

ANALYSIS OF THE CONTRIBUTION OF FLIGHTPLAN ROUTE SELECTION ON ENROUTE DELAYS USING RAMS

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Abstract

The absence of predictability of flight operations in the National Airspace System (NAS) is a significant source of excess costs, requiring airlines to pad flight schedules, staff for worst-case scenarios, and build and maintain mitigation plans and equipment. Flight plan routes are selected by airlines to optimize their operations (e.g. minimize delays, fuel burn). In the absence of coordination of flight plan route selection, flights can converge at the intersection of the flight plan routes, creating delays and fluctuations in Air Traffic Control (ATC) workload (leading to Miles and Trail restrictions and other workload mitigation measures that create delays). Furthermore, due to the high degrees of freedom available in flight plan route selection and the varying constraints in the NAS, flight plan route selection can appear as a random phenomenon. This paper evaluates the role of flight plan route selection in the stochasticity and performance of the NAS.

Flight plan routes for Origin Destination (OD) pairs were extracted from historic data. For the schedule of June 01 2010, one hundred simulations were run using Reorganized Air Traffic Control (ATC) Mathematical Simulator (RAMS). For every run flights (subject to availability of alternate route for the given OD) were randomly assigned flight plan routes from the extracted data.

The results indicated that by randomly varying flight plan routes for 32% (limited by the extracted data) of the flight the overall total delay had a standard deviation of 6849 minutes about the mean total delay of 161358 minutes. The maximum total delay was 174559 minutes (8% above the mean) and the minimum total delay was 141876 (12% below the mean). The

total number of en-route conflicts had a standard deviation of 201 about a mean of 29202 conflicts. The maximum number of conflicts recorded was 29751 (2% above the mean) and the minimum number of conflicts recorded was 28760 (2% below the mean). There was no correlation between the number of conflicts the total delays, though the variance in total delays was more than en-route conflicts. A further break up of conflicts showed that about 80% of the conflicts were between flights flying in opposite direction to each other; about 15% were between flights flying in same direction, and the remaining 5% were between flight flying in perpendicular to each other

Introduction

In current practice most flights operate along a fixed network of airways rather than flying directly from a departure airport to arrival airport [1]. Though this network of airways is fixed there are several routes that connect an Origin and a Destination. Every such route constitutes a flight plan route.

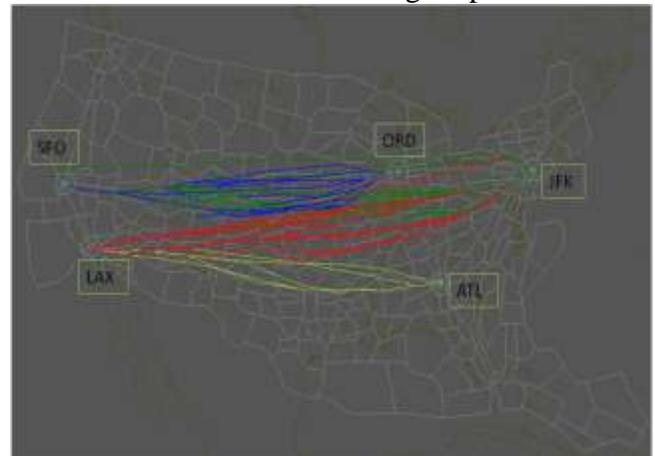


Figure 1. Plot of current Flight Plan routes

Flight plan routes are selected by airlines to optimize their operations (e.g. minimize delays, fuel burn). Figure 1 shows flight plan routes connecting some of the major airports in NAS. The number of flight plan route connecting airports is not constant.

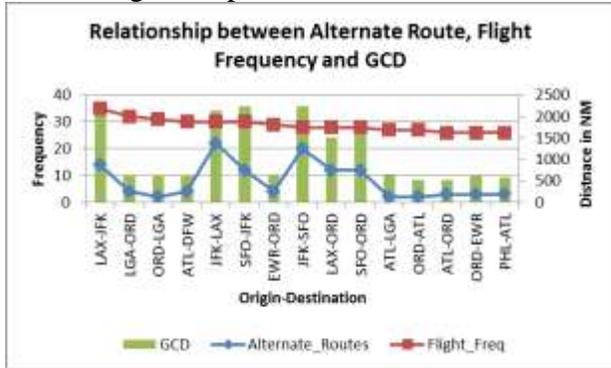


Figure 2 Alternate Routes as a function of flight frequency and GCD.

The Figure 2 shows a sample plot where the OD pairs are arranged along X-axis in the decreasing order of flight frequency as indicated by the red line with square boxes. The blue line with diamonds is the number of alternate routes and the green bars are the Great Circle Distances (GCD). It can be seen that OD with greater distance have higher number of alternate routes relative to the flight frequency. The number of alternate routes seemed to also vary with direction. For instance OD pair JFK-LAX have more alternate routes compared to LAX-JFK. In addition to varying in number, the flight plan route also vary in the spread about the direct route or the great circle route. Even with the few routes show in Figure 1 it should be clear that these route form a complex network with a lot of intersection. In the absence of coordination of flight plan route selection, flights can converge at the intersection of the flight plan routes, creating delays and fluctuations in Air Traffic Control (ATC) workload (leading to Miles and Trail restrictions and other workload mitigation measures that create delays). Furthermore, due to the high degrees of freedom available in flight plan route selection and the varying

constraints in the NAS, flight plan route selection can appear as a random phenomenon. The objective of this paper is to evaluate the role of flight plan route selection in the stochasticity and performance of the NAS. The performance was measured in terms of total delays and total en-route conflicts.

Methodology

Data Used

The Traffic Flow Management System (TFMS) data for June 1st 2010 was considered. The following information was extracted from the Flight and Route tables of the TFMS database,

- Flight Table
 - Flight Id
 - Origin
 - Destination
 - Cruise Flight Level
 - Scheduled Departure Time
 - Scheduled Arrival Time
 - Actual Arrival Time
- Route Table
 - Flight Id
 - Route Waypoints as specified by the first filed flight plan

In addition, the TFMS grid information was used to extract NAS sector boundary coordinates, Navaid and Fixes coordinates, and Airport coordinates.

Simulator Used

The simulation was done using Reorganized Air Traffic Control (ATC) Mathematical Simulator (RAMS). RAMS is a comprehensive Air Traffic Management (ATM) gate-to-gate fast-time discrete-event simulation software package providing

functionality for the study and analysis of airspace structures, Air Traffic Control systems, future ATC concepts, and airport ground movements and ground delay. RAMS can be used to measure and quantify wide variety of ATM questions, such as workload, delay, and capacity for airport and airspace systems given varying traffic levels, as well as measuring the benefits of physical or procedural modifications.

Method of Analysis

The method of analysis is depicted in Figure 3. Simulations were run using RAMS. Between runs the schedule (departure time) were maintained to be the same, but route selection were done randomly for flights flying in excess of 500NM.

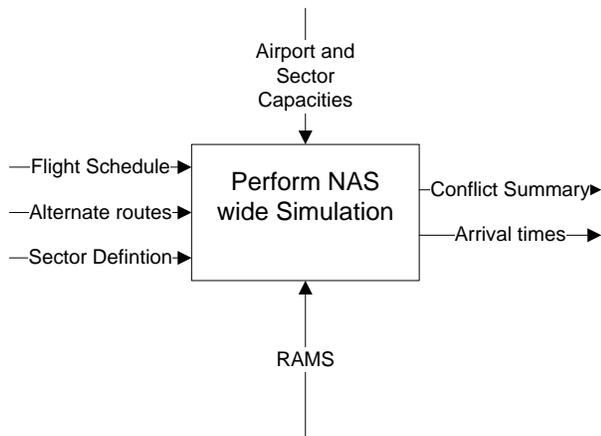


Figure 3. Context Diagram for Simulation Model

The factors influencing flight's On-time performance were sector and airport capacities. The sector capacities were set to Monitor Alert Parameter (MAP) as specified in the TFMS grid information. RAMS treats MAP values as sector resource, when a flight enters a sector it is made to request for a resource, if the resource available it is given one and is allowed to fly through, else it is made to wait until a resource is available, causing delay. On existing the sector the flight returns the resource and requests for resource from the

next sector it enters. The airport capacities were defined in terms of hourly arrival rate and departure rate, as specified in the TFMS grid files. In case of arrivals these capacities took effect when the aircraft was at a predefined distance (50NM) from its destination airport. The aircraft was slowed down as much as needed when the airport was at capacity, causing delay. In case of departure the aircrafts were held on ground when the airport was at capacity.

In the interest of better simulation runtime performance, only flights relevant to the analysis were considered. The relevance was defined based on the following criteria,

- The flight should have had,
 - Departed or Arrived between 06/01/2010 05:00 to 06/02/2010 08:00 (Zulu).
 - Departed and/or Arrived from/at an US airport.
 - Cruise altitude of Flight Level (FL) 180 or greater.

The first criterion was used to filter out flights outside the targeted time frame, the second criterions was used to filter out flights that did not enter or originate from the US and the third criterion was used to filter out low level flying objects such as helicopters and small general aviation aircraft.

The schedule and the route information for all the relevant flights were combined with the NAS airport and sector information to generate the followings RAMS input files,

- Traffic
 - Schedule
 - Route
- Sector
 - Sector Boundary
 - Sector Floor and Ceiling

- Sector Controller
- Sector Capacity
- Airport
 - Arrival and Departure Capacity
 - Location Coordinated

The schedule and the route information were also used to extract alternate routes for a given Origin-Destination (OD) pair. This was done only for OD pairs with distance greater than 500 nautical miles (NM). It was presumed that route selection for short haul flights (distance less than or equal to 500 NM) would not have impact on delays and conflicts. A summary of filtered flights were as follows,

- Total number of flights considered after filtering out noise, 32,363.
- Total number of OD pairs, 10,492.
- OD pair with distance greater than 500NM, 5917.
- OD pair with distance greater than 500NM and having alternate routes, 1821.
- Total number of flights with alternate route options, 10,466.

The filtering process yielded a total of 32,363 flights. These flights originated and terminated from 10,492 OD pairs. Of these ten thousand OD pairs there were 5917 (~56%) OD pair with distance greater than 500NM. The data did not yield alternate routes for every OD pair. Though the number of alternate routes was more for OD pair with high flight frequencies and greater GCD, that was not always the case. As indicated by Figure 4 most OD pairs had five alternate routes or less. There were 1821(~30%) of 5917 OD pairs for which alternate routes could be extracted from the data. Only 10% percent of the 1821 OD pairs had five or more alternate routes. There were 10,466(~32%) flights that flew these 1821 OD pairs, with 2213(~7%) flights having five or

more
route

alternate
route

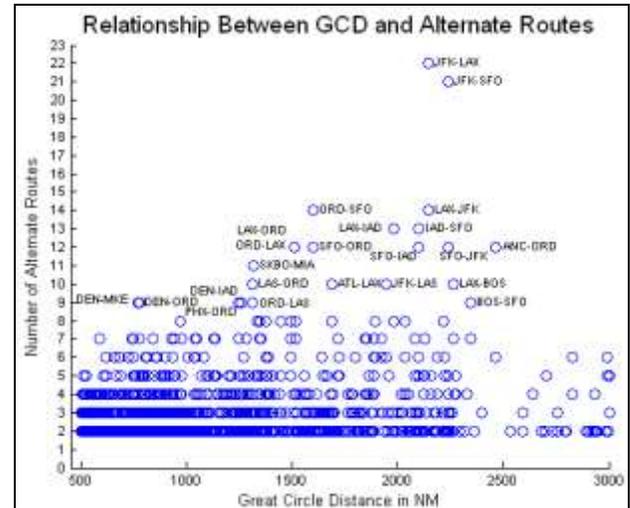


Figure 4 Number of Alternate route as a function of GCD.

For each simulation run RAMS generated a flight summary and a conflict summary file. These output files were processed to generate the delay, conflict metrics.

The delay metrics were computed as follows,

$$AOTPi = AAI - SAI$$

$$AAP = \sum AOTPi$$

$$SOTPi = STi - SAI$$

$$ASP = \sum SOTPi$$

Where,

AOTPi – Actual On-Time Performance of flight i.

AAi – Actual Arrival time of flight i.

SAi – Schedule arrival Time of flight i.

AAP – Aggregate Actual time Performance.

SOTPi – Simulated On-Time Performance of flight i.

STi – Simulated arrival Time of flight i.

ASP – Aggregate Simulated time Performance.

The Actual On-Time Performances (AOTP) of flights were computed as the difference between the Actual Arrival (AA) time and the Schedule Arrival (SA) time, as specified in the database. If the AOTP yielded a positive number the flights were considered to be delayed, else considered early. The sum of the all the AOTPs were computed as the Aggregate Actual time Performance (AAP). The Simulated On-Time Performances (SOTP) of flights were computed is the same way with exception of Simulated arrival Time (ST) (out of RAMS) being used instead of AA.

RAMS categorizes conflicts based Angle, Direction and Convergence. The Angle is subcategorized as Parallel, Small Angle, Wide Angle and Perpendicular, based on the angle between the two flight vectors. The Direction is subcategorized as Same and Opposite. The Convergence is either Converge if flights are converging or is Diverge if the flights are diverging. Figure 5 explains the Angle and Direction. For instance, if “000” in Figure 5 was to be considered as the vector of one of the flights, then depending on the vector of the second flight the conflict could be categorized as shown in the figure. Consider a conflict specified as “WideAngle” “OppDir” “Converge”. This should be interpreted from the Figure 5, as the first flight being between angle 010 and 350 and second flight being between angle 210 and 260, and both converging towards each other.

Model Validation

The Actual NAS On-time performance of flights were computed and compared to the Simulated On-time performance of the first simulation. In the first simulation the flight were made to fly the actual routes as filed in the route table. This was done to gauge the difference in the actual NAS performance and RAMS simulation. The Figure 6 compares the

distributions of the actual and simulated On-time performance. The x-axis is the delay bins and y-axis is the percentage of total flights. The statistics of the on-time performance distribution are tabulated in Table 1

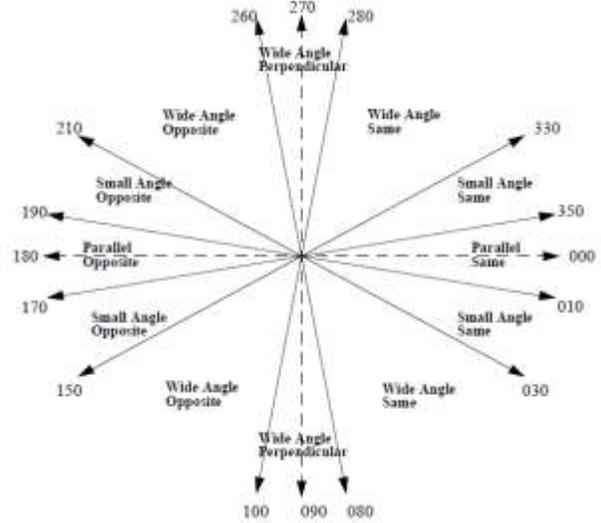


Figure 5 Conflict Categorization Geometry

Table 1: On-time Performance Statistics

Unit of time: minutes	Actual	Sim1
Total flights	32357	32357
Flight considered	31500	30827
Flights Delayed	27226	15439
Flights Ontime or Early	4274	15388
Total Delay	872674.0	339771.1
Total Time saved	-31682.0	-204996.1
Min	-299.0	-289.6
25tile	8.0	-7.8
Median	18.0	0.0
75tile	35.0	10.0
Max	300.0	299.9
Standard deviation	33.8	33.9
Mean Delay	32.1	22.0
Mean Time saved	-7.4	-13.3

Flights having delays in excess of ± 300 minutes were considered as outliers, hence the flights considered for building the distribution vary in case of the Actual and Simulated On-time performance. The Actual On-time performance indicated that were 27226 (~86%)

flights that were delayed. The total delay for these flights was 872674 minutes, with an average of 32.1 minutes delay per flight. There were 4274 (~14%) of flights that made it early. The total time saved by these flights was 31682 minutes, with an average of 7.4 minutes per flight. About 25% of the flights had delays in excess of 35 minutes. The Aggregate Actual On-time performance was 840,992 minutes with the mean of 27 minutes per flight

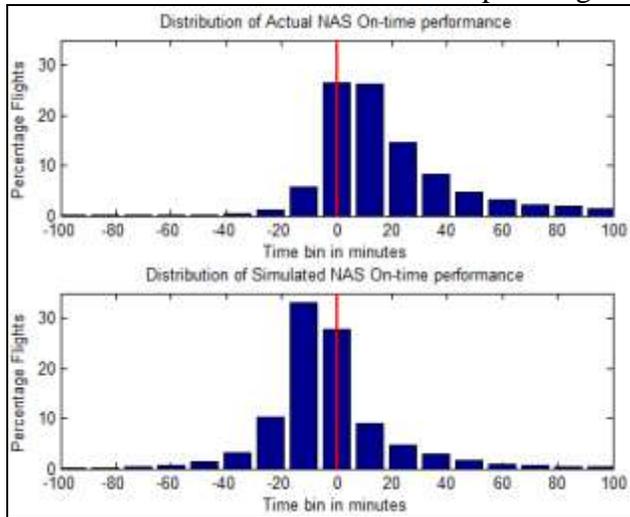


Figure 6 Distribution of On-time Performance

The Simulation On-time performance indicated that were 15439(~51%) flights that were delayed. The total delay for these flights was 339771.1 minutes, with an average of 22 minutes delay per flight. There were 15388 (~49%) of flights that made it early. The total time saved by these flights was 204996 minutes, with an average of 13.3 minutes per flight. About 25% of the flights had delays in excess of 10 minutes. The Aggregate Simulated On-time performance was 134,775 minutes with the mean of 4.37 minutes per flight. There was no weather or any of Traffic Flow Management (TFM) initiatives built into the simulation. The conflict resolution was also not made, though the number and type of conflict were recorded. The delays were only due to sector and airport capacities.

Results

After simulating the actual NAS, simulations were performed by varying routes randomly for flights flying greater than 500NM. The option of alternate route was restricted to the information provided by one day worth of TFMS data. The simulations were run by varying routes for 10,466(~32%) flights, with 4126(~14%) flights having to pick between just two alternatives. There were 2213(~8%) flights with 5 or more alternate route options.

Figure 7 shows a plot of the Aggregate Simulated On-time performance for hundred simulations.

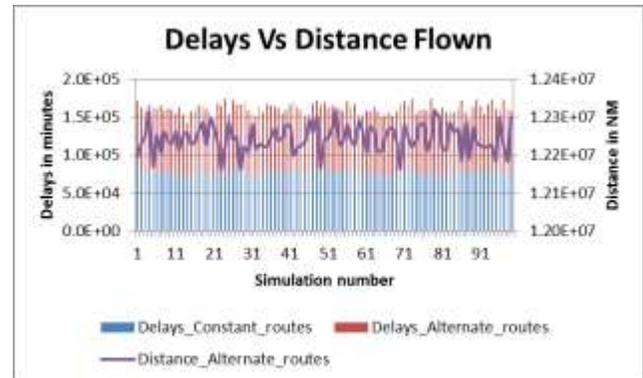


Figure 7 Variation in On-time Performance (delays)

The x-axis is the simulation number, the left y-axis is the aggregate delay in minutes and right y-axis is the total distance flown by all the flights in nautical miles. The line is the total distance flown by flights with route options. The vertical bars are the aggregate time (delay). The red half of the bar represents delays for flights with route option and the blue half are for flights with constant routes. It was found that the variation in route selection caused variation in delays for flights with constant route, in addition to the variation in delays for flight with route option and the aggregate delays.

By randomly varying flight plan routes for 32% (limited by the extracted data) of the flights the overall total delay had a standard

deviation of 6849 minutes about the mean total delay of 161358 minutes. The maximum total delay was 174559 minutes (8% above the mean) and the minimum total delay was 141876 (12% below the mean).

The analysis conflicts revealed that the 55% of the conflicts happen in the terminal area and 45% en-route. From the perspective of route selection and its influence on potential conflicts, the en-route conflicts were assumed to be more relevant. The mean of the total en-route conflicts for all simulation was found to be 29202. The total number of en-route conflicts had a standard deviation of 201 about a mean of 29202 conflicts. The maximum number of conflicts recorded was 29751 (2% above the mean) and the minimum number of conflicts recorded was 28760 (2% below the mean). There was no correlation between the number of conflicts the total delays as shown in Figure 8.

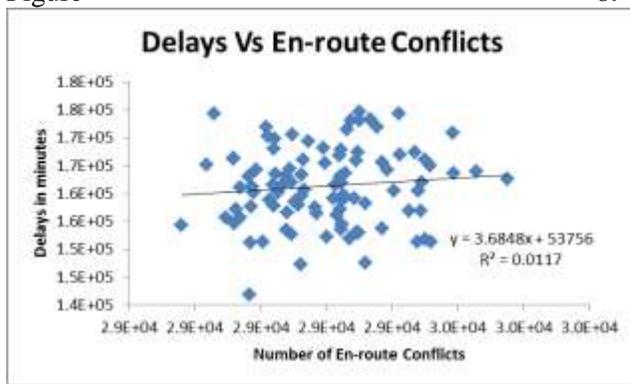


Figure 8 Relationship between delays and Conflicts

Figure 9 shows a scatter plot to understand the relationship between variance in total delays and en-route conflicts. The x-axis is the percentage change in the total delays with respect to the mean total distance. The y-axis is the percentage change in the total en-route conflicts with respect to the mean total en-route

conflict

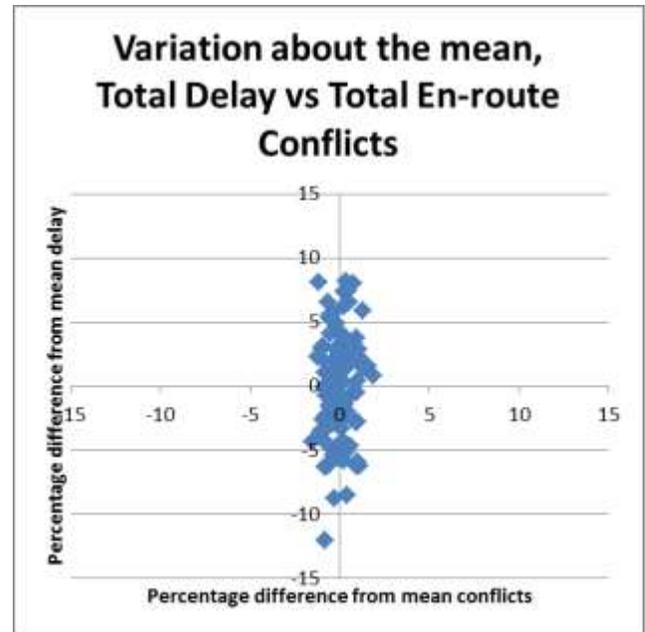


Figure 9 Variation of Delays to Conflicts

The above plots indicate that route selection had a larger influence on total delays than total number of conflicts.

Further analysis of conflict showed that about 80% of the conflicts were between flights flying in opposite direction to each other; about 15% were between flights flying in same direction, and the remaining 5% were between flight flying in perpendicular to each other. Figure 10 show a break up of types of en-route conflicts.

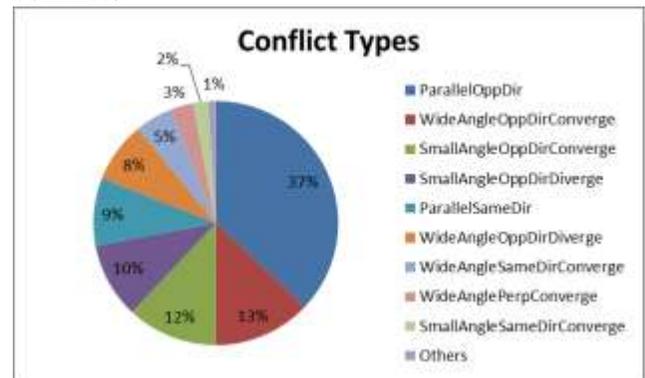


Figure 10 Types of conflict

The top three conflict types were “Parallel Opp Dir”, “WideAngle OppDir Converge” and “SmallAngle OppDir Converge”. The conflicts type “Parallel Opp Dir”(Flight vector angle between 0 to 10 degrees, flight in opposite direction) accounted for 37% of the total conflicts. Table 2 shows top 50 routes with this type of conflict and the GCD of these routes.

Table 2: Routes with Parallel Opp Direction Conflict

Route1	GCD	Route2	GCD	Conflict
MIA_SKBO	1314	SKRG_MIA	1210	15
SKRG_MIA	1210	MIA_SKBO	1314	11
DCA_DFW	1033	DFW_RDU	920	8
OAK_PHX	560	PHX_OAK	560	8
DFW_RDU	920	DCA_DFW	1033	7
ORD_BDL	678	ORD_BDL	678	7
MSP_IAH	900	IAH_MCI	561	7
BOS_MDSD	1437	MDSD_JFK	1349	6
SKBO_MIA	1314	MIA_SKBO	1314	6
OAK_PHX	560	PHX_SJC	539	6
SFO_DEN	838	MDW_SFO	1607	6
LAX_MIA	2030	IAH_LAX	1196	6
CYYC_IAH	1519	IAH_CYYC	1519	6
JFK_LAX	2144	LAX_JFK	2144	6
BUR_PHX	320	TUS_LAS	317	6
LAX_ORD	1512	JFK_LAX	2144	5
MIA_SKBO	1314	SKCG_FLL	974	5
SFO_ORD	1599	ORD_SFO	1599	5
SFO_ORD	1599	JFK_SFO	2240	5
CLT_PHX	1537	PHX_CLT	1537	5

Flights flying between Miami to South America had higher conflicts on an average. But there was no specific route within the NAS which had a significantly higher number of conflicts. The GCD did not appear to bear any relationship to the number of conflicts either.

Conclusion

The role of random flight plan route selection in the stochasticity and performance of the NAS was evaluated using RAMS model. It was found that by randomly varying flight

plan routes for 32% (limited by the extracted data) of the flights the overall total delay had a standard deviation of 6849 minutes about the mean total delay of 161358 minutes. The maximum total delay was 174559 minutes (8% above the mean) and the minimum total delay was 141876 (12% below the mean). The mean of the total en-route conflicts for all simulation was found to be 29202. The total number of en-route conflicts had a standard deviation of 201 about a mean of 29202 conflicts. The maximum number of conflicts recorded was 29751 (2% above the mean) and the minimum number of conflicts recorded was 28760 (2% below the mean). The random flight plan route selection had a larger influence on total delays than total number of conflicts. Also 80% of the conflicts were between flights flying in opposite direction to each other; about 15% were between flights flying in same direction, and the remaining 5% were between flight flying in perpendicular to each other

References

- [1] S. Magill, “The Effect of Direct Routing On ATC Capacity,” in *2nd USA/Europe Air Traffic Management R&D Siminar*, 2nd USA/Europe Air Traffic Management R&D Siminar, 1998, p. 305.

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