jose and Salt Lake City) were used as inputs into our model. Once we completed the models we were then able to conduct simulation runs and examine our system.

6.3 Results

Our first simulation run was for flights from New York to Chicago only. **Table 1** below shows the average wait time for the 20 replications.

Table 1: Results from 20 replications (units are in minutes)

	Avg Wait	Half-Width	Avg Min	Avg Max	Min	Max
NY to Chicago	0.0184	0.0000	0.0054	0.0345	0.0000	1.2347

As you can see, the average wait time is only 1.10 seconds (0.0184*60). Of the 20 replications, 14 had an average wait time equal to the MIT wait time. Since the MIT process box is not part of the DASS ribbon, this means that 70% of the runs had absolutely no delay. The results from these simulation runs affirmed our belief that there is not enough volume between two cities to warrant a city-pair network design. We did not investigate this alternative further.

Examining **Figure 8** below shows how the majority of the delay time in accumulated in the MIT box.

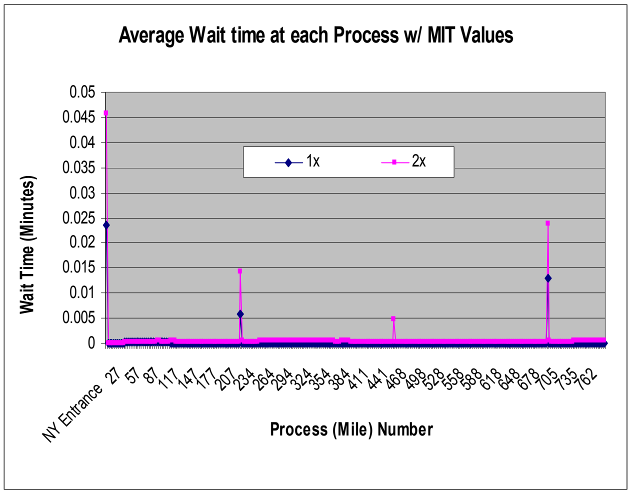

Figure 8: Wait time for 1 and 2 times flight load. Spikes occur at MIT boxes.

To examine the chokepoints of our system we will have to focus in on the bottom part of graph. If we zoom in about 200x we will be able to observe the chokepoints in the DASS ribbon. The spikes in **Figure 9** show us where the chokepoints are and, as expected, they are located at the entrance points into the ribbon. At sixteen times the flight load the maximum wait time to enter the ribbon is approximately 15 seconds, meaning that entering into our ribbon is not really an issue if we enforce a 3 mile MIT restriction. The problem is more with how planes will organize themselves in order to approach the ribbon 3 miles apart. For the New York MIT, which has the highest MIT wait time, the wait appear manageable even for 8x the flight load (avg MIT wait = .95 minutes), but the MIT wait time then clearly becomes unmanageable at 16x the flight load (avg MIT wait = 15.90 minutes).

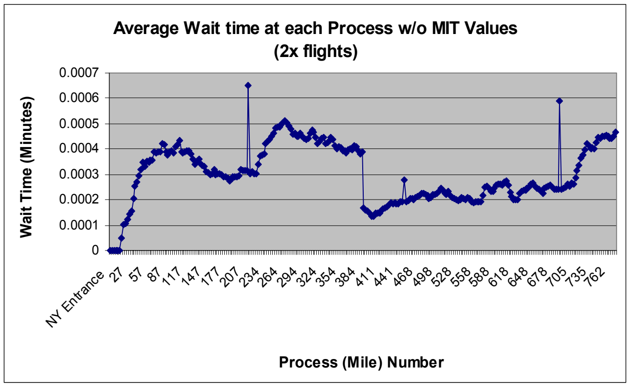

Figure 9: Internal wait time only (without MIT wait)

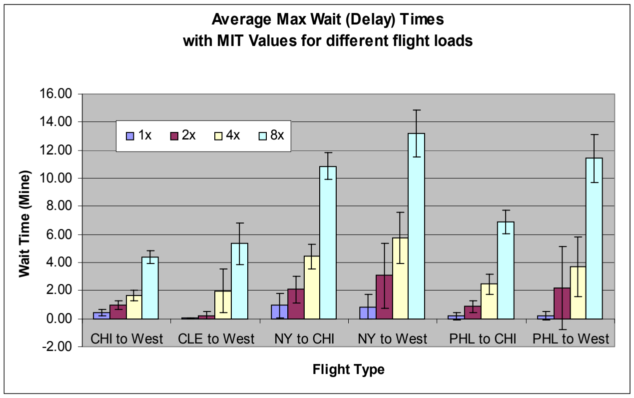

Figure 10: Average of the maximum wait times from each replication

The second problem we will address is that of capacity. In order to examine this issue we will need to look at the maximum wait time for aircraft in our ribbon. Because aircraft in or ribbon are constrained by a narrow flight route, they must maintain a certain speed in order to fly at the correct altitude. This means that there is a limit to how much delay they can absorb while still staying in the DASS sector. **Figure 10** shows the average maximum wait time, which sums up the maximum wait time from each replication and divides it by the number of replications (20 in our case). The standard deviation is also shown. It should be clear that our ribbon can handle the current flight load and it is the belief of the team that the system can handle up to 4x the normal flight load. It should be noted that **Figure 10** contains the MIT value in the delay time, meaning the delay time within the ribbon will be less. The MIT value was included in order to calculate the standard deviation.

7 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 DASS system appears to offer many benefits over the current system in the realms of safety, workload, capacity, and delay for example. However, more work needs to be done to quantitatively assess these benefits. In addition, we need to determine in more depth how the DASS system will interact with the rest of the NAS. In this study, we assumed that the DASS system would receive aircraft synchronously at the entrances. We also assumed that at the exits, terminal airspace would be able to handle DASS arrivals. In order for the DASS system to be the most utilized, the systems at these endpoints would also need to be reformed.

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