PERFORMANCE ASSESSMENT OF OPERATIONS IN THE NORTH ATLANTIC ORGANIZED TRACK SYSTEM AND CHICAGO O'HARE INTERNATIONAL AIRPORT NOISE STUDY

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Thesis submitted to the Faculty of the Virginia Polytechnic Institute
And State University in partial fulfillment of the requirements for the degree of

Master of Science
In
Civil Engineering

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June 15, 2016
Blacksburg, Virginia

Keywords: Demand, North Atlantic Organized Tracks, Reduced separations, Airport Noise, Simulation

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ABSTRACT

This thesis consists of two topics. The first topic is a performance assessment study of the flight operations in the North Atlantic Organized Track System. This study begins with the demand shortfall analysis of demand sets provided by the Federal Aviation Association (FAA). These sets were used to simulate OTS traffic for a number of scenarios that consider different separation minima. For this reason, algorithms were developed to modify the NAT OTS configuration applying reduced lateral separation between tracks and estimate the probability that any given flight that traverses the Atlantic will use the OTS. The preliminary results showed that the scenario with reduced lateral separation minimum (RLatSM) (25 nm) and the reduced longitudinal separation minimum (RLongSM) (8 nm) was the most optimal among all five that were simulated. The application of RLatSM also decrease the mean fuel consumption of flights that shift from traversing the OTS to flying random routes. The second topic is a noise study performed for the Chicago O'Hare International Airport. The contributions to this topic were three fold: 1) we analyzed data to understand the current operations at ORD airport 2) we verified the noise contours produced in 2002 by the FAA, Chicago Department of Aviation (CDA) and the engineering contractors 3) we produced noise contours for today's airport activity.

ACKNOWLEDGEMENTS

First of all, I would like to express my deepest gratitude to my advisor, Dr. Antonio A. Trani for his support and guidance throughout the research. The door to Dr. Trani's office was always open whenever I ran into a trouble spot or had a question about my research or writing. He consistently allowed this paper to be my own work, but steered me in the right the direction whenever he thought I needed it.

I am particularly grateful to my committee members: Dr. Montasir M. Abbas and Linbing Wang for being great professors and serving on my committee.

Special thanks to Nicolas Hinze for his assistance during the development of the Matlab codes that I used for this study.

Finally, I must express my very profound gratitude to my parents and to my brother for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

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CHAPTER 1 INTRODUCTION

1.1 Objective of the Study

This study tries to assess the impact of the reduced aircraft separations in the operations in the operations at the North Atlantic Organized Track System (OTS). Nowadays, the minimum lateral separation between aircraft pairs in the OTS is 1^{o} (52nm - 54 nm) and the minimum longitudinal separation is 5 minutes (40 nm) if both of them are properly equipped with avionics required to maintain this separation. Otherwise the minimum longitudinal separation is 10 minutes in trail (80 nm). The longitudinal and lateral separations are the two degrees of freedom used in this analysis. The scenarios modeled differentiate due to reduced lateral separations (1/2^{o} latitude), reduced longitudinal separations (1 min in trail) or both.

The introduction of new technologies will allow aircraft pairs to be more closely separated in the OTS. The need for reduced separations is driven by the fact that the traffic in the North Atlantic increases and the current system will not be able to accommodate the traffic in the future while maintaining a satisfactory level of service. What is more, reduced separations will allow aircraft to fly altitudes that are closer to the optimal flight level.

The separations standards are directly associated with the navigation, surveillance and communication equipage required. For this reason a number of different scenarios will be assessed in order to identify what are the benefits of the application of each separation standards. The model developed for the purposes of this study can be used in an extensive cost benefit analysis of the proposed equipage for the application of reduced separations.

The performance metrics used include fuel consumption, travel time and the level of service which can be calculate comparing track and flight level that each flight requested prior to the entrance in the OTS against the assigned track and flight level.

1.2 The North Atlantic Region

1.2.1 Background

The north Atlantic is the busiest oceanic airspace in the world (Figure 1). More than 450,000 flights per year traverse a region whose lateral dimensions include the Control areas of Reykjavik, Shanwick, Gander, Santa Maria, Sondrestrom, Bodo plus a portion of the New York Oceanic Center which is north of 27^{0} but excluding the area which is west of 60^{0}W and south of 38^{0}30'N [1]. The preceding areas form the Minimum Navigation Performance Specification airspace (MNPS). All aircraft flying inside this airspace and between FL285 and FL420 inclusive shall have the appropriate navigation performance equipage that will guarantee:

i. The standard deviation of lateral track errors be less than 6.3 NM (11.7 km)

ii. The proportion of total flight time spent by the aircraft 30 NM (56 km) or more off the cleared track be less than 5.3 x 10-4

iii. The proportion of total flight time spent by the aircraft between 50 and 70 NM (93 and 130 km) off the cleared track shall be less than 13 x 10-5

All aircraft that do not meet these criteria can fly inside the MNPS but below FL285 or over FL420 [2].

Figure 1: North Atlantic Eastflow Traffic on May 30, 2016 (www.flightradar24.com)

1.2.2 The Organized Track System

Given the high demand of air traffic over the North Atlantic there is a need for an Organized Track System (OTS) to accommodate a portion of the traffic (Figure 2). The OTS has been providing a successful trade-off between capacity and operating efficiency [3]. The peak traffic flows between North America and Europe occur during different Coordinated Universal Time (UTC) periods as a result of a number of factors that include:

- Passenger demand
- Time zone differences
- Airport noise restrictions

Eastbound flights from North America to Europe depart in the evening local time whereas westbound flights take-off from Europe in the morning local time. The OTS has to be consistent with peak traffic periods for each direction to accommodate as many flights as possible.

Typically, the OTS hours of validity are as follows:

- Day-time OTS for westbound flow: 1130 UTC to 1900 UTC at 30°W
- Night-time OTS for eastbound flow: 0100 UTC to 0800 UTC at 30°W

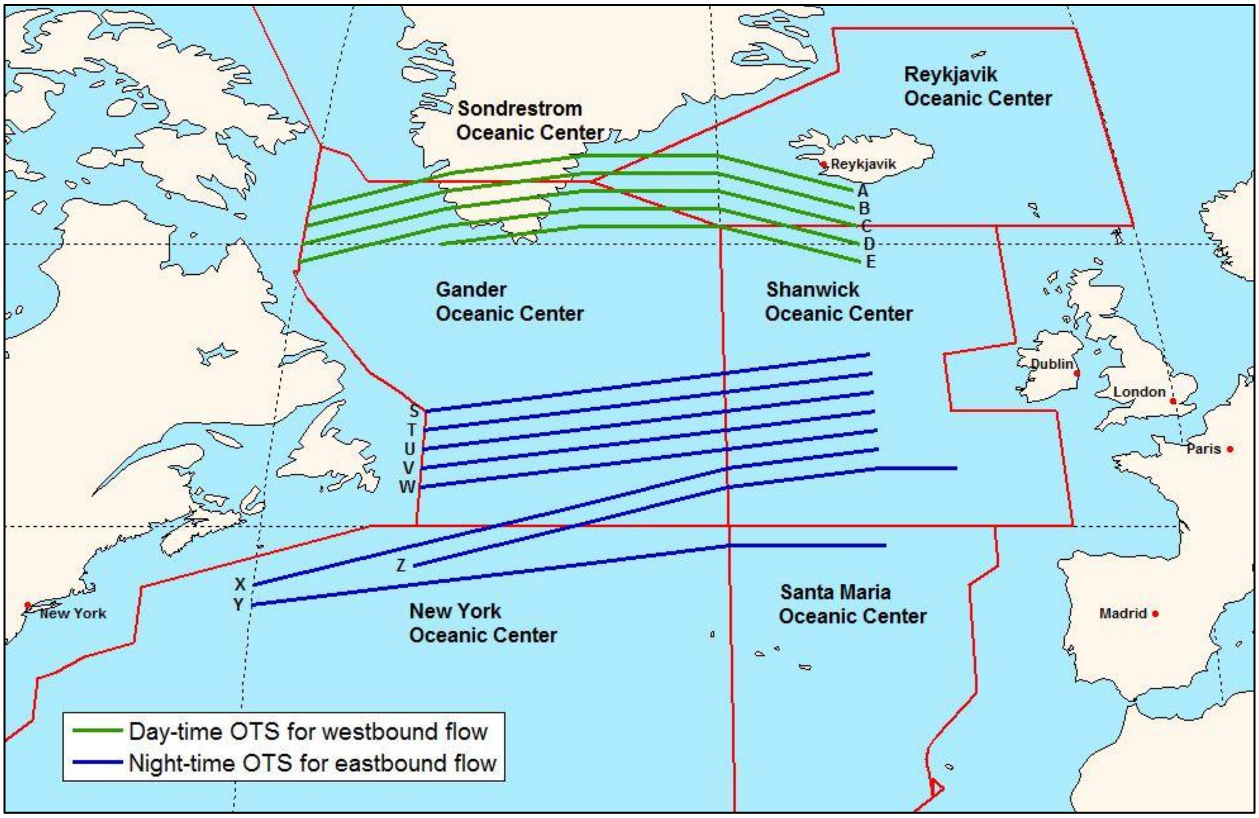

Figure 2: Illustration of NAT Oceanic Centers and the Track System (March 03, 2014)

The night-time OTS is designed by Gander Oceanic Air Traffic Center (OAC) and the day-time OTS is designed by Shanwick OAC (Prestwick). The design of the tracks incorporates any requirement for tracks within the New York, Reykjavik, Bodø and Santa Maria Oceanic Control Areas (OCAs) [2]. These tracks follow the minimum time routes between various OD pair airports.

Most of the aircraft that traverse the North Atlantic operate economically between FL310 and FL400. What is more, during peak hours many aircraft compete for the same flight levels so there is need to increase the number of available flight levels in the economical flight band. The Reduced Vertical Separation Minima (RVSM), which allows aircraft to be vertically separated by 1,000 feet instead of 2,000 feet, is used inside the OTS between FL290 and FL410.

On February 7, 2013 commenced Phase 1 of the Data Link Mandate (DLM) for the North Atlantic. From that date on, all aircraft fling along two reserved tracks from FL360 to FL390 (inclusive) must be equipped with CPDLC and ADS-C equipment. On February 5, 2015 Phase 2 of the DLM NAT began. As of that date, all aircraft operating in the OTS from FL 350 to

FL390 (inclusive) are required to be equipped with CPDLC and ADS-C [4]. Future Air Navigation Systems (FANS) platform consists of avionics systems that enable direct data link communication between pilots and Air Traffic Controllers (ATC). The FANS 1/A platform includes the Controller Pilot Data Link Communications (CPDLC) and the Automatic Dependent Surveillance – Contract (ASC-C). Below we show some services provided by CPDLS and ADS-C:

- CPDLC
  - Replaces verbal ATC instructions and pilots read-backs
  - Automates ATC processes
- ADS-C
  - Gives accurate position reporting
  - Allows additional data reporting (wind, temperature etc.)
  - Ability to report in regions out of radar coverage
  - Significantly increases traffic that can be handled in remote areas [5].

The avionics equipment of each aircraft is defined in the flight plan "EQUIPMENT" field (Figure 3) using the appropriate alphanumeric code which has the format shown in Figure 3:

```
SDE2E3FJ2J4J5M1HIZWRGY/LB1D1
```

Each of the letters or the combination of a letter and the following number corresponds to one avionic system. For instance, "D1" designates "ADS-C with FANS 1/A capabilities" and "L" designates "Mode S, ACFT ID, pressure altitude, extended squitter (ADS-B) and enhanced surveillance capability" [6].

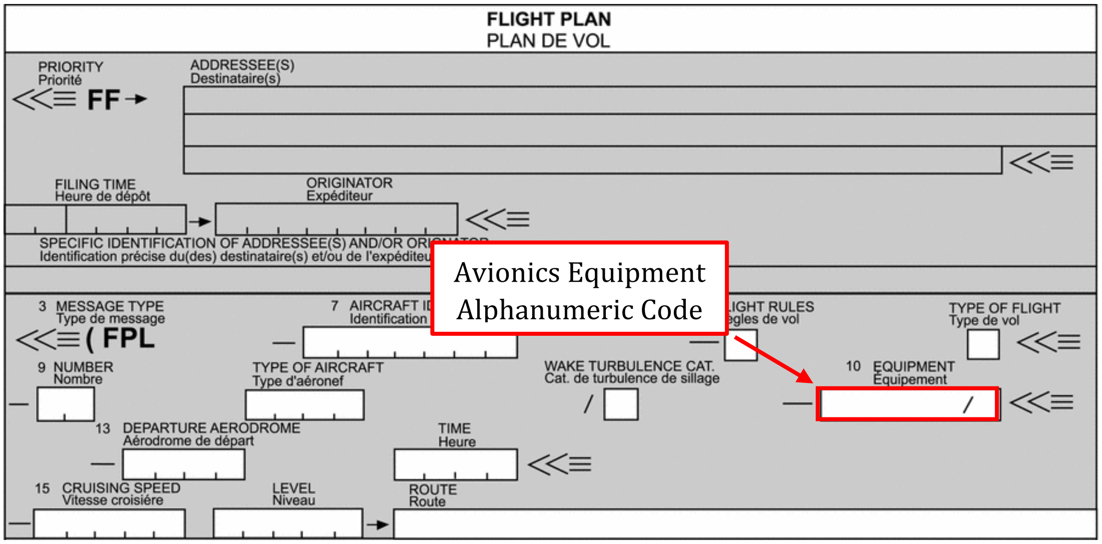

Figure 3: Equipment Filed in the ICAO Flight Plan

Two Aircraft equipped with FANS 1/A capabilities can be longitudinally separated by 5 minutes in the OTS whereas if at least one of the successive aircraft is not equipped with FANS 1/A then the longitudinal separation distance becomes 10 minutes (Figure 4).

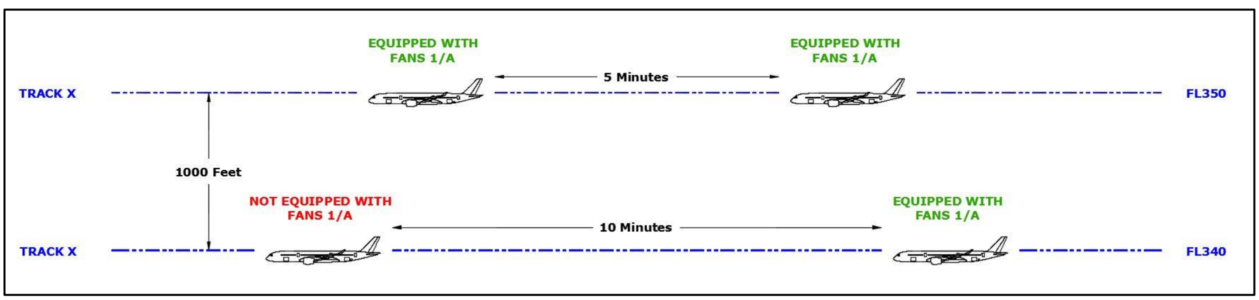

Figure 4: Longitudinal and Vertical Separations in the OTS

1.2.3 Design of the North Atlantic Organized Track System

Gander is the Oceanic Airspace Center responsible for designing the eastbound tracks and Shanwick for the westbound tracks. Oceanic Airspace Center planners use the airline preferred routes for a number of O-D pairs in order to define the core tracks. All NAT operators (both scheduled and non- scheduled) are urged to provide information by Aeronautical Fixed Telecommunication Network (AFTN) message to the appropriate OACs regarding the optimum tracks of any/all of their flights which are intended to operate during the upcoming peak traffic periods. Such information should be provided, in the correct format, as far in advance as possible, but not later than 1900 UTC for the following day-time

OTS and 1000 UTC for the following night-time OTS [2]. During the procedure of construction of the OTS OAC planners take into account the following factors:

- Weather conditions
- Airspace restricted areas like those considered dangerous or some that are reserved for military use
- Contiguous OACs opinion to guarantee that the proposed track system is feasible and it will not create any safety or operational problems
- The volume of opposite direction traffic to ensure that there is ample space to serve those flights
- Route structures that connect the domestic with the oceanic airspace.

After the completion of the OTS design process, OACs release the NAT track messages that contain all the necessary information to navigate in the track system (Figure 5). Each track is defined by a name (A-H for westbound tracks and Q-Z for eastbound tracks) and a series of waypoints with latitude and longitude coordinates in degrees. Some track waypoint series contain an entry and/or an exit waypoint specified by a five character alphanumeric string (i.e ALLRY, MUNEY). A named waypoint is the last one before entry to the OTS or the first one after exiting the OTS and part of routes that lead to the OTS converge at these waypoints (Figure 6). All tracks are laterally separated by at least one degree.

```
FF CYZZWNAT
102152 EGGXZOZX
(NAT-3/3 TRACKS FLS 310/390 INCLUSIVE
FEB 11/1130Z TO FEB 11/1900Z
PART THREE OF THREE PARTS-
H 43/40 41/50 39/60 MUNEY
EAST LVLS NIL
WEST LVLS 320 340 360 380
EUR RTS WEST NIL
NAR NIL-
REMARKS.
1. TMI IS 042 AND OPERATORS ARE REMINDED TO INCLUDE THE
TMI NUMBER AS PART OF THE OCEANIC CLEARANCE READ BACK.
2. ADS-C AND CPDLC MANDATED OTS ARE AS FOLLOWS
TRACK A 350 360 370 380 390
TRACK B 350 360 370 380 390
TRACK C 350 360 370 380 390
TRACK D 350 360 370 380 390
TRACK E 350 360 370 380 390
TRACK F 350 360 370 380 390
TRACK G 350 360 370 380 390
END OF ADS-C AND CPDLC MANDATED OTS
```

Figure 5: Sample of Westbound NAT Track Message

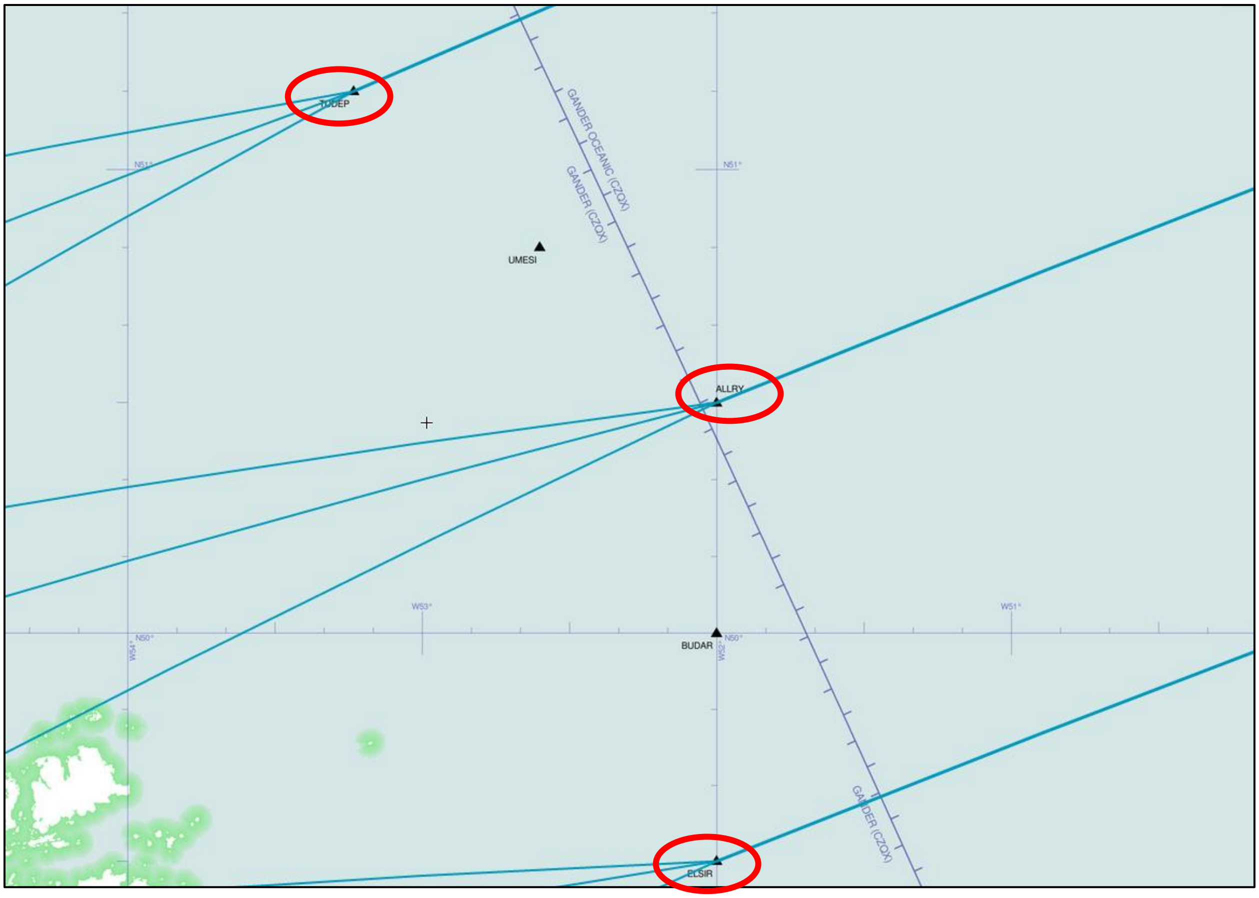

Figure 6: Eastbound Tracks and the First Waypoints of the OTS (Skyvector: October 20, 2015)

1.2.4 Random Airspace

The existence of the OTS does not make its use mandatory. Individual flights can choose whether to utilize it or flight their own flight plan. In fact, around 50% of NAT flights make use the OTS [2]. The other half can file flight plans that stay away from the OTS, approach it or even intersect with it. In such case Air Traffic Controllers will try to clear random flights (i.e. non OTS flights) without disrupting OTS operations by either assigning new flight levels or detouring random flights when there is probability of collision with OTS flights.

One important difference between OTS and random airspace is the vertical separation given that the hemispherical rule is applicable in random airspace. Eastbound flights (magnetic heading from 0° to 179°) flight odd thousand flight levels whereas westbound flight (magnetic heading from 180° to 359°) flight even thousand flight levels.

1.3 North Atlantic Traffic

The fixed routes presented earlier are essential in order to minimize the flight times while maximizing safety in one of the highest traveled regions in the world. Roughly 1,700 flights traverse the North Atlantic diurnal, half of which make use of the NAT.

According to the flight demand sets prepared by the FAA, it is estimated that the North Atlantic traffic will grow by 59% from 2015 to 2035 (Figure 7).

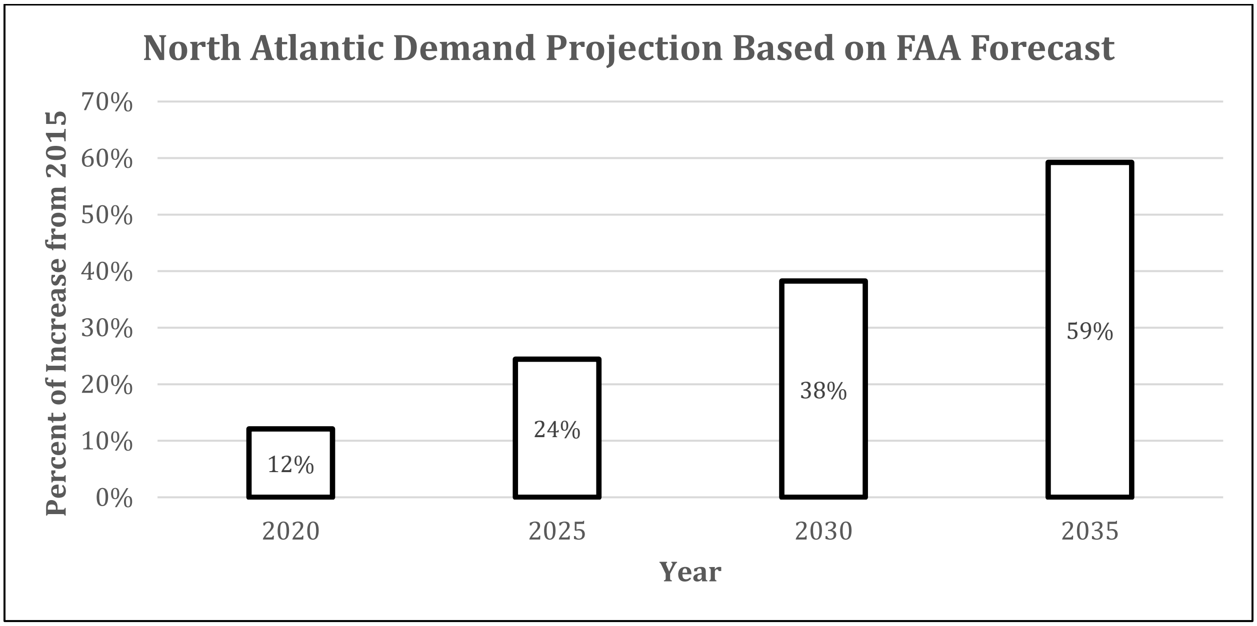

Figure 7: North Atlantic Demand Forecast Derived by TFMS Demand Sets Provided by the FAA

CHAPTER 2 LITERATURE REVIEW

Almira Williams et al. 2006 developed a discrete event simulation model that estimates the potential benefits from reduced horizontal and lateral separation in the OTS. The authors evaluated three demand sets for 2005, 2010 and 2015 generated using 2004 actual NAT traffic data. For each demand set they applied 5 equipage levels (0, 0.25, 0.50, 0.75, and 1) and the assessed the OTS performance in terms of fuel and flight time savings, potential cargo revenues and improvements in system efficiency [7]. The results of this study show potential fuel and time savings per flight that are proportional to the equipage level of all OTS flights and vary from 0.18% (when 25% of traffic is equipped) to 0.39% (when 75% of traffic is equipped). What is more, the more the traffic over the North Atlantic increases the more the benefits increase. For instance, the fuel and time savings per flight (when 75% of traffic is equipped) on 2015 are double the number of 2005.

Ryan Chartrand et al. 2008 tried to assess the benefits of ADS-B and In-Trail Procedure (ITP) in NAT OTS. This study was performed using the Traffic Manager (TMX) as the simulation tool and 9 days of actual air traffic data collected by the Shanwick Oceanic Center. The results demonstrated improvements in terms of fuel savings and operational parameters like request approval rates when new policies are applied[8]. The main variable used for the assessment of the outputs of this analysis was the fuel burned during the entire flight divided by the total travel time. Based on the results, an average fuel saving of 20 lbs/hour is achievable applying the ITP.

Aswin Gunnam et al. 2012 built a simulation model called North Atlantic Simulation and Modelling (NATSIM) to analyze the effects of a number of OTS different operational policies in terms of potential fuel savings and level of service improvements. The scenarios tested in this study include reduced lateral and longitudinal separations, the application of the data link mandate and other parameters like variable Mach number profiles or cruise-climb profiles. The simulation model assigns track and flight level at each OTS flight based on a cost matrix which estimates the fuel burned if the flight use any of the available tracks in any of the available flight level. What is more, the model calculates the fuel consumption when the flight follows a random flight path and it finally decides whether the use of the OTS is beneficial or not. Regarding demand, the authors used actual TFMS traffic data [9].

Similarly, Olga Rodionova et al. 2014 formulated an optimization mathematical model in an effort to assess the benefits of reduced separation in the NATOTS. Contrary to the previous one, this study focuses only on the part of the flight that is inside the OTS while it considers only eastbound actual traffic data collected by the Shanwick Oceanic Center. The model is even more constrained given that aircraft are allowed to change flight level only at waypoints and this change happens instantaneously. The improvements (i.e. more optimal flight level) for each flight are evaluated using a genetic algorithm [10].

Table 1: Literature Review Synopsis

Year	Authors	New OTS Policies	Track Assignment Method	Simulation Method	Demand Sets	Assessment Metrics
2006	Williams et al.	Reduced horizontal and lateral separations	Exhaustive search algorithm	Discrete event simulation model	2005, 2010,2015 forecasted using 2004 flight data	Fuel, Flight time, Cargo revenue, System efficiency
2008	Chartrand et al.	Introduction of ADS-B and In-Trail Procedure (ITP)	Actual track used (from demand sets)	Traffic Manager (TMX)	9 days of actual traffic data from Shanwick OC	Fuel, Request approval rates
2012	Gunnam et al.	Reduced longitudinal and lateral separations, Introduction of DLM	Cost Matrix (No. Tracks x Flight Levels + Non OTS Flight Plan)	North Atlantic Simulation and Modelling (NATSIM)	2012 TFMS air traffic data	Fuel consumption, Travel Time, Track Assignment, Level of service
2014	Rodionova et al.	Reduced longitudinal separations	Actual track used (from demand sets)	Optimization mathematical model	2 days of eastbound traffic from Shanwick OC	Flight Time, En route conflicts

CHAPTER 3 DATA COLLECTION AND ANALYSIS

3.1 TFMS Demand Sets

TFMS (previously ETMS) is a data exchange system for supporting the management and monitoring of national air traffic flow. TFMS processes all available data sources such as flight plan messages, flight plan amendment messages, and departure and arrival messages. The FAA's airspace lab assembles TFMS flight messages into one record per flight. TFMS is restricted to the subset of flights that fly under Instrument Flight Rules (IFR) and are captured by the FAA's enroute computers [11].

For the purposes of development of the Global Oceanic Model the FAA provided the Air Transportation Systems Laboratory of Virginia Tech six demand sets for sixteen (16) different calendar days (Table 2). These demand sets consist of exclusively oceanic flights that either originate or end in the US airspace. The first demand set is a baseline and includes actual flights that took off at 2013 and 2014. The other five sets refer to years 2015, 2020, 2025, 2030, and 2035. These demand sets include all flights from the baseline scenario enhanced with some cloned flights from the baseline scenario in order to address the forthcoming increase in air traffic in the following years.

Table 2: 16 TFMS Seed Days

TFMS Seed Days			
October 06	February 08	April 26	July 10
October 10	February 17	May 01	August 15
December 12	March 02	May 28	September 08
December 28	March 07	June 24	September 21

These sets where provided in text (.txt) format. A number of steps where followed to process the analysis of these sets (see Figure 8). The first step of the analysis was to import them in Matlab and convert them into binary (.mat) files. The flights where then classified based on the oceanic region they traverse. Four new fields were added to the demand sets to identify the oceanic region they traverse as Pacific, Atlantic, WATRS and ZNY. Each flight was marked with either 1 or 0 when it crossed or not the boundaries of each of the preceding areas. Subsequently, the ICAO four letter airport coding was replaced with the corresponding three letter IATA code. This process was essential in order to check for potential missing O-D pairs using the Official Airline Guide (OAG) data. The last step was to plot all flights (Figure 9) in order to visual inspect any anomalies (ex. Non-oceanic flights). Unrealistic flights based on distance, aircraft type or departure and arrival airports were identified and eliminated.

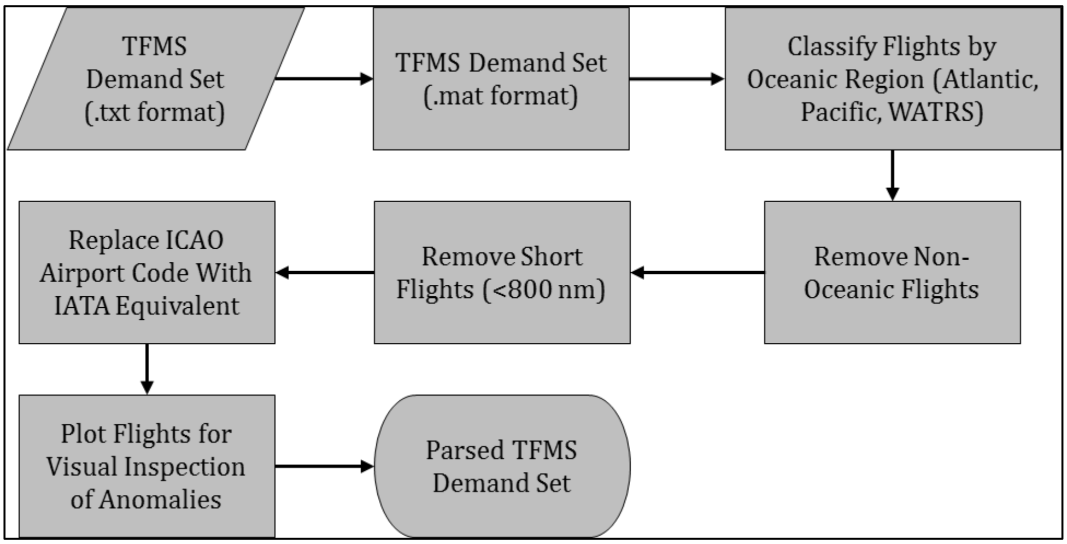

Figure 8: Flowchart of TFMS Data Analysis Process

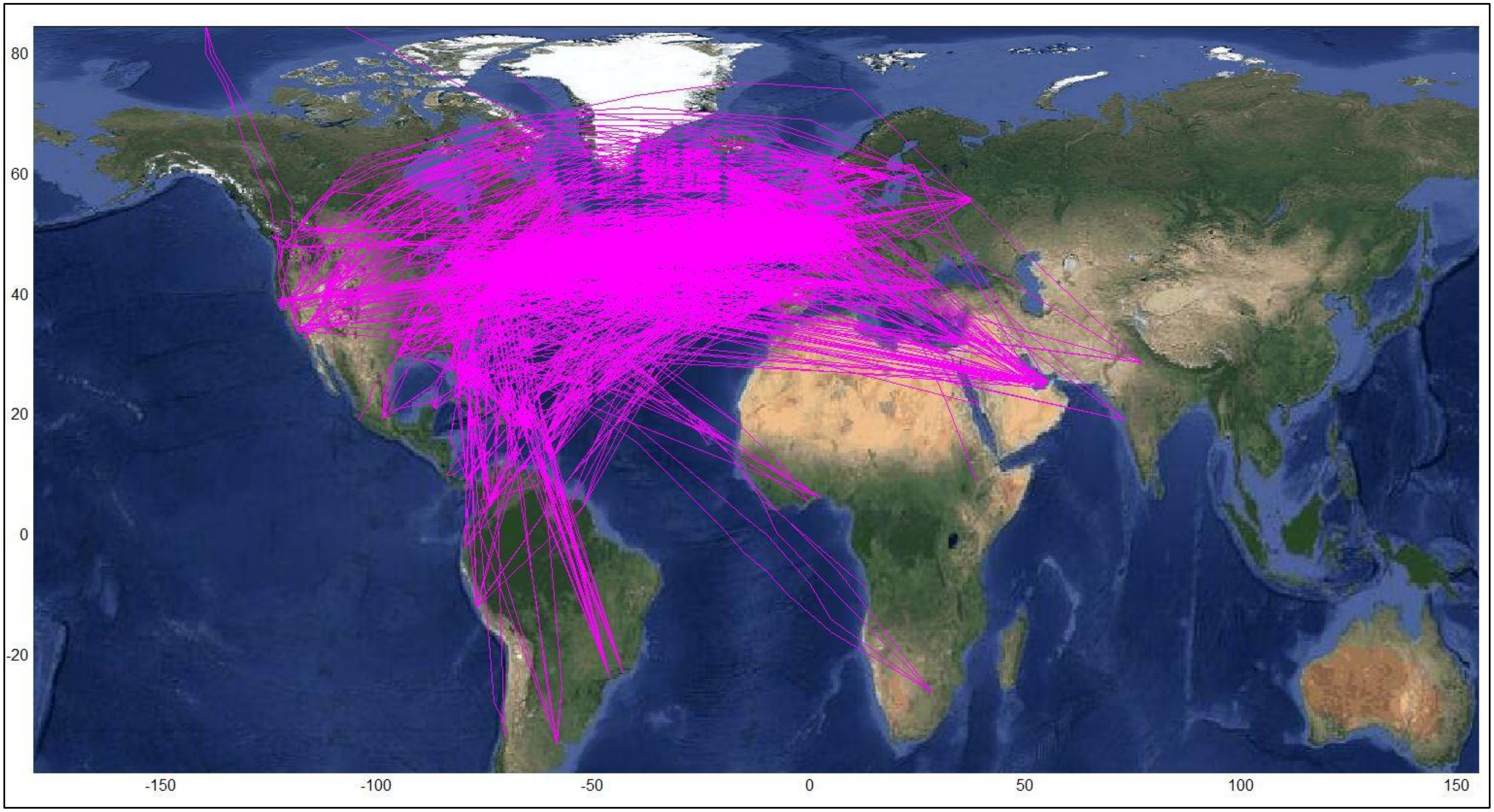

Figure 9: TFMS Atlantic Flights (August 15, 2014

3.2 OAG Demand Sets

The Official Airline Guide (OAG) is a database of airline schedules including future and historical data for commercial passenger and cargo flights around the world. OAG databases besides their unrivalled scale, are comprehensive and accurate. For all these reasons, OAG was selected as an alternative source of air traffic flight data to address the potential shortfall demand of TFMS data. OAG data are more complex than TFMS and as a result they require a lengthier analysis (see Figure 10).

The first step was to download the full OAG flight schedule for the same 16 seed days. It is worth mentioning that the user has to download the flight schedule for the day of interest as well as for two days before and two days after to account for long haul flights that span over a 24 hour period. Furthermore, the departure time in OAG is reported in local time and the conversion to UTC may eliminate or neglect some flights. The Coordinated Universal Time is the time standard used in aviation (OTS opening and closing time, Oceanic clearances).

OAG datasets were imported into Matlab and a data structure file was created. Next, using a World Airport Database, the origin and destination airport coordinates were added to the file in order to classify flights by oceanic region and remove all non-oceanic flights. Non-oceanic are the flights that do not traverse the Pacific, the North Atlantic or WATRS and fall beyond the scope of this study. A second filtering step was applied to keep only jet aircraft to be simulated in the Global Oceanic Model (GOM). Short route flights (<800 nm great circle distance from origin to destination) were also excluded from the demand set. The user has to remove duplicate records that occur because of schedule errors that the OAG databases have (see Table 3). Then, the local departure time was converted to UTC to be compatible with TFMS data and only those flights that depart from 0:00 to 23:59 at each of the 16 seed days are kept to the final sample. Finally, the remaining flights were plotted to visually inspect any anomalies (ex. Non-oceanic flights). Unrealistic flights based on distance, aircraft type or departure and arrival airports are identified and eliminated. (Figure 11).

Table 3: Typical Instance of OAG Flight Schedule Problems

Flight Specifications	1st Record	2nd Record
Flight ID	EY130	EY130
Origin	IAD	IAD
Destination	AUH	AUH
From Date	23-12-2013	29-12-2013
To Date	28-12-2013	31-12-2013
Sunday (U)	-	-
Monday (M)	2	2
Tuesday	3	3
Wednesday	4	4
Thursday	5	5
Friday	6	6
Saturday	7	7
Frequency	3	2

Table 3 illustrates one of the greatest challenges that is related to the processing of OAG data. In this example flight EY130 appears to change schedule on December 29, 2013. However, it is not clear which days of the week this flight operates because Monday through Saturday are marked as days when the flight took off but the frequency is 3 for the first instance and 2 for the second instance. The basic assumption is that the flight operated at the opening and closing dates. This means that for the first instance the flight took off on Monday and Saturday and for the second instance the flight took off on Sunday and Tuesday.

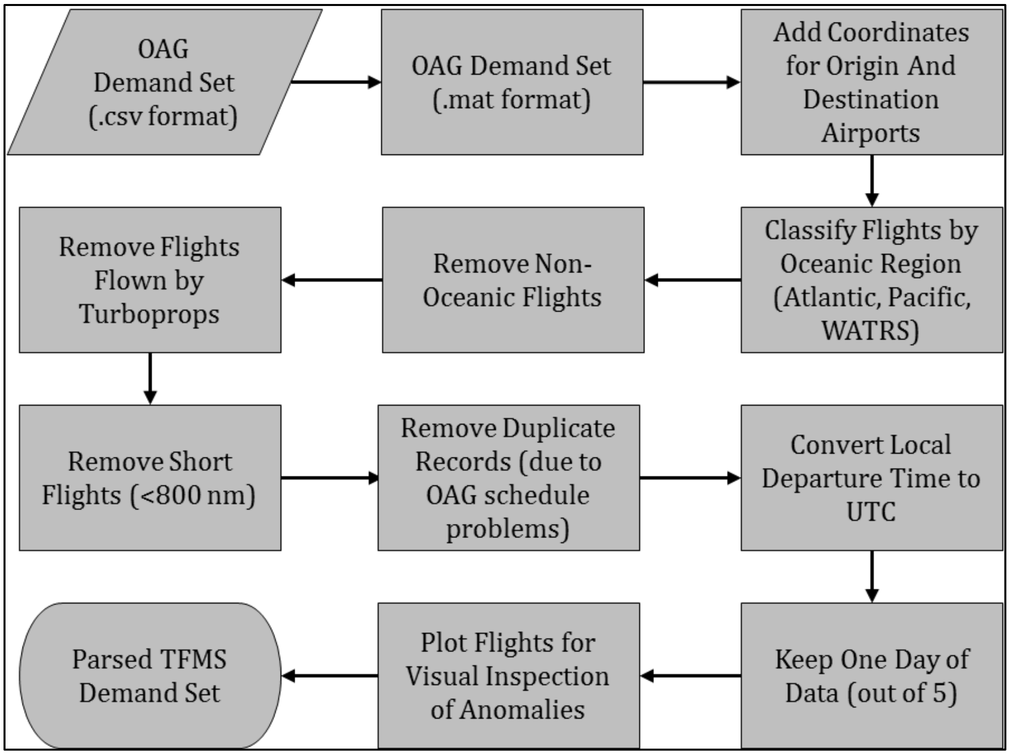

Figure 10: Flowchart of OAG Data Analysis Process

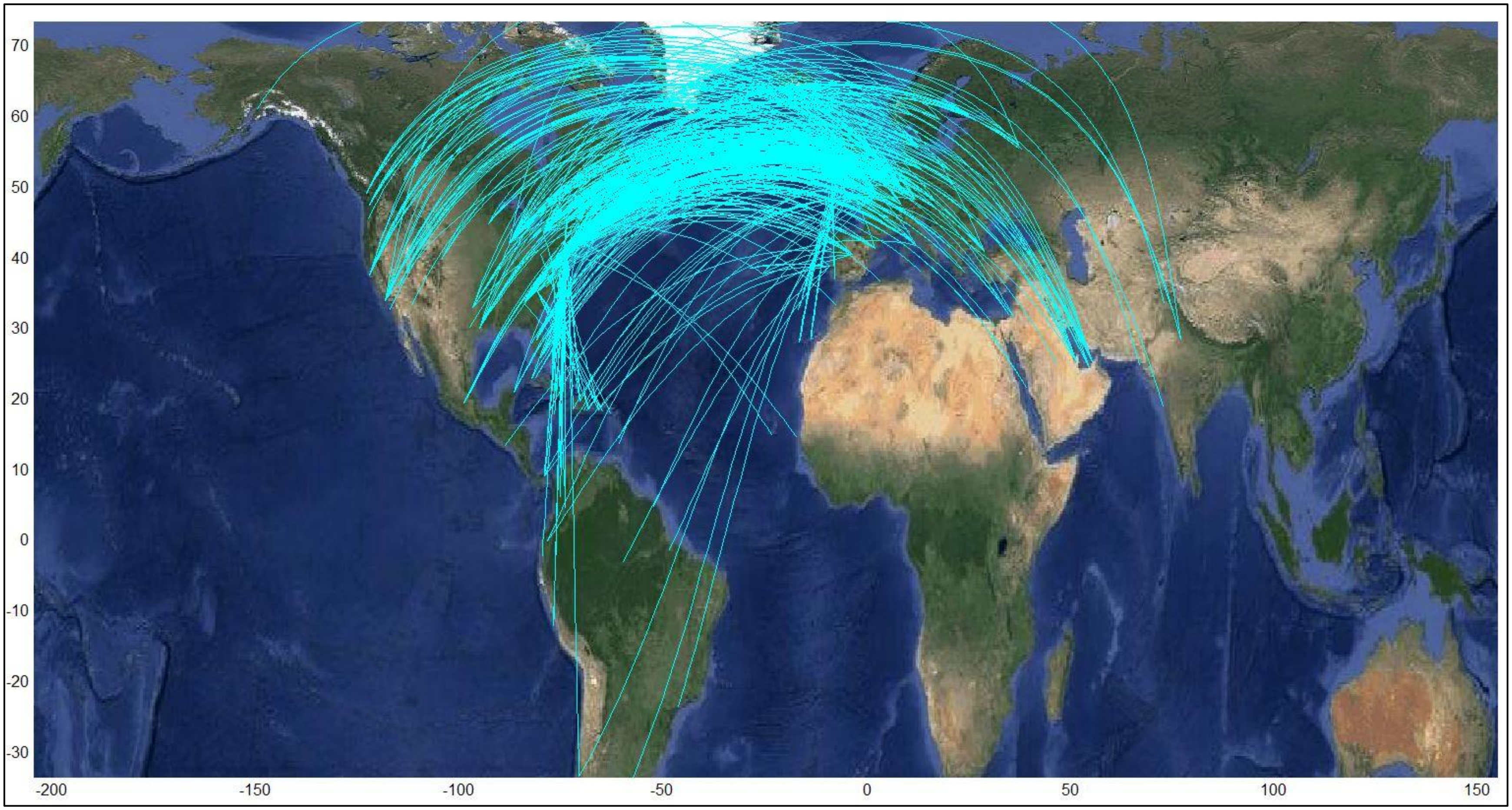

Figure 11: GOM Complementary Atlantic Flights (August 15, 2014)

3.3 TFMS Demand Shortfall Analysis

The shortfall analysis of TFMS demand sets consisted of three phases, equal to the demand sets provided by the Federal Aviation Administration in different time periods. The need for preparation of demand data in different periods is a consequence of the output of this study. After each phase, a feedback was given to the FAA concerning the shortfall of the demand sets that had been provided to the ATSL at the beginning of the phase. It is worth mentioning that the feedback prepared for was not constrained only in the shortfall analysis but it included other significant deficiencies of the data. At the end of this process, the demand sets were significantly improved both in terms of completeness and validity of flight records.

Phase 1: The first step of this analysis was performed using demand sets prepared by the FAA in 2014. The data included Atlantic and Pacific flights that took off in July and August, 2014. The processing of these sets was quite complicated because there was a number of deficiencies that had to be address before extracting results with regard to the shortfall. One of the main issues was the existence of duplicate and/or incomplete flight records. One of these example in Figure 12 shows a flight from John F. Kennedy International Airport, NY (JFK) to Hong Kong International Airport (HKG) that has two overlapping records, one of which represents the total number of available waypoints from origin to destination while the other one contains waypoints that start at the origin airport and cover the first around 365 nautical miles of this flight.

The shortfall analysis for these datasets was focused more on the Pacific demand. The comparison of TFMS and OAG datasets for the same region and dates showed that a substantial number of flights were not part of the TFMS demand sets. In fact, the missing flights were up to 44% for some of the dates that were analyzed (**Error! Reference source ot found.**). The shortfall was even greater when talking about specific regions of the Pacific like Hawaii for which TFMS represent only 20% of the total traffic (**Error! Reference source ot found.**).

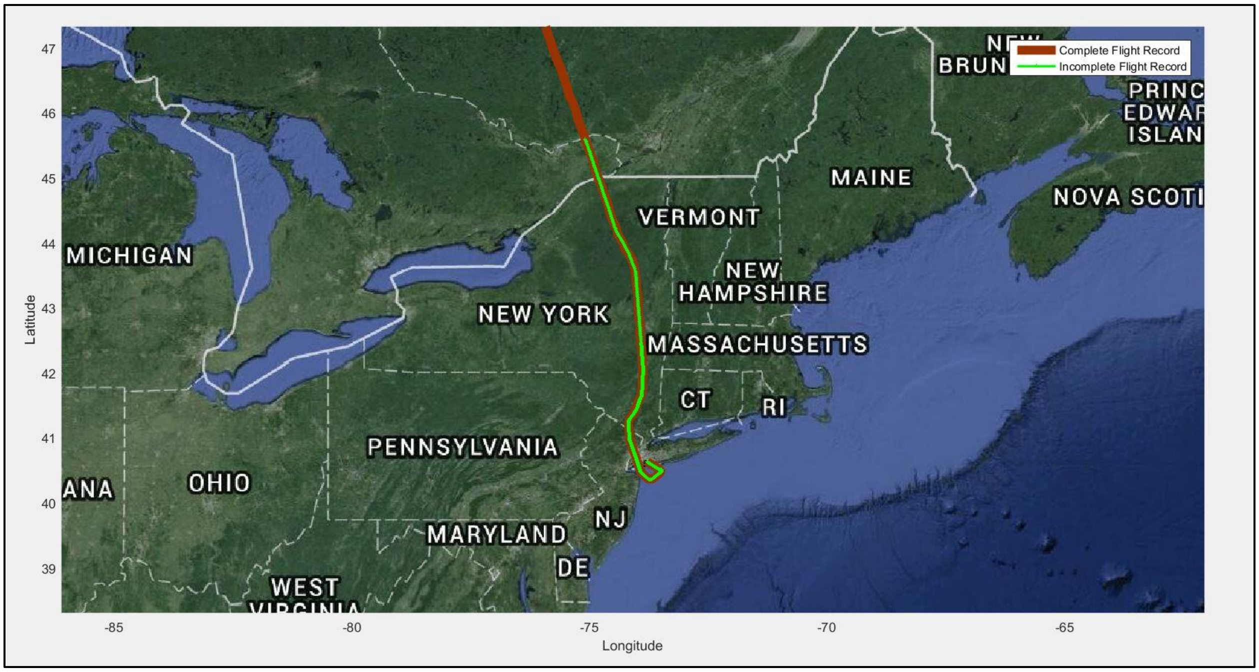

Figure 12: Example of Duplicate Records in TFMS Data (JFK - HKG)

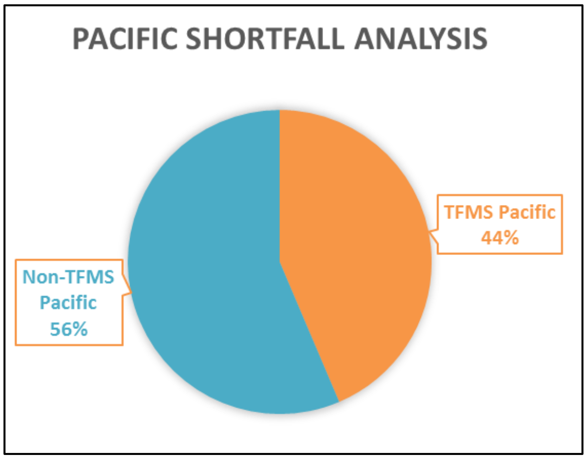

Figure 13: Pacific Traffic Shortfall Analysis

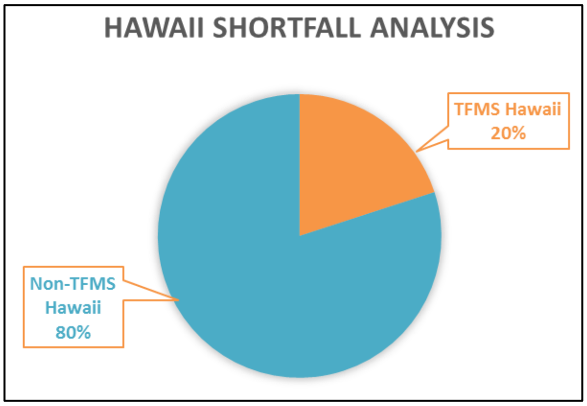

Figure 14: Hawaii Traffic Shortfall Analysis

Phase 2: The second step of was the analysis of newer demand sets prepared after the identification, documentation and presentation of all the issues found during Phase 1. The impact of the results of Phase 1 was apparent because Phase II demand sets did not contain any duplicate records. However, the shortfall was still significant for all three oceanic regions of interest (Atlantic, Pacific, WATRS[1] and ZNY[2]). The comparison between TFMS and OAG data for the same date and region at the level of OD pair showed that the percentage of missing flights for the Atlantic was the greatest among all four oceanic regions (Figure 15).

The following step, was the identification of the behavior of the flights that were not included in the TFMS traffic data sets. For the Pacific, WATRS and ZNY regions there was no apparent explanation for the missing flights. On the other hand, it was clear that no Atlantic flight that never travels inside the domestic airspace or the New York Air Route Traffic Control Center was included in the demand sets. However, these flights are important for the scope of the study and should be simulated by the model.

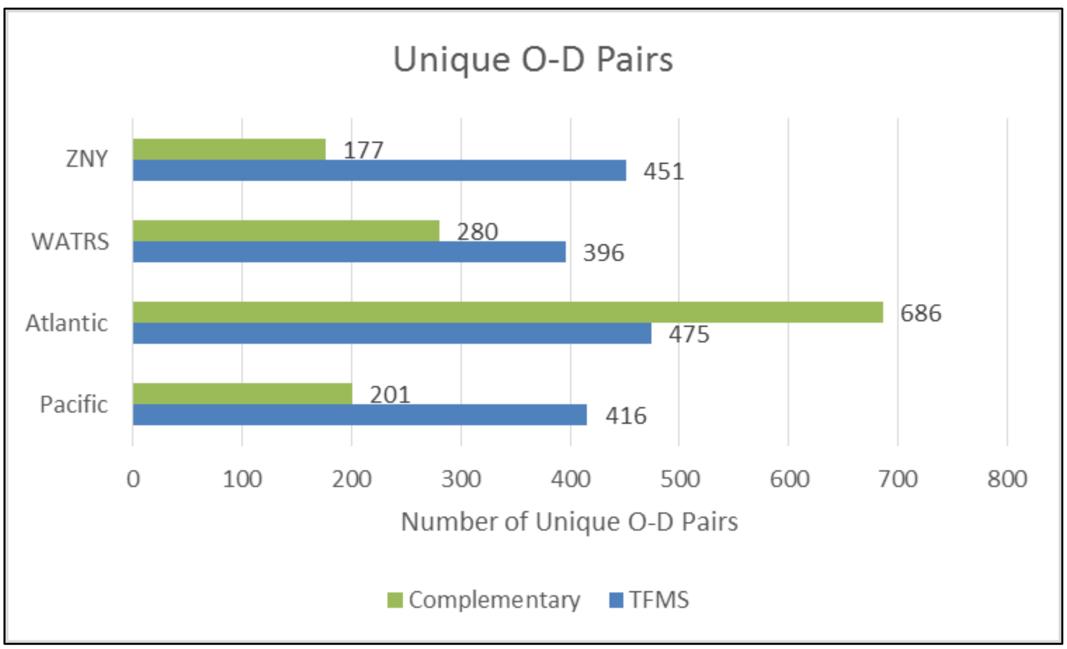

Figure 15: Phase 2 Oceanic Traffic Shortfall Analysis

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[1] West Atlantic Route System
[2] New York Air Route Traffic Control Center

Phase 3: The third sets of demand files consisted of full, unparsed TFMS demand sets for the entire airspace of the U.S either domestic or oceanic. These demand sets were analyzed using the same code but with enhanced with more filters to exclude some records (ex. domestic flights, turboprops etc.). The results are quite remarkable because the percentage of complementary flights was limited to as low as 3.9% for the WATRS while the higher percentage was 19.5% for the Pacific (Figure 16). The improvement is significant compared to Phase 2 when the complementary flights accounted for 41.4% for the WATRS while the highest was the Atlantic with 59%.

This was the last iteration of the demand shortfall analysis and the corresponding demand sets were the demand input files for all analyses performed with the Global Oceanic Model. Especially for the Atlantic the TFMS coverage of the total demand ranges from 74% to 89% (see Figure 17) which is acceptable. For a number of reason the TFMS demand sets cannot be complete. For instance, there are flights that never traverse U.S airspace so they are not recorded by TFMS.

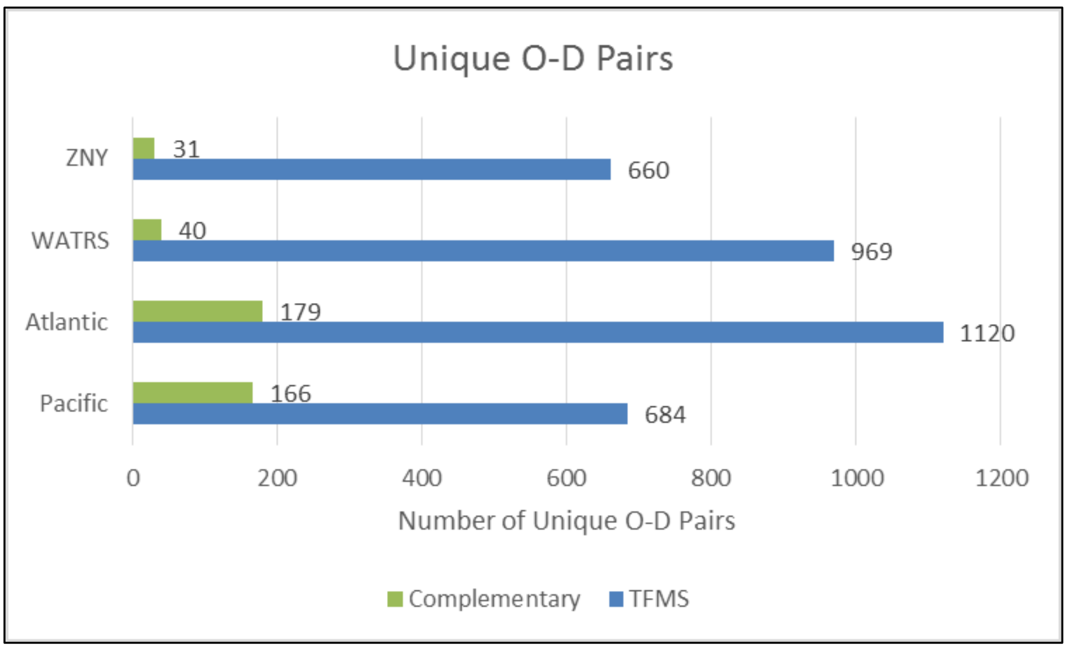

Figure 16: Phase 3 Oceanic Traffic Shortfall Analysis

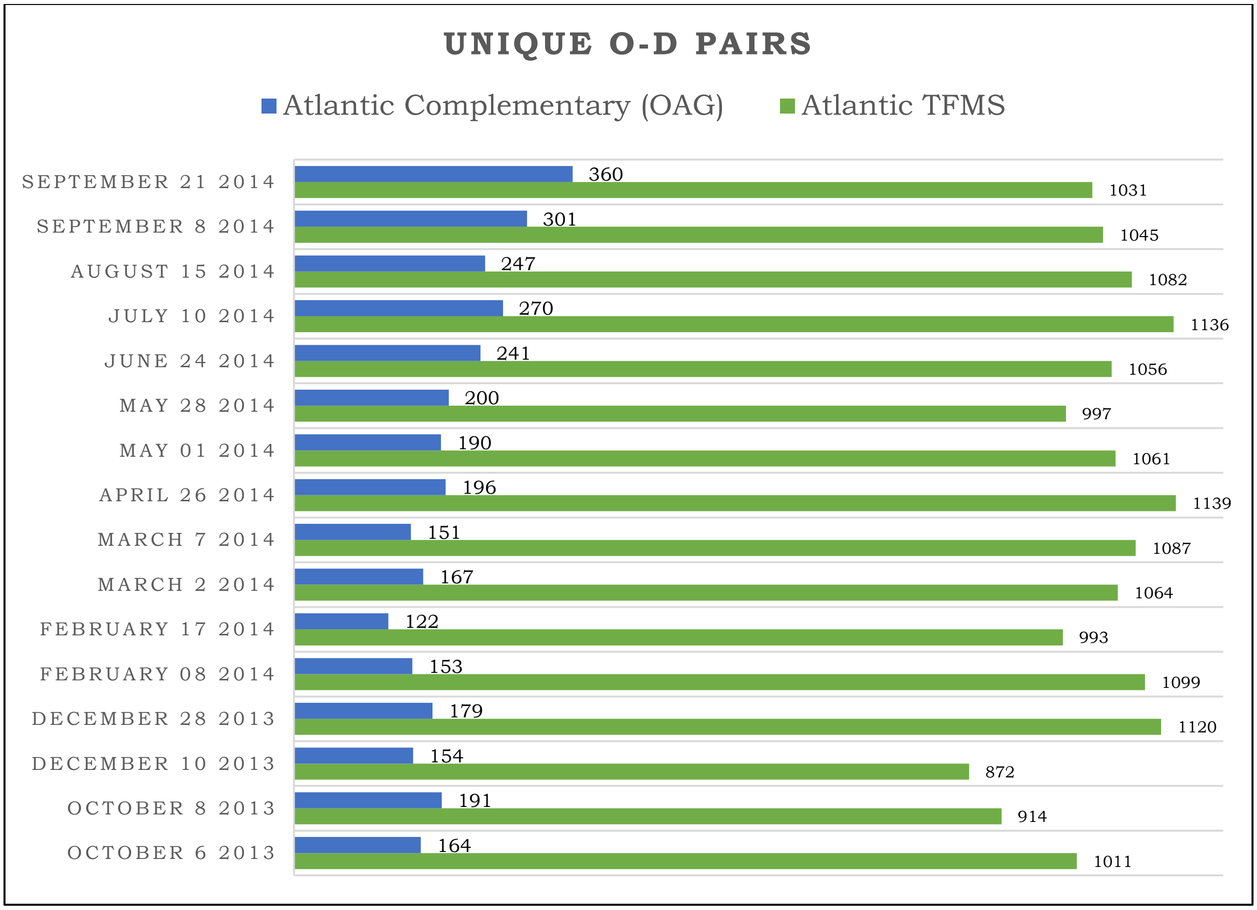

Figure 17: Unique O-D Pairs per Day for the Final Demand Sets

3.4 NAV Canada OTS Performance Data

NAV CANADA is a private, non-share capital corporation that owns and operates Canada's civil air navigation service (ANS). NAV Canada provided Virginia Tech with 8 days of data for NAT OTS performance analysis (Table 4). The goal of this part of the study is to assess the performance of the OTS and detect deficiencies. The analysis included the following steps:

- Track Configuration (Figure 18)
- Track Loading (Figure 19)
- Temporal Distribution of the Entry Time in the NAT OTS (Figure 20)
- Headways at the Entry Point of the NAT (Figure 21)
- Headways at the Entry Point of the NAT Adjusted for Delta Mach (Figure 21)
- Delta Mach for Closely Separated Aircraft (Figure 22)

- Equipage Rate per Track Flight Level (Figures 23 & 24)

Table 4: Days of NAV Canada Data

03 March 2014	08 September 2014
10 March 2014	15 September 2014
09 June 2014	08 December 2014
16 June 2014	15 December 2014

NAV Canada data include information regarding aircraft avionics equipment. Each flight record contains, among others, the avionics equipment alphanumeric code of the aircraft (Figure 3). This field was analyzed in order to label each aircraft as "equipped" if it was equipped with ADS-C and CPDLC or "non-equipped" if one or both systems were not available. The key for the analysis of this field was the following ICAO list of indicators for various aircraft avionics (Table 5):

Table 5: ICAO Indicators of Avionics Equipment

Indicator	Avionics Equipment	CPDLC	ADS-C
J1	CPDLC ATN VDL Mode 2	Yes	No
J2	CPDLC FANS 1/A HFDL	Yes	Yes
J3	CPDLC FANS 1/A VDL Mode A	Yes	Yes
J4	CPDLC FANS 1/A VDL Mode 2	Yes	Yes
J5	CPDLC FANS 1/A SATCOM (INMARSAT)	Yes	Yes
J6	CPDLC FANS 1/A SATCOM (MTRSAT)	Yes	Yes
J7	CPDLC FANS 1/A SATCOM (Iridium)	Yes	Yes
D1	ADS-C with FANS 1/A capabilities	Yes	Yes
G1	ADS-C with ATN capabilities	No	Yes

This information is important to better understand the separation rules used in the OTS that are affected by equipment of each aircraft pair. In addition, we can examine whether some tracks or flight levels are reserved exclusively for equipped aircraft and what is the equipage rate per airframe in the NAT OTS.

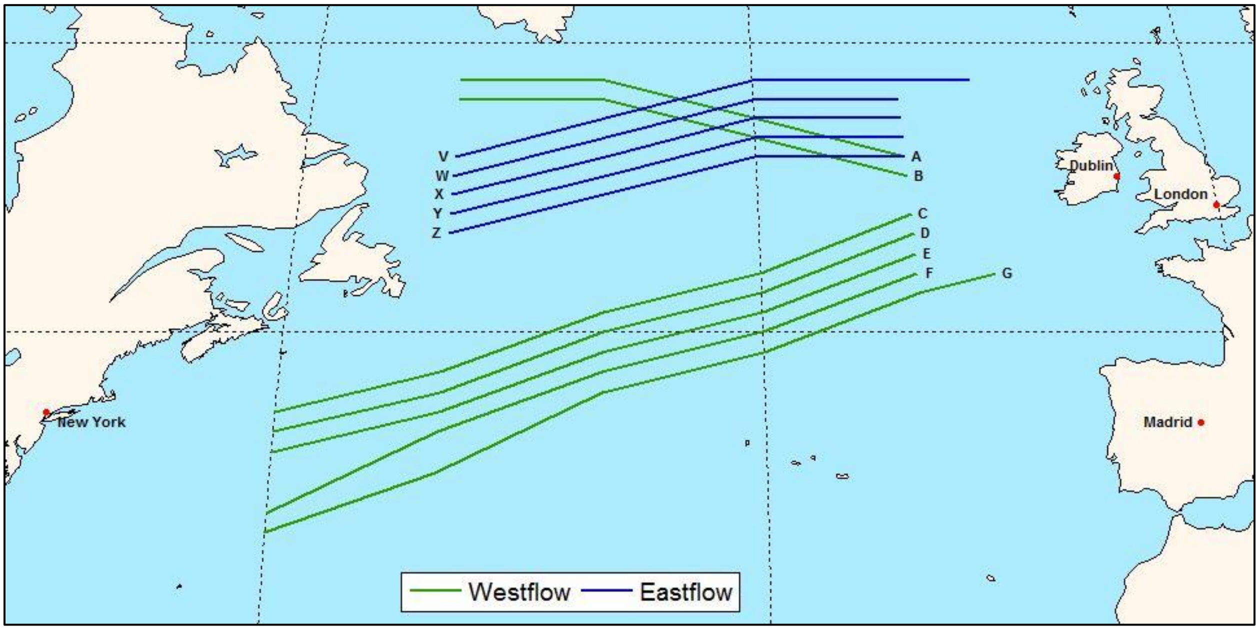

Figure 18: Sample Track Configuration from NAV Canada Data (September 08, 2014)

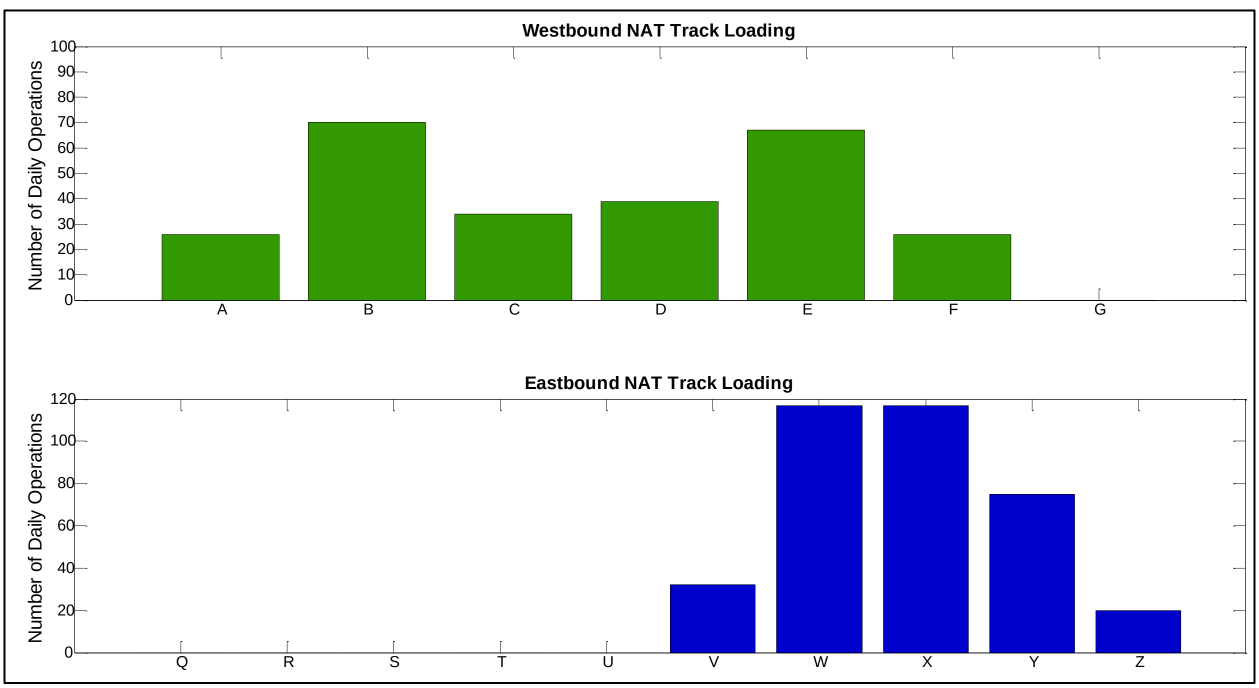

Figure 19: NAT OTS Loadings (September 08, 2014)

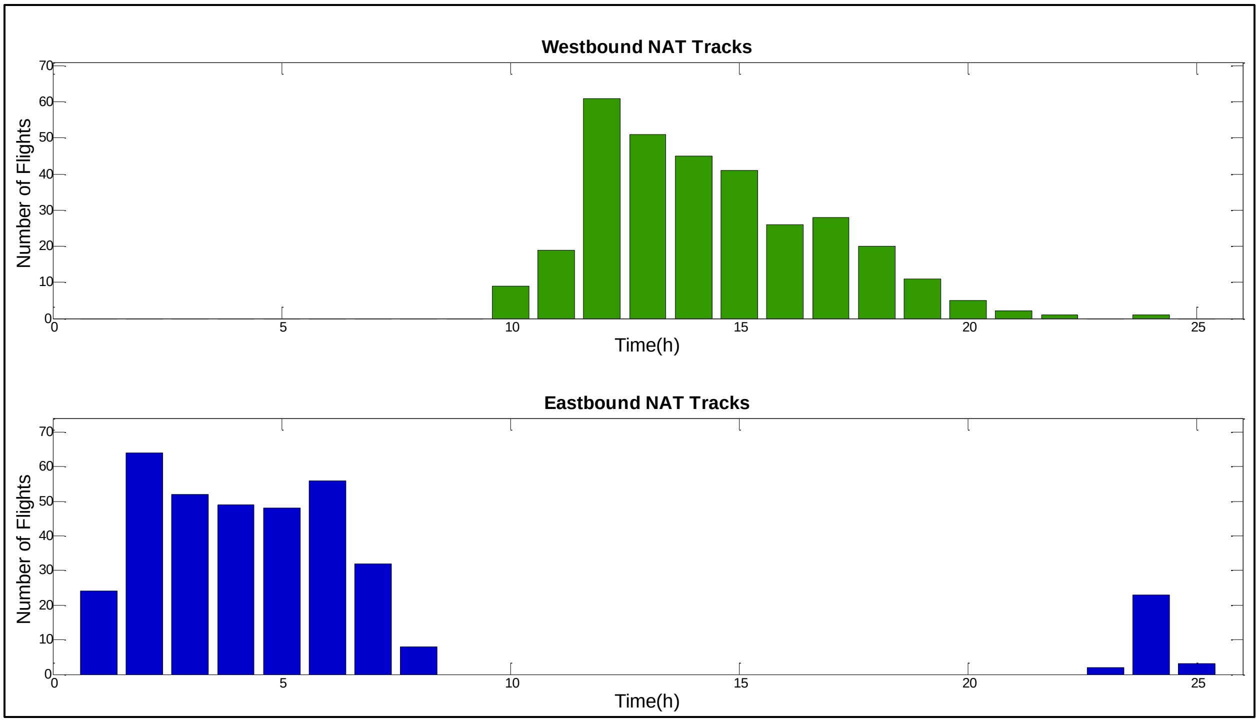

Figure 20: Temporal Distribution of Flight Entry Time in the NAT OTS (September 08, 2014)

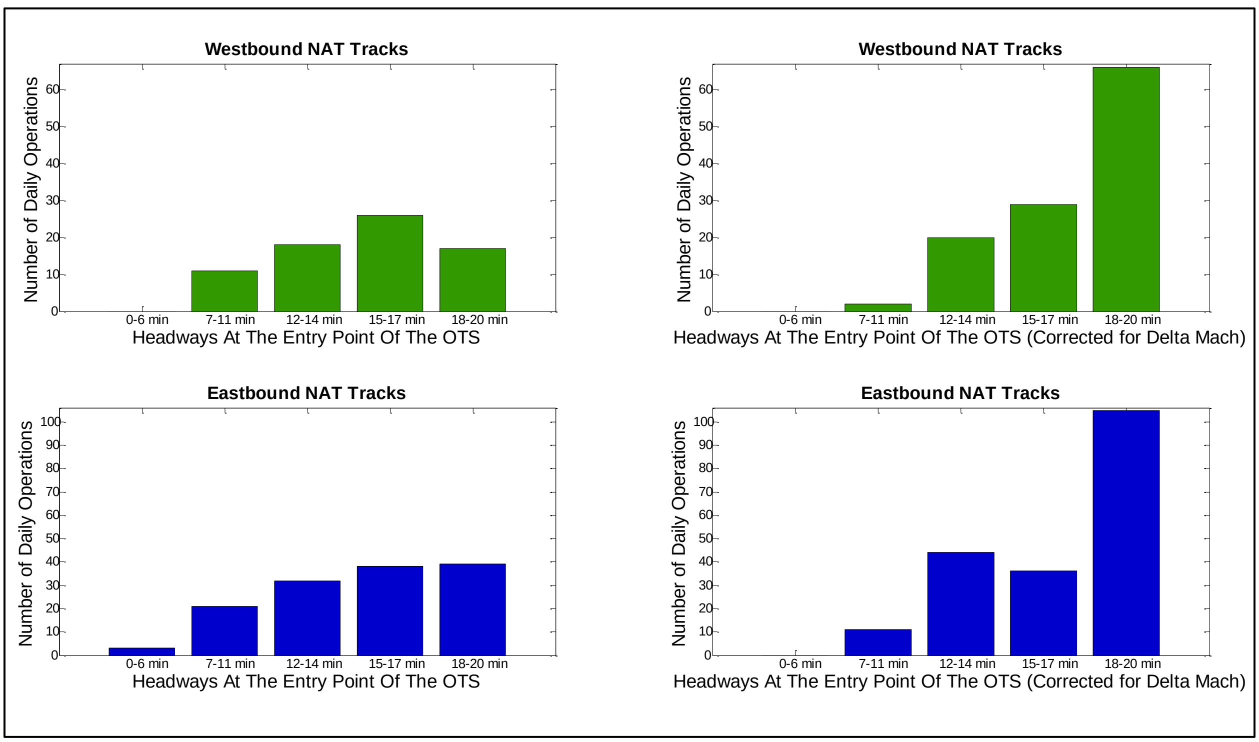

Figure 21: Headways at the Entry Point of the NAT (September 08, 2014)

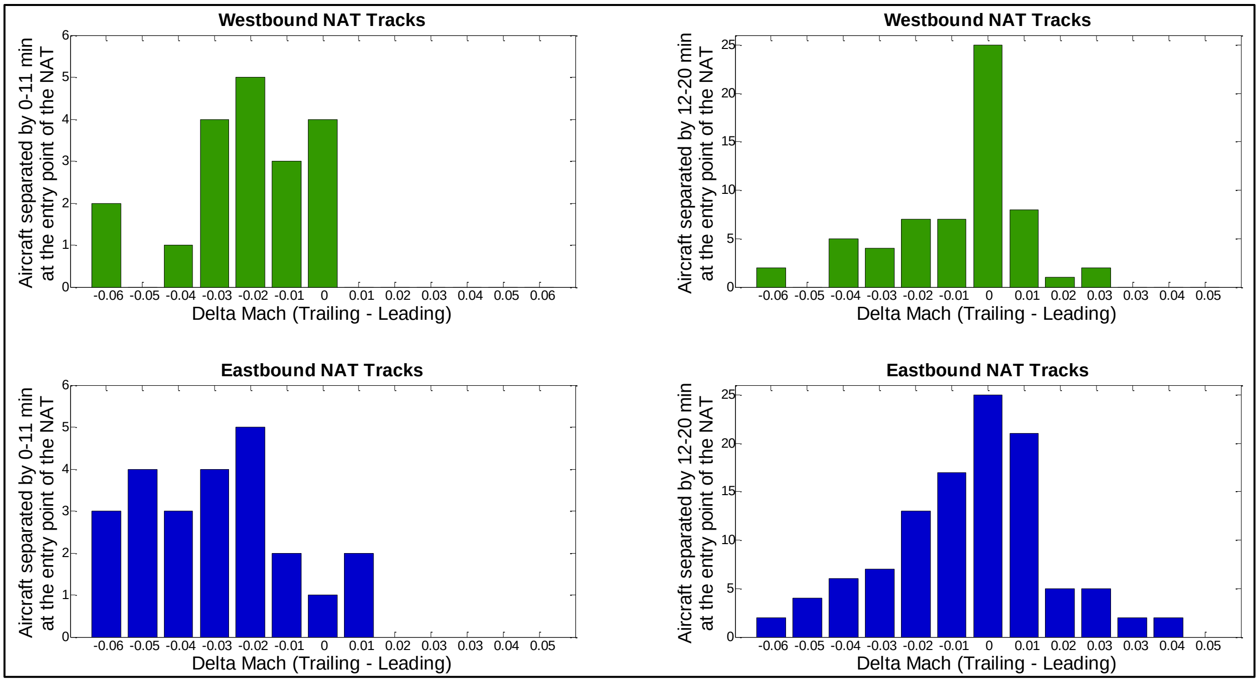

Figure 22: Delta Mach for Closely Separated Aircraft (September 08, 2014)

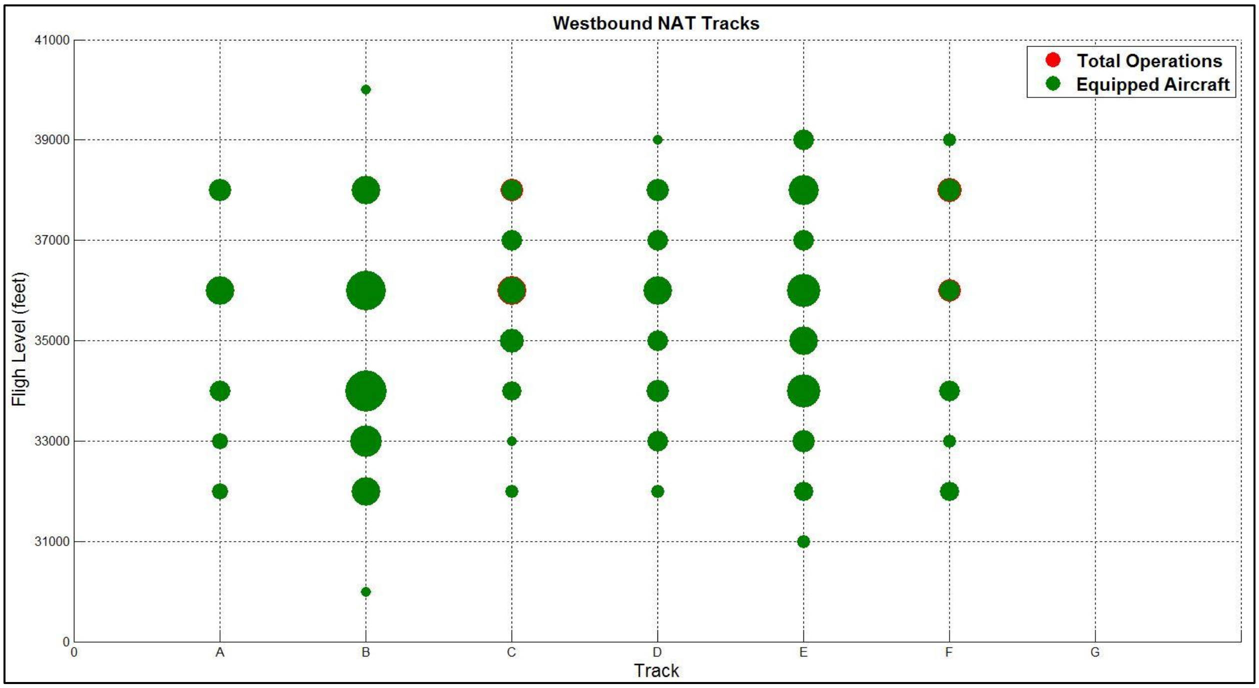

Figure 23: Equipage Rate per Track per Flight Level (Westbound September 08, 2014)

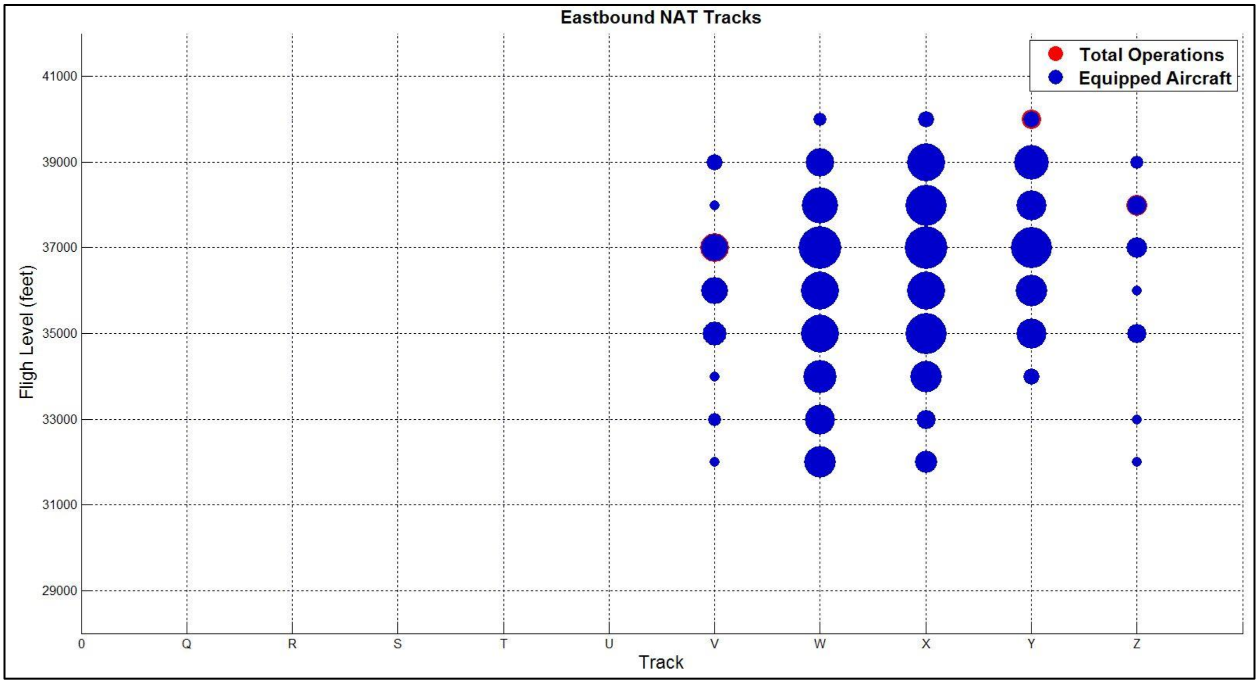

Figure 24: Equipage Rate per Track per Flight Level (Eastbound September 08, 2014)

At this point it is worth elucidating some parameters of the analysis. First of all, the headway time intervals were chosen in order to better understand the critical number of flights that are separated by 5 min or 10 min. What is more, the precision of the times reported in NAV Canada data is minutes that is why the time intervals to capture headways of 5 and 10 minutes are 0-6 and 7-11. In other words, if the true headway is 5.6 minutes then this is calculated as 6 minutes but it is very close to 5 minutes so this aircraft pair is considered as separated following the 5 minute rule.

There was need to account for speed difference when calculating headways (Figure 25 and Figure 26). Air traffic controllers modify the separation between aircraft by increasing or decreasing the headway of each successive aircraft pair based on ΔMach. According to a simple empirical rule three minutes of separation are added for each 0.01 Mach difference between successive aircraft (Equation 1).

$$H_{i,j} = T_i - T_j + 1*(V_i - V_j) \quad (1)$$

- Headway at the entry point of the OTS
- T_i = Time that trailing aircraft crosses the entry point of the OTS (minutes)
- T_j = Time that leading aircraft crosses the entry point of the OTS (minutes)
- V_i = Speed of trailing aircraft (Mach)
- V_j = Speed of leading aircraft (Mach)

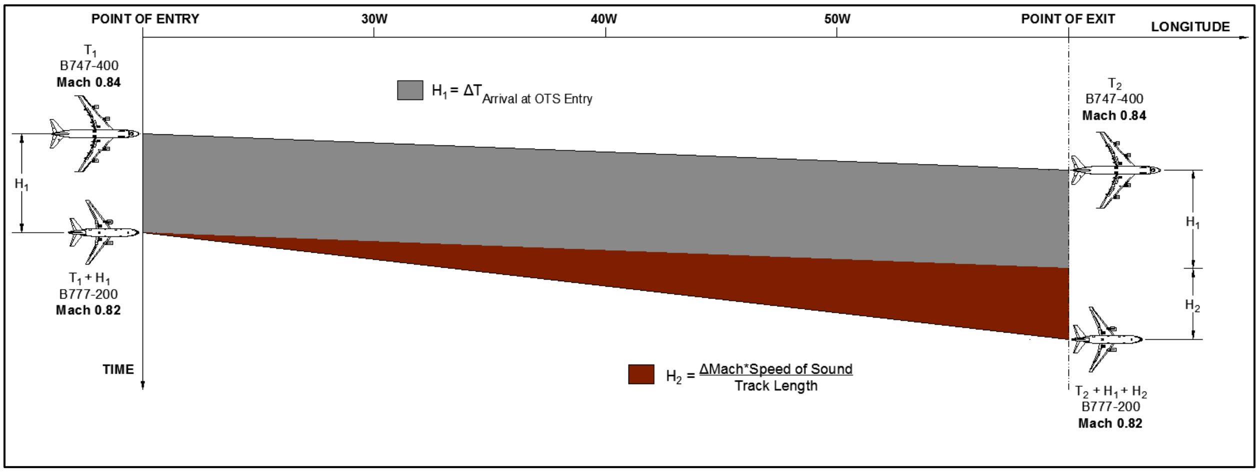

Figure 25: Headway Rules (Opening Case)

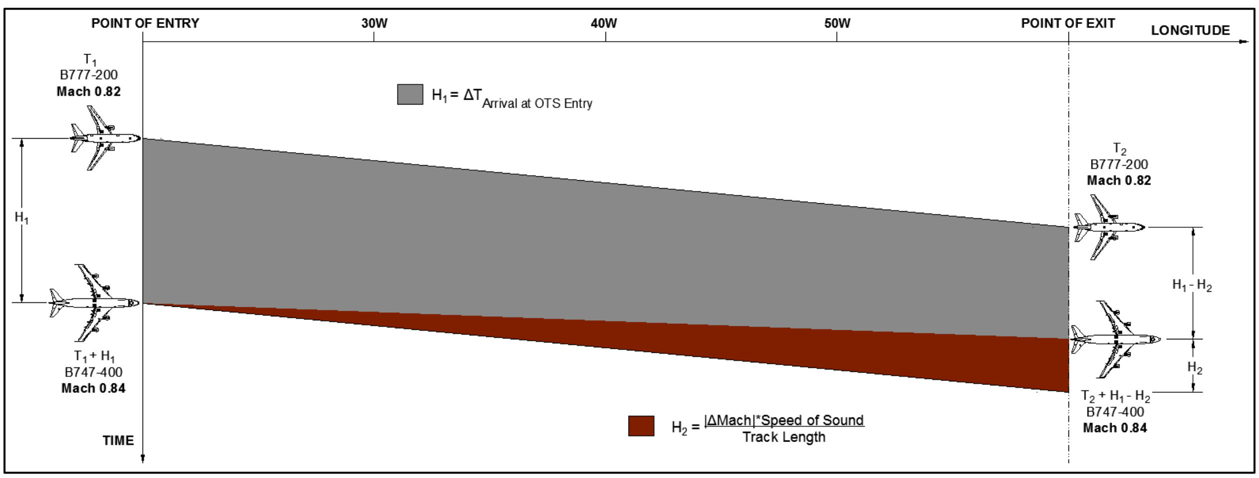

Figure 26: Headway Rules (Closing Case)

Results

Based on the results of the analysis, the Organized Track System seems to operate efficiently. There are few cases of successive aircraft separated by 10 minutes or less and even fewer separated by 5 minutes. These numbers decrease more when we account for the extra headway that is expected to be created inside the OTS due to Mach speed difference between the two aircraft. In fact, the majority of aircraft that are separated 10 minutes or less. The situation is more balanced for aircraft separated by 11-20 minutes as there is a significant number of trailing aircraft that are faster than the leading one. However, the maximum speed difference between trailing and leading does not exceed 0.04 Mach.

Furthermore, the design of the OTS is not always successful for each of the days that were analyzed. In general, the core tracks are the most wind optimal and we expect to see the majority of traffic concentrating in these tracks. In spite of that, on June 16, 2014 the core tracks were less loaded than the outboard tracks (Figure 27).

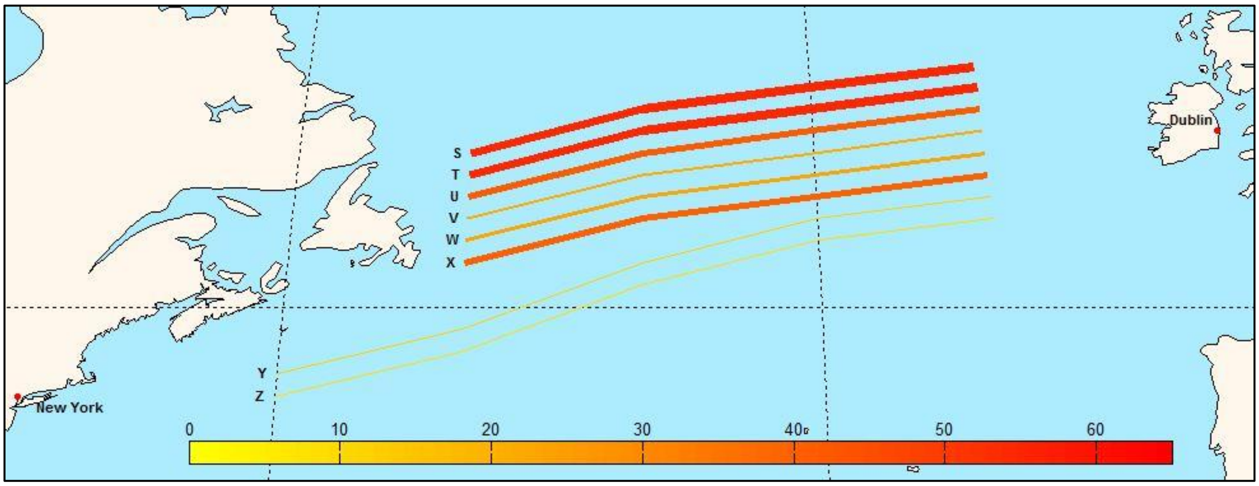

Figure 27: Core Tracks Less Loaded Than Outboard (June 16, 2014)

An important fining of this study is the management of some aircraft pairs that violate the longitudinal separation rules inside the OTS. This happens primarily because different separation criteria apply in domestic airspace or close the shore of the U.S or Europe where there is radar coverage and the oceanic airspace. It is worth mentioning that the longitudinal separation under radar coverage can be as low as 5 NM whereas in Oceanic Airspace the minimum today is 40 NM. This transition may result in separation violations in the OTS. Based on our analysis it was observed that when this occurs, the air traffic controllers decide to descend one of the conflicting aircraft for a portion of the trip in OTS in order to augment the separation. Figure 28 shows one of these cases when the separation at the entry point is 2 minutes instead of 5 minutes request to the the leading aircraft to descent at a lower flight level before returning to its optimal flight level after the distance with the trailing aircraft is greater than 5 minutes.

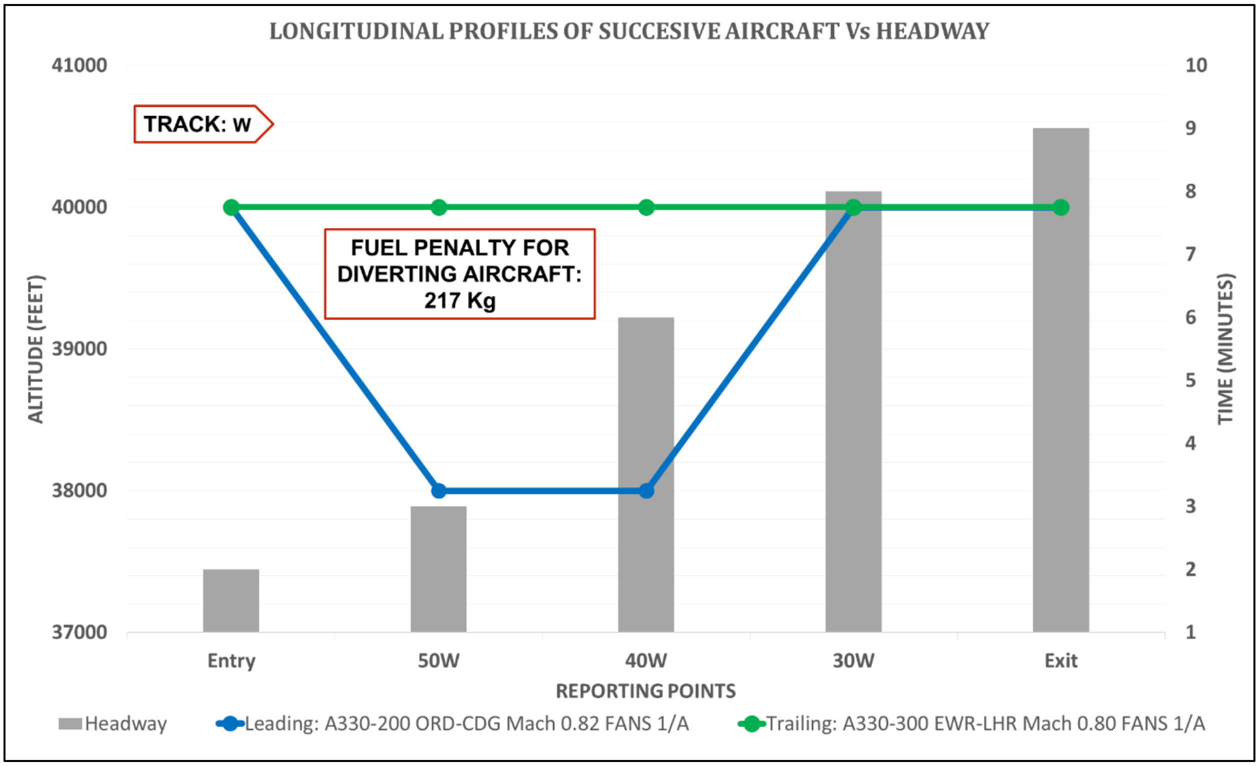

Figure 28: Conflict Resolution in OTS

CHAPTER 4 MODELING PROCESS

4.1 Global Oceanic Model

In 2012 Aswin Kumar Gunnam developed a numerical integration and simulation model called North Atlantic Simulation and Modeling (NATSAM II) to study the effects of new operational procedures in the North Atlantic Organized Track System. The flight paths adopted for modeling OTS flights were a hybrid of great circle path and OTS tracks. The model was estimating the fuel burned for each track and flight level and then it was creating a cost matrix based on which the most optimal airway was selected.

In 2014 Tao Li built a discrete-time simulation model, which updates the system every time step (ex. 5 seconds). This NATSAM III makes use of the cost matrix (NATSAM) to assign a track to each aircraft when it approaches the OTS. If the requested track and flight level are not available based on the minimum longitudinal separation inside the system, the routine tries to assign an alternative flight level below the optimal or an alternative track.

The enhanced version of NATSAM III is the Global Oceanic Model and has the ability to simulate both random and OTS oceanic flights. The model updates the position and state of each aircraft in the air every time step and checks for potential climbs for fuel efficiency or plans detours for collision avoidance. It also creates a 4-D projection of the flight path and detects conflicts. The conflict detection and resolution is performed during two stages. The first one is before the aircraft enters the oceanic airspace (strategic conflicts) and the second one (tactical conflicts) is during the traversal of the High Level Airspace (HLA).

4.2 Organized Track System Analysis and Enhancement

4.2.1 Required Navigation Performance (RNP)

Required Navigation Performance (RNP) equipment provides onboard navigation capability that allows crews to fly aircraft along a precise flight path with exceptional accuracy, and most importantly, the ability to determine aircraft position with both accuracy and integrity [12]. Before the entrance to the oceanic airspace the aircrew has the ability to select the requisite navigation ability according to the airspace. RNP 10 requires the use of two long range navigation systems and the lateral total system error which is the difference between the true position and the desired position should be less than 10 nm for 95% of the total flight time. RNP 4 also requires the use of two long range navigation systems while the lateral total system error should be less than 4 nm for 95% of the total travel time (Figure 29).

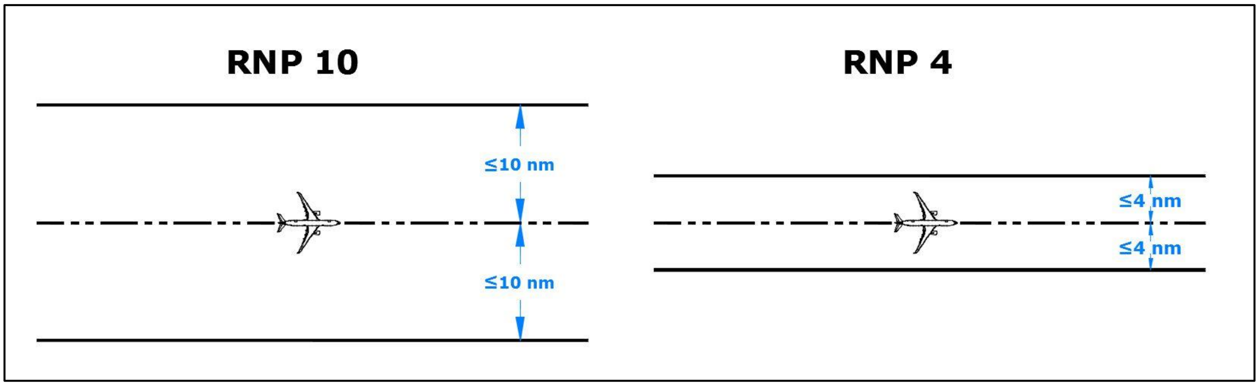

Figure 29: RNP 10 and RNP 4

4.2.2 Reduced Lateral Separation Minimum (RLatSM)

The Reduced Lateral Separation Minimum (RLatSM) is a new approach that applies 25 nm or ½ degrees lateral separation between aircraft flying in the North Atlantic OTS. Normally, aircraft flying out of radar coverage are not allowed to approach each other laterally in less than 1^{o} of latitude which is equal to 52-54 nm. The implementation of this strategy commenced on November 2015 in a portion of the North Atlantic OTS [13]. During the trial implementation (Phase 1) of RLatSM three core tracks are spaced by ½^{o} latitude while the rest of the system maintains the normal 1^{o} separation (Figure 30). The eligibility requirements for flights to use RLatSM tracks are:

a) Required navigation performance (RNP) 4 approved
b) Automated Dependent Surveillance–Contract (ADS-C) equipped
c) Controller-pilot data link communications (CPDLC) equipped

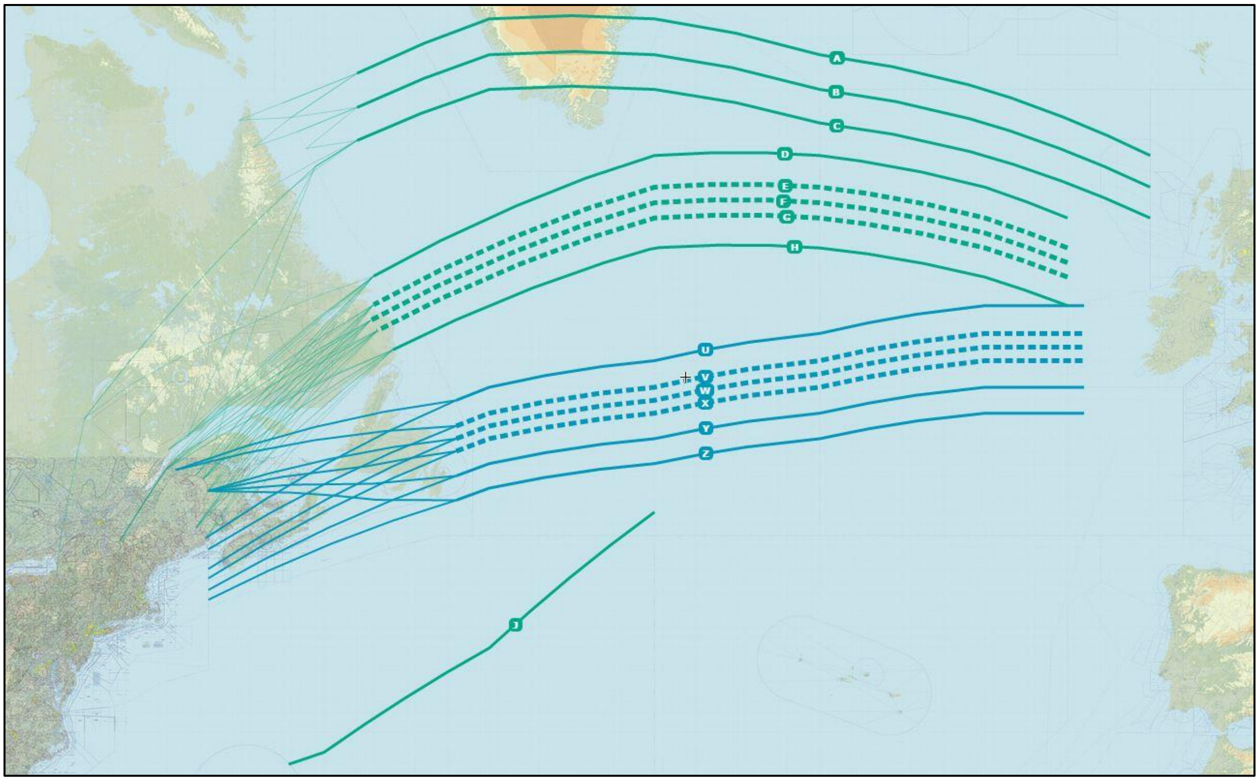

Figure 30: R.Lat.S.M. Phase 1 Trial (Skyvector: May 04, 2016)

Phase 2 is planned to commence six to twelve months after Phase 1, which will see the RLatSM be implemented in the entire Organized Track System. RLat tracks are defined between flight levels 350 to 390. The full one degree separated tracks continue to exist for all flight levels (see Figure 31).

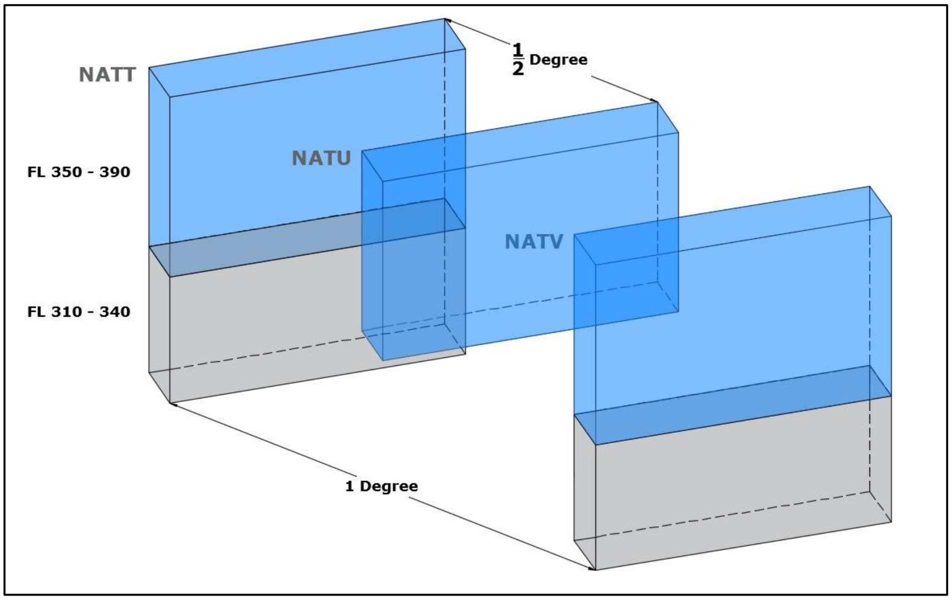

Figure 31: 3-D Representation of the Reduced Separation Minima in OTS

4.2.3 Analysis Process and Enhancement Methodology

The Organized Track System configuration for the date selected for modeling (August 15, 2014) was made available due to OTS data provided by the FAA. The data included information regarding: date, track ID, waypoints, flight levels, time period and exclusive flight levels for properly equipped aircraft. These data were analyzed in order to produce an OTS input file that will be compatible with GOM input files (Figure 32).

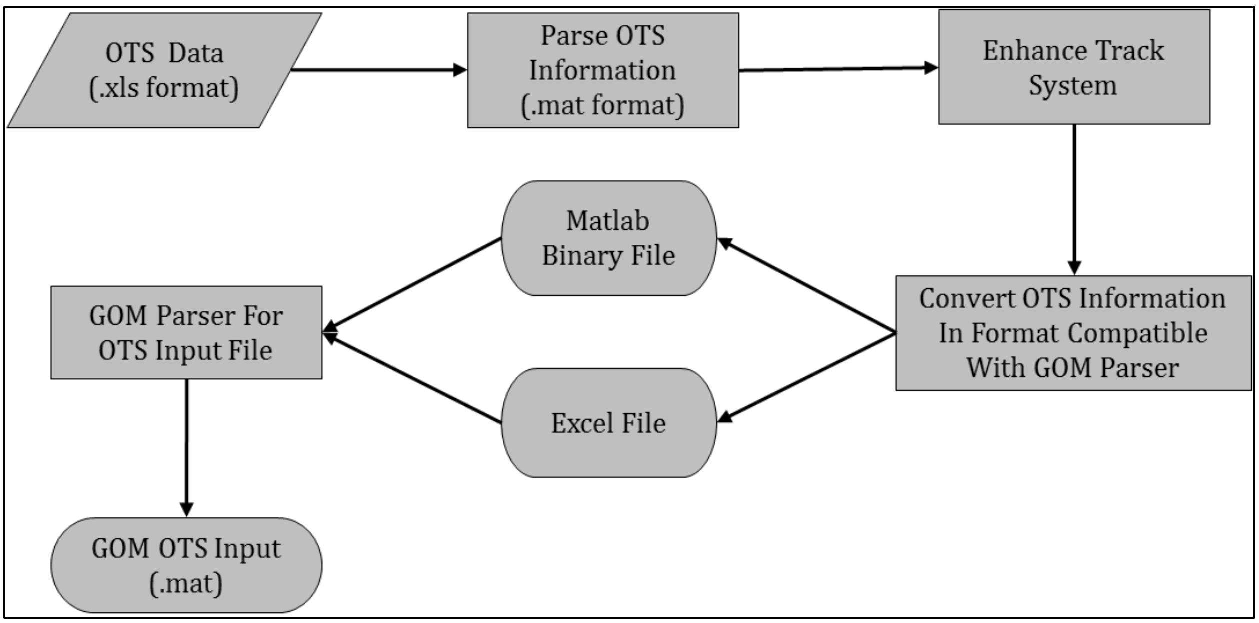

Figure 32: OTS Information Processing

The most critical part of this process was the enhancement of the Organized Track System. The phrase "Enhanced Track System" that is frequently mentioned in this study refers to a North Atlantic track system that consists of:

- Basic Configuration: 5 to 10 tracks per direction separated by 1° of latitude
- Extra Tracks Inside The Basic Configuration: One new track between every two tracks separated by 1° of latitude. The new track is separated by 0.5° of latitude from side tracks and its design is identical to those tracks.

A sample representation of an enhanced track system is shown in Figure 33.

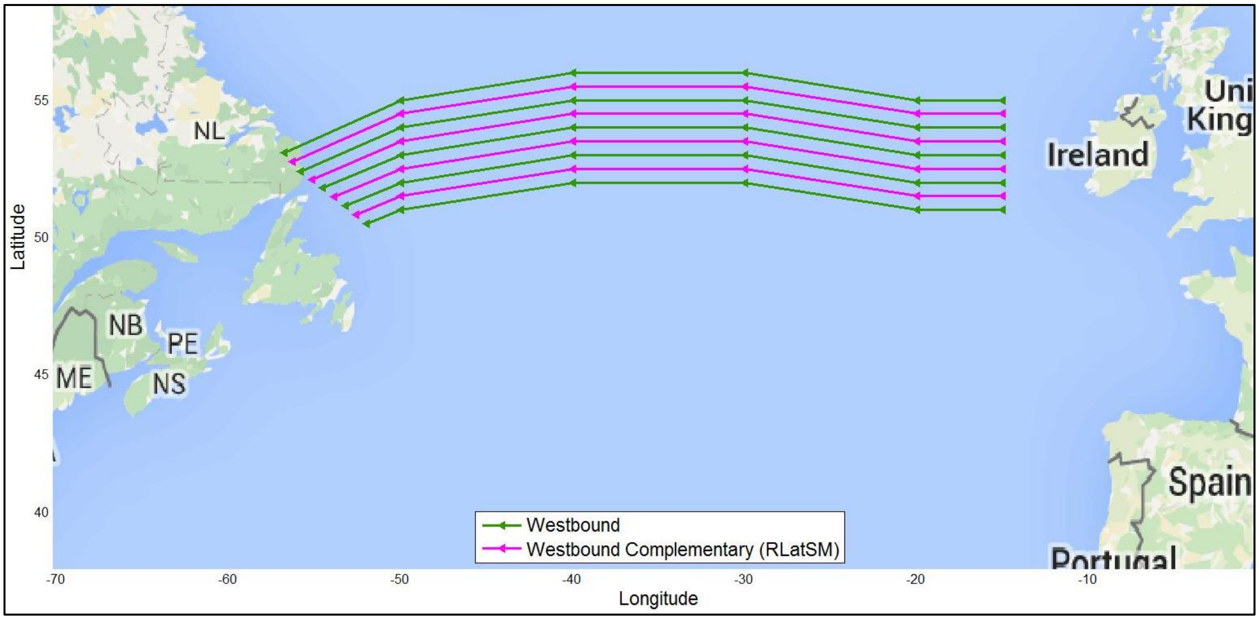

Figure 33: Westbound Enhanced Organized Track System (August 15, 2014)

The need for an enhanced OTS can be justified by the fact that usually airlines compete for the core tracks which are the most wind optimal when the track system is designed correctly (Figure 34). What is more, given the projected increase in demand in the future (Figure 7) the existing OTS may not be able to accommodate all flights while retaining a high Level of Service (LOS) during peak periods. This is the thrust of our analysis.

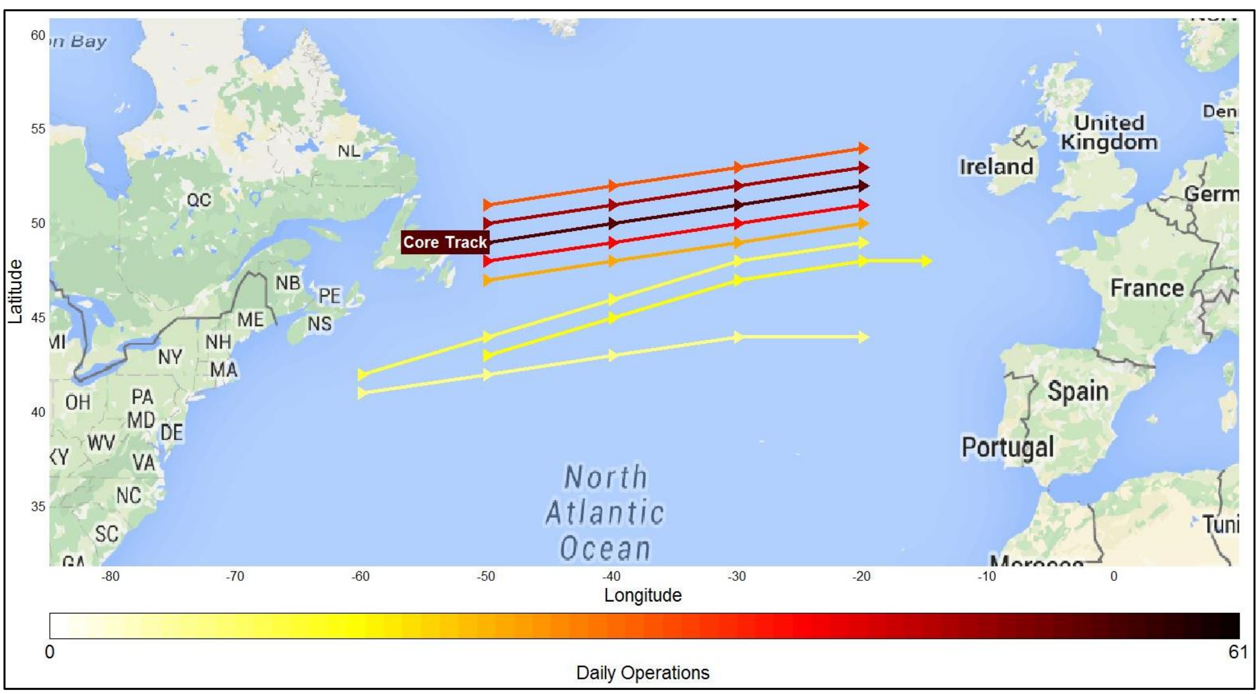

Figure 34: Eastbound OTS Loading (March 03, 2014)

4.3 OTS Assignment Algorithm

The processing of the data provided by the FAA revealed that not only some flights were missing from them but also critical information regarding the North Atlantic track requested was not reliable. What is more, there is significant difference between the OTS request information between westbound and eastbound flights. Eastbound flights have more complete flight plans in terms of number of waypoints and they present more information about the track that was filed during the flight planning process, in sharp contrast with westbound flights (Figure 35).

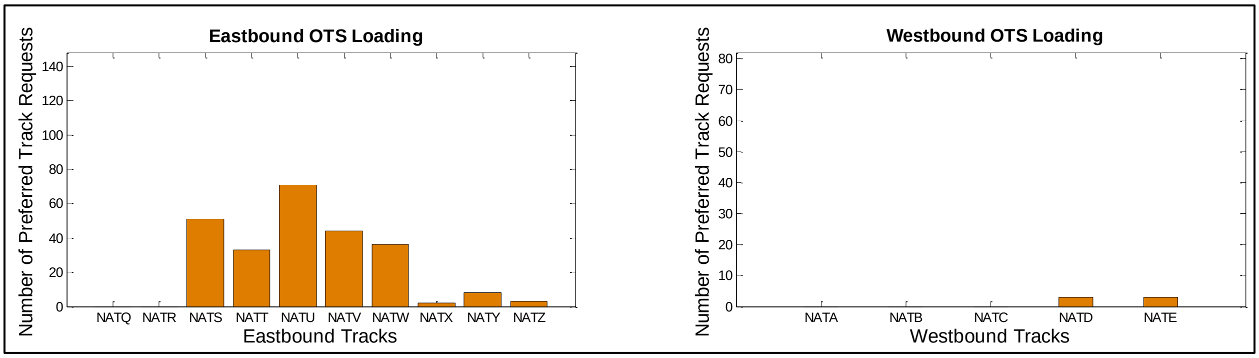

Figure 35: North Atlantic Track Request Information for TFMS Data (August 15, 2014)

Adding to this, OTS information is not available for OAG flights that were included in the demand sets following the demand shortfall analysis and harmonizing the input data for a simulation is very important in order to derive valid results. The solution to this problem was given by the use of a set of functions that can evaluate a number of flight plans (random or OTS) for each NAT flight. The output metrics include travel time and flight consumption for each route, forming the cost matrix of the flight (Figure 36). To reduce the computational time, we eliminated fuel and travel time calculations for tracks that are not likely to be used because they are distant from the filed flight plan. This is the reason why a simple rule was used to reduce the cost matrix calculations. Based on this rule, the decision for the tracks that are likely to be used is taken 250 nm before the entry point of the Organized Track System. The distances between that location of the aircraft and the entry point of each track are calculated and the five closest tracks are selected for evaluation. The other dimension of the cost matrix that needs to be constrained is the list of possible flight levels. When a requested flight level is not available air traffic controllers either ask the pilot to climb 1000 feet or descend up to 3000 feet. This logic was applied in the generation of the reduced cost matrix (Figure 37).

Fuel Consumption (Kg)	Tracks									
Flight Levels (feet)	NATQ	NATR	NATS	NATT	NATV	NATU	NATW	NATX	NATY	NATZ
39,000	77777777	77777777	77777777	77777777	77777777	55555555	55555555	55555555	55555555	55555555
38,000	77777777	77777777	77777777	77777777	77777777	55555555	55555555	55555555	55555555	55555555
37,000	77777777	77777777	77777777	77777777	77777777	55555555	55555555	55555555	55555555	55555555
36,000	75405	75094	89967	92672	94929	55555555	55555555	55555555	55555555	55555555
35,000	75893	75602	90619	93371	95662	55555555	55555555	55555555	55555555	55555555
34,000	76493	76221	91387	94188	96516	55555555	55555555	55555555	55555555	55555555
33,000	77276	77003	93218	95158	97518	55555555	55555555	55555555	55555555	55555555
32,000	78132	77858	93329	96211	98602	55555555	55555555	55555555	55555555	55555555
31,000	77777777	77777777	77777777	77777777	77777777	55555555	55555555	55555555	55555555	55555555

55555555: Big Number Assigned to Tracks Not Selected for Evaluation
77777777: Big Number Assigned to Flight Levels Not Selected for Evaluation

Figure 36: Fuel Cost Matrix for a Set of OTS Flight Plans (CVG-BRU, Boeing 744-400)

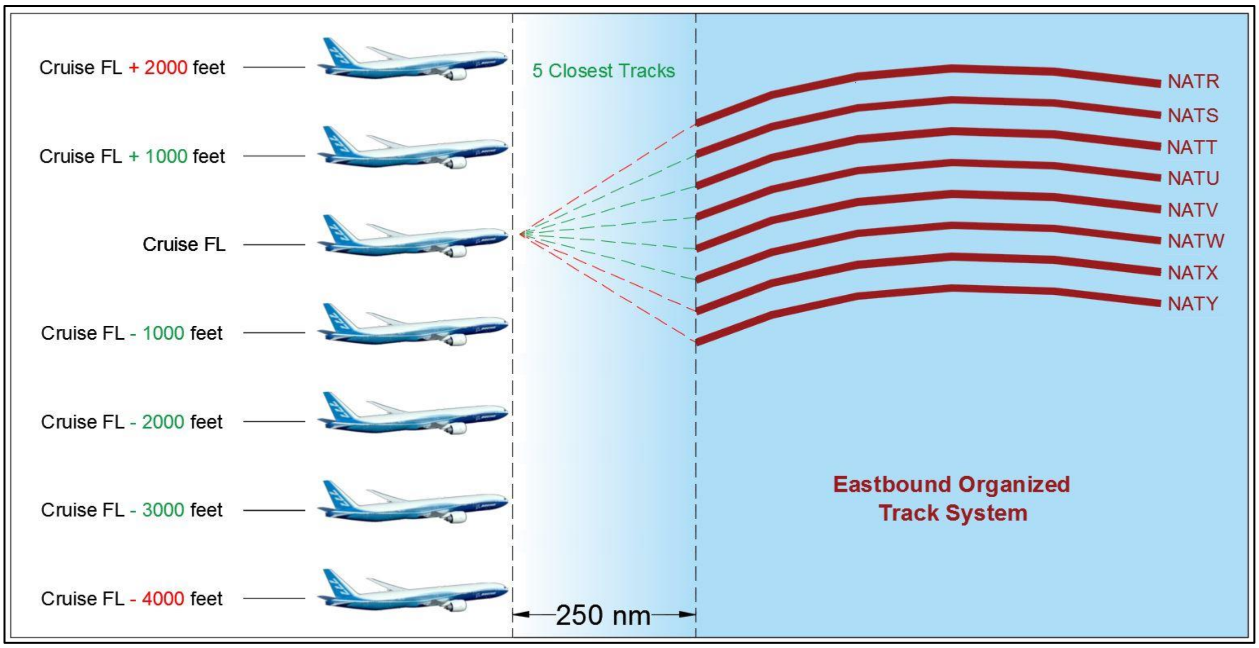

Figure 37: Reduced Cost Matrix Logic

Special attention should be given to flights whose optimal flight plan is to fly a random route (non OTS) which intersects with the OTS. The OTS assignment algorithm provides solutions to this type of problems. Firstly, it categorizes these flights into two categories:

I. Flights that intersect with the OTS over a long distance (Figure 38)
II. Flights that pierce only a small part of the OTS (Figure 39)

Secondly, it applies the most optimal solution for each case:

I. Either assign a track or descent below 30,000 feet

II. Detour or descent below 30,000 feet

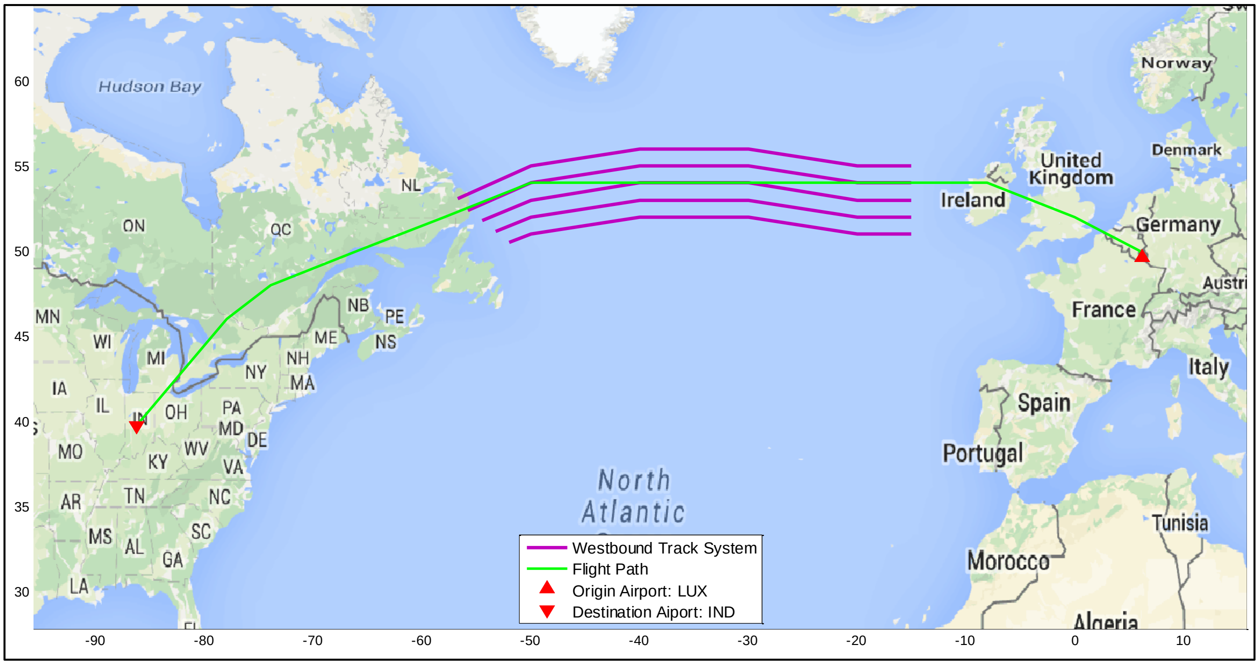

Figure 38: Random Flight That Intersect With The OTS (Case I)

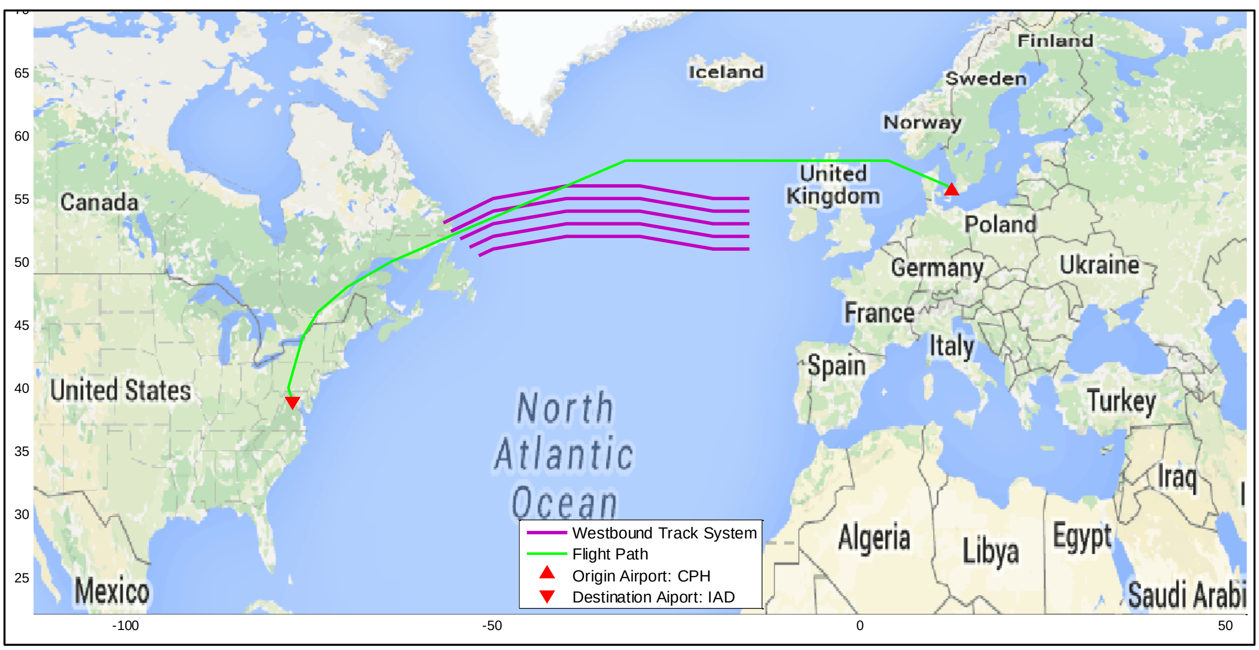

Figure 39: Random Flight That Intersect With The OTS (Case II)

The OTS assignment algorithm proved to have a positive effect on the harmonization of the data. The requested OTS level increased significantly for both eastbound and westbound tracks (Figure 40). The aggregate number of flights that use the OTS after the Cost Matrix analysis is closer to the actual number of daily traffic than it was before this analysis.

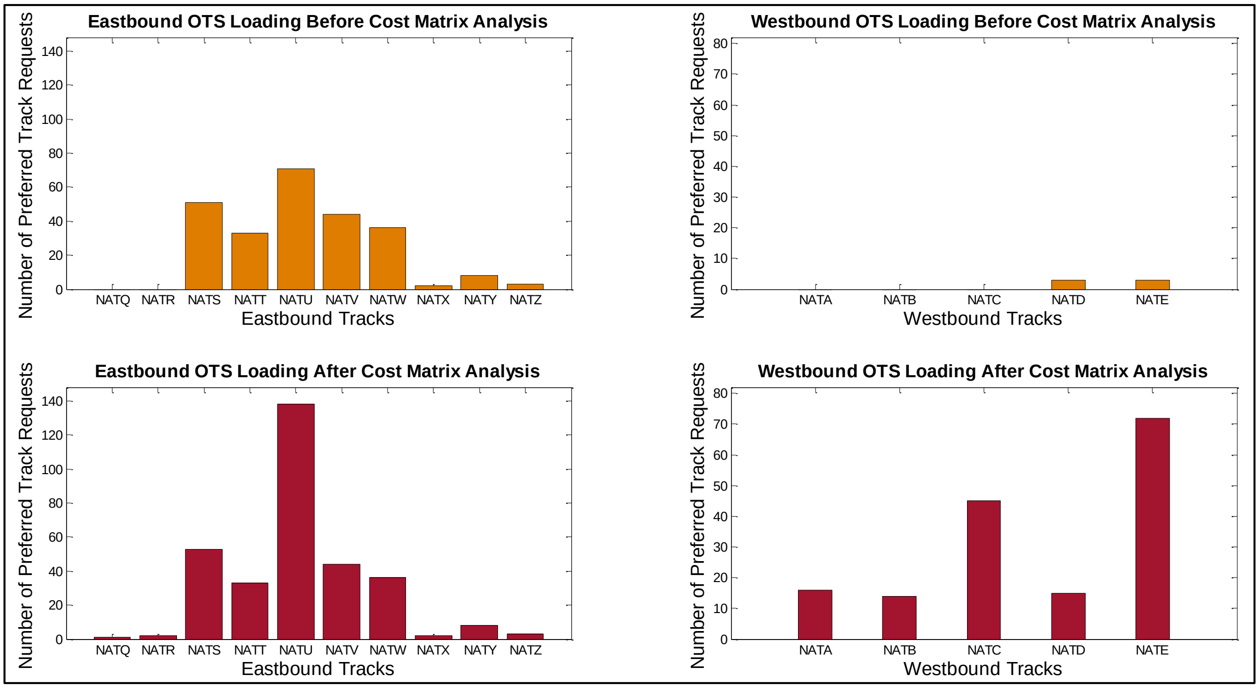

Figure 40: The Effect of The OTS Assignment Algorithm On The OTS Loadings

4.4 Analytic Climb Profile Calculation Logic for the Global Oceanic Model

The analysis of Global Oceanic Model's Matlab code proved that there was an inconsistency between the aircraft performance calculations between distinct stages of the flight. The climb profile was being calculated using a pre-calculated solution available at BADA 3.11 files while the flight segment from Top of Climb (TOC) to Top of Descend (TOD) was calculated using the aircraft performance equations. The first step of this process was the estimation of the takeoff weight as a function of the aircraft type, the trip distance, the direction of the flight and a random factor that tries to address the lack of payload information. The next step was the calculation of the cruise altitude interpolating the BADA 3.11 values. Finally, the model was estimating the fuel burned for takeoff, the duration and distance covered interpolating BADA 3.11 that have been computed for an aircraft that departs at maximum takeoff weight.

This inconsistency and the fact that the "actual" takeoff was was not used for the calculation of the climb profile, made as think that we should address this issue applying a different technique. The solution was to create a function reusing parts of other functions that had been developed in the Air Transportation Systems Laboratory, Virginia Tech. This Climb Profile function initially calculates the takeoff weight of the aircraft as a function of the aircraft type, the trip distance, the direction of the flight and a random factor. After, it interpolates BADA 3.11 values for the nominal profile to find an estimated cruise altitude. The hemispherical rules are also applicable in this analysis. Then it uses BADA 3.11 coefficients for 21 aircraft types and integrates numerically the flight path from the origin airport to the maximum flight level that the aircraft can aspire. Finally, it trims the flight path from the origin to the Top of Climb (TOC).

This technique improved the validity of the climb profile calculations of the model. The resulting profiles showed a greater stochasticity compared to the profiles calculating using simple interpolating routines (see Figure 41). What is more, the comparison of the results generated by these two methods revealed that the first approach that uses BADA interpolated solutions overestimates the fuel burned from the origin airport to the TOC. This happens mainly because the takeoff weight of the aircraft is seldom near to the maximum for all the flights (see Figure 42).

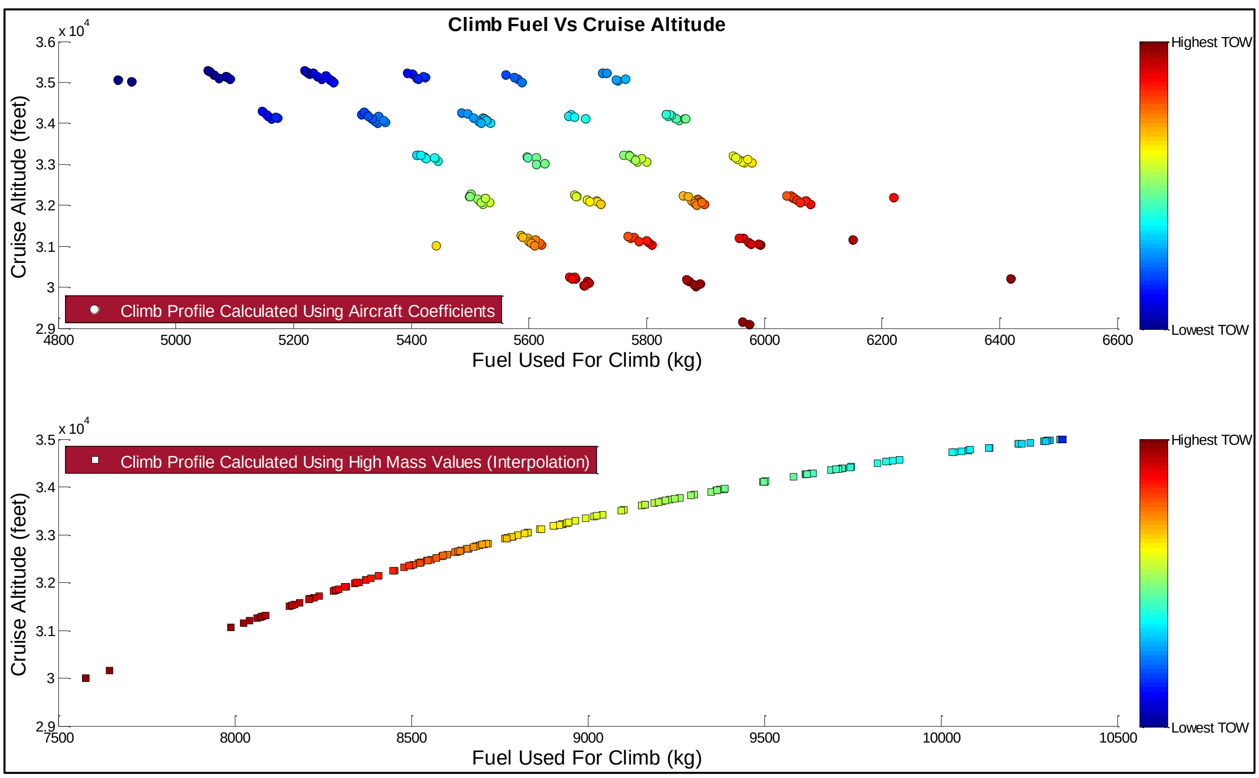

Figure 41: Comparison of Climb Profiles Generated Using Different Methods (B747-400)

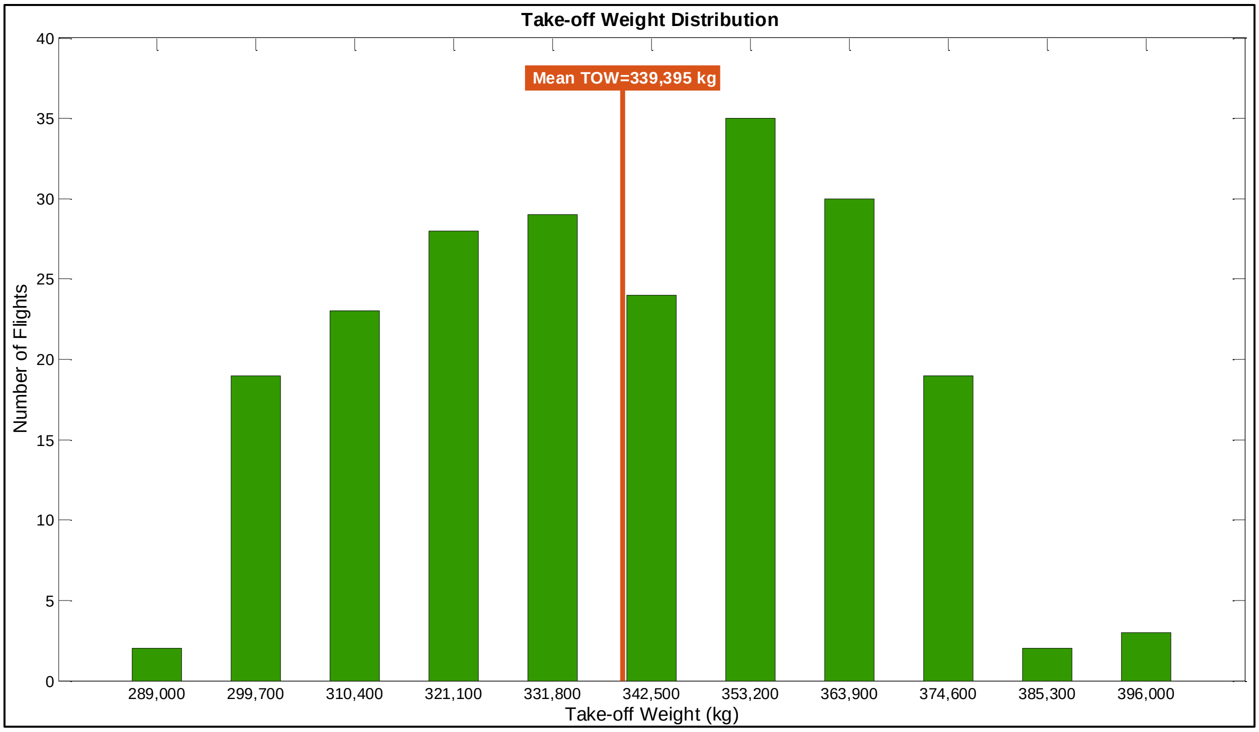

Figure 42: Takeoff Weight Distribution (B747-400)

4.5 OTS Simulation with the Global Oceanic Model

The Global Oceanic Model, as mentioned earlier, was designed to simulate all oceanic traffic, either random or organized in the daily track system. Initially, there were two separate models, one for random flights and one for OTS (NATSAM III). Running two models in parallel based on the type of flight was not a realistic method because OTS and random flights coexist in the same airspace either before the NAT High Level Airspace or inside its boundaries. The interaction between more aircraft triggers more conflicts that affect the 4-D flight paths of all flights. For this reason, the best approach was to integrate two models into one. The integration consisted of three main steps:

Step 1: Simulation of random flights

Step 2: Conflict detection and resolution for all flights inside the HLA

Step 3: Simulation of OTS flights

Step 3 of the integration process falls within the scope of the current study.

The execution of both types of flights required some modifications in the demand input files that should include information of the preferred track and flight level for OTS flights.

The takeoff weight and climb profile calculations (fuel, time, and distance) used in the simulation should be consistent with the values used in the OTS assignment algorithm so they became part of the demand input file as well.

The most critical part of this integration step was the modification of the main simulation function of the Global Oceanic Model. The routines and the methodology used in NATSAM III are the base of this process. However there was need for logical assessment of the execution of each routine and then identification of the parts of the Global Oceanic Model where these routines should be used.

All these additions resulted in an improved model in terms of the ability to simulate each flight that is included in the demand set and travels inside the High Level Airspace. On the other hand, the execution time increased given the greater complexity of calculations and the rise of conflicts inside the HLA.

4.6 Simulation Scenarios

4.6.1 High Level Airspace Operations Optimization Task Force

The Federal Aviation Administration (FAA) along with the aircraft manufacturer Boeing, CSSI[3], Massachusetts Institute of Technology and Virginia Tech formed a group for collaboration in an effort to define the most optimal way to operate the HLA in the future. Key elements of the discussion were:

- The improvement of the efficiency and the capacity of the airspace to the airspace users in terms of:
    - Fuel consumption
    - Increased payload
    - Environmental benefits
- The maintenance of the same level of safety
- The cost-benefit analysis of the proposed solutions for:
    - Air Navigation Service Providers
    - Airlines
    - Individual Users

[3] CSSI is a private company that specializes in Transportation Safety, Operations, & Systems Management

- The timelines for the implementation of the changes

4.6.2 Communication and Surveillance Capabilities over the North Atlantic

Required Communication Performance (RCP) is a metric to state the performance requirements for operational communication that support ATM functions without reference to any specific technology and is open to new technology. The RCP type is a label (e.g., RCP 240) that represents the values assigned to RCP parameters for communication transaction time, continuity, availability, and integrity [14]. The RCP value for SATCOM Controller–pilot data link communications (CPDLC) is 240 seconds. Aircraft equipped with CPDLC can be separated by 30 nm laterally and 5 minutes longitudinally. A second type of satellite based communication equipage is the CPDLC that makes use of the Iridium NEXT[4] satellite service and the Inmarsat[5] SwiftBroadband allowing for an RCP value of 60 seconds. Very few aircraft are also equipped with SATCOM Voice which has the same performance as Very High Frequency (VHF) Voice with RCP value of 10 seconds.

Required Surveillance Performance (RSP) defines system technical performance requirements independent of technology and architecture to be met by an Air Traffic Service (ATS) surveillance system in order to support a particular ATS service or function. The ADS-C[6] has an RSP value of 180 seconds and allows for separation minima to be used. ADS-B out Automatic Dependent Surveillance–Broadcast (ADS-B) is the satellite-based successor to radar. It uses GPS to determine an aircraft's location and broadcasts that information to a network of ground stations, and to nearby aircraft equipped to receive that information via ADS-B In.

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[4] Iridium uses a constellation of 66 satellites at an altitude of 780 km (450 miles) in six orbital planes, with eleven satellites in each orbital plane, providing global coverage. Additionally there are a number of spare satellites to replace any in-orbit failures.

[5] The Inmarsat network of satellites is in geostationary orbit directly above the earth equator at an altitude of 5,786 km (22,236 miles).

[6] Automatic Dependent Surveillance-Contract (ADS-C) is an Air Traffic Service (ATS) application established by contract in which aircraft automatically transmit, via data link, data derived from onboard navigation systems.

4.6.3 Strategic Alternatives for North Atlantic Operations

The HLA operations optimization task force defined a number of alternatives that should be evaluated and compared to the baseline in order to find the one that brings the highest benefit to the system (ANSP, Operators, Passengers, etc.). The factor that differentiates these alternatives is the avionics equipage of the aircraft flying in the HLA and their corresponding RCP and RSP values. These two values along with RNP are used to establish the minimum separation distances (lateral and longitudinal) for both random and OTS flights.

Baseline

The baseline scenario assumes aircraft fleet equipped with datalink (FANS 1/A) with RNP4, RCP240 and RSP180. Aircraft send position reports every 14 minutes and when they change a waypoint or deviate from the flight plan. The separation for equipped aircraft that flight the OTS is 23 nautical miles laterally and 40 nautical miles longitudinally (5 minutes with Mach number technique). For non-equipped aircraft the separation increases to 60 nautical miles laterally and 80 nautical miles longitudinally (Figure 43).

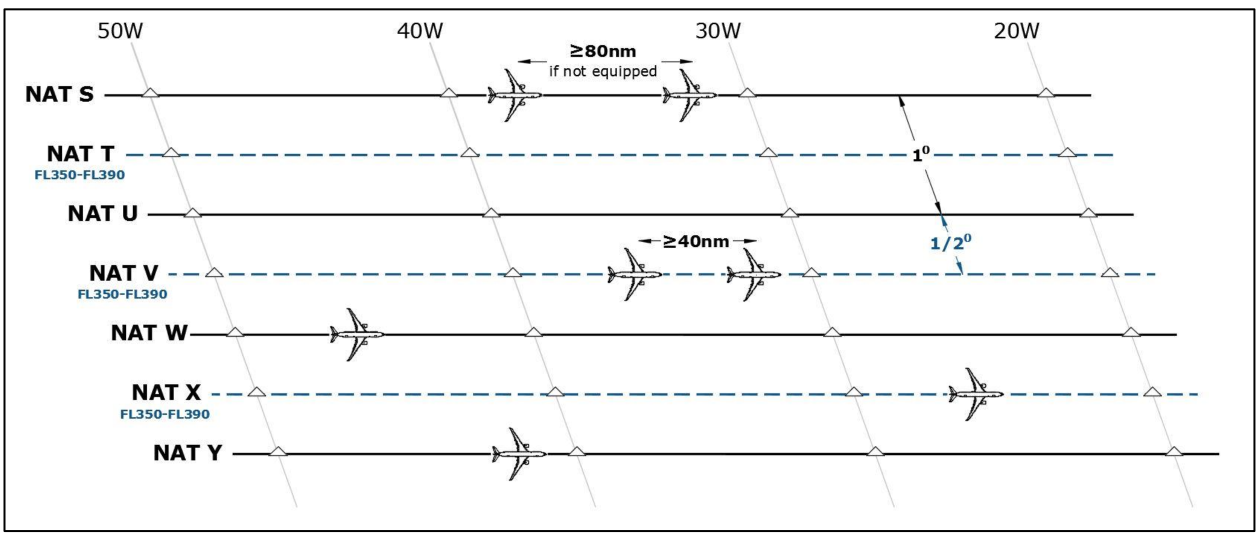

Figure 43: Baseline Scenario

Alternative 1

Alternative 1 assumes the same equipage levels as the baseline while applying the Climb/Descend Procedure (CDP). Climb/Descend Procedure (see Figure 44) is designed to improve service to properly equipped aircraft by allowing an oceanic air traffic controller to have an option for granting an altitude change request when other standard separations, such as ADS-C distance-based 30 nautical miles (NM) longitudinal separation minima, do not allow for a climb or descent through the altitude of a blocking aircraft. It is an air traffic control (ATC) tool to be applied between maneuvering and blocking aircraft pairs utilizing 15 NM or 25 NM longitudinal separation [15].

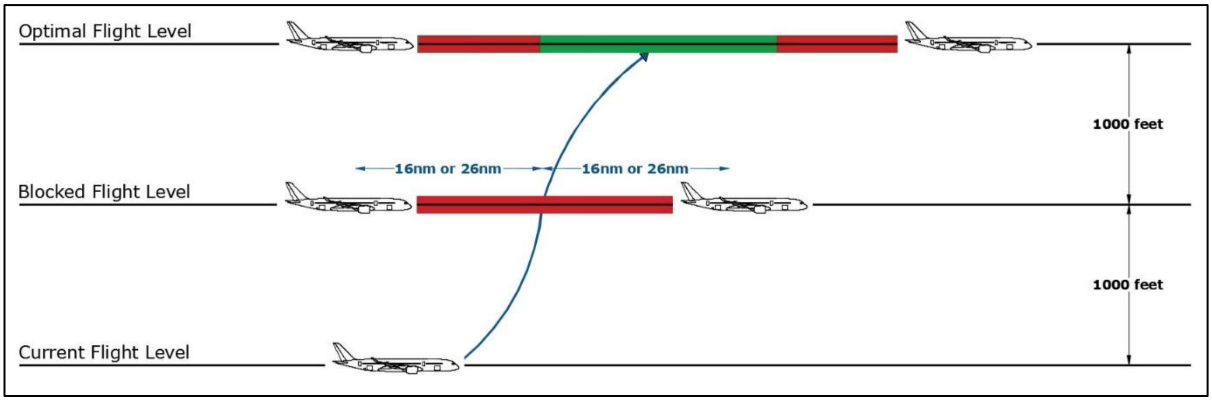

Figure 44: Climb/Descend Procedure

Alternative 2

Alternative 2 also assumes the same equipage levels as the baseline with the addition of ADS-B Out and In capabilities with RNP4, RCP240 and RSP180. These equipage levels allow the implementation of In-Trail Procedures (see Figure 45). ITP is a procedure employed by an aircraft that desires to change its flight level to a new flight level by climbing or descending in front or behind one or two aircraft on the same-track, potentially-blocking aircraft which are at an intermediate flight level [16]. In this scenario, properly equipped aircraft can be longitudinally separated by 10 nm while all users of the airspace report their position every 14 minutes.

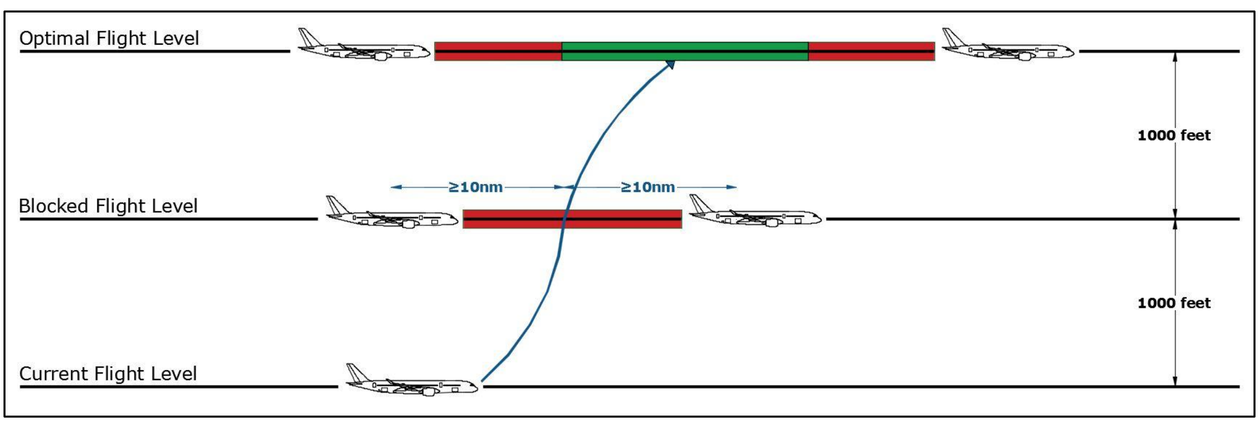

Figure 45: In-Trail Procedure

Alternative 3

Alternative 3 sees avionics equipage similar to the baseline (FANS 1/A with RNP4). This scenario assumes better communication and surveillance than the baseline, with RCP130 and RSP90. Position reporting from HLA aircraft are sent once every 64 seconds minimum plus at a time of waypoint change or deviation from the flight plan. The improved communication and surveillance suitably allows equipped aircraft to be longitudinally separated by less than 5 minutes.

Alternative 4

Alternative 4 is a slightly modified version of Alternative 3. The only difference between these scenarios is that the Required Navigation Performance (RNP) of equipped aircraft should be no greater than 2 nautical miles for 95% of the travel time.

Alternative 5

Alternative 5 concerns a completely new High Level Airspace (HLA) traffic management logic, the Pairwise Trajectory management. In this scenario aircraft are equipped with datalink (RCP≤130 and RSP180), RNP4 and ADS-B In which gives pilots the ability to know their position in relation with other aircraft in the system. The longitudinal separation can be as low as 8.5 or 6.5 nautical miles depending on geometry and flight path, which is the lowest longitudinal separation among all scenarios. Aircraft report their position once every 14 minutes (see Figure 46).

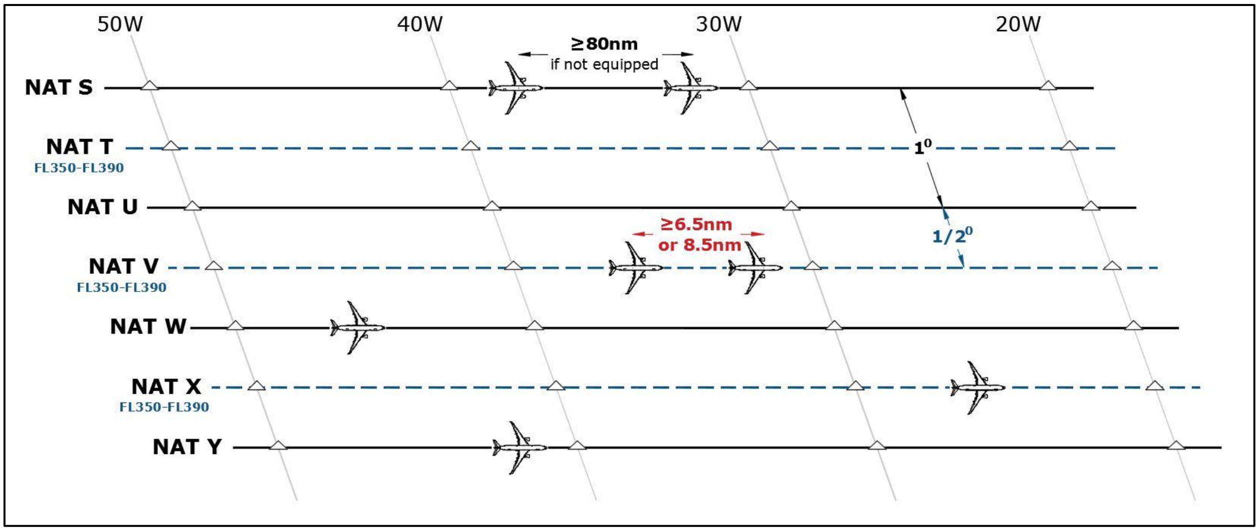

Figure 46: Pairwise Trajectory Management

Alternative 6

Alternative 6 assumes that aircraft operating in the HLA are equipped with space-based ADS-B Out and FANS 1/A with RNP4. This scenario is based on a Required Communication Performance (RCP) value of 130 seconds and a very low Required Surveillance Performance (RSP) value of 5 seconds while the Required Navigation Performance (RNP) value is 4 nautical miles. These performance characteristics can bring the lateral separation in the OTS to 23 nm and the longitudinal to 15 nautical miles (see Figure 47). The very low RSP value allows aircraft to report once every 8-15 seconds.

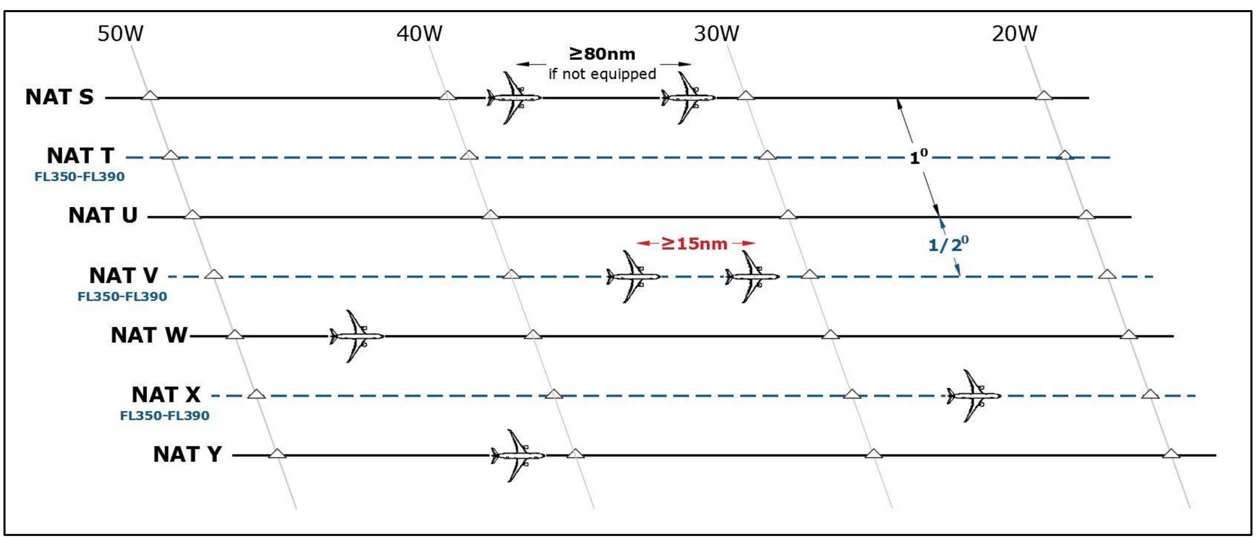

Figure 47: Space-Based ADS-B for 23/15

Alternative 7

Alternative 7 is a variation of Alternative 6. All parameters remain the same except from the RNP value that is 2 nm and the lateral separation that is 15 nautical miles, the lowest among all scenarios (see Figure 48).

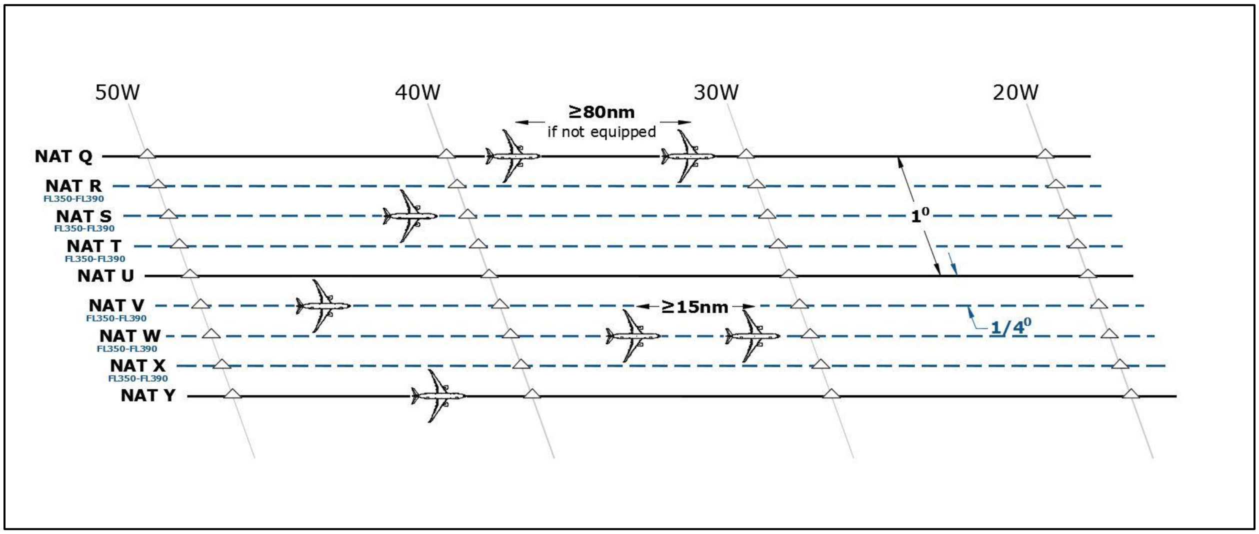

Figure 48: Space-Based ADS-B for 15/15

4.6.4 Simulation Scenarios

The simulation of all the scenarios presented above was not possible with the current version (June 2016) of the Global Oceanic Model. Two basic functions that are not part of this version of the model are the following:

- Climbs inside the Organized Track System
- Simulation of tracks separated by less than 0.5 degrees

The first of these functions prohibits the simulation of Alternative 1 and Alternative 2 while the second one prohibits the simulation of the Alternative 7.

Adding to these, the discussion on these scenarios has not finished yet. This is to say that, critical information is missing from some scenarios that should not be considered for simulation. The scenarios that fall in this category are No 3 and No 4 for which we do not know what will be the reduced longitudinal separation inside the system.

However, the current state of the model allows the user to explore more alternatives and compare with the ones proposed by the HLA operations optimization task force. For this purpose we included two new scenarios in the simulation analysis:

- **Alternative 8**: Whole degree laterally separated tracks with 10 minutes longitudinal separation between aircraft that are not properly equipped and 5 minutes minimum longitudinal separation for equipped aircraft pairs (see Figure 49).
- **Alternative 9**: Whole degree laterally separated tracks with 10 minutes longitudinal separation between aircraft that are not properly equipped and 2 minutes minimum longitudinal separation for equipped aircraft pairs (see Figure 50).

The scenarios that were simulated for the purposes of this thesis are summarized in Table 6.

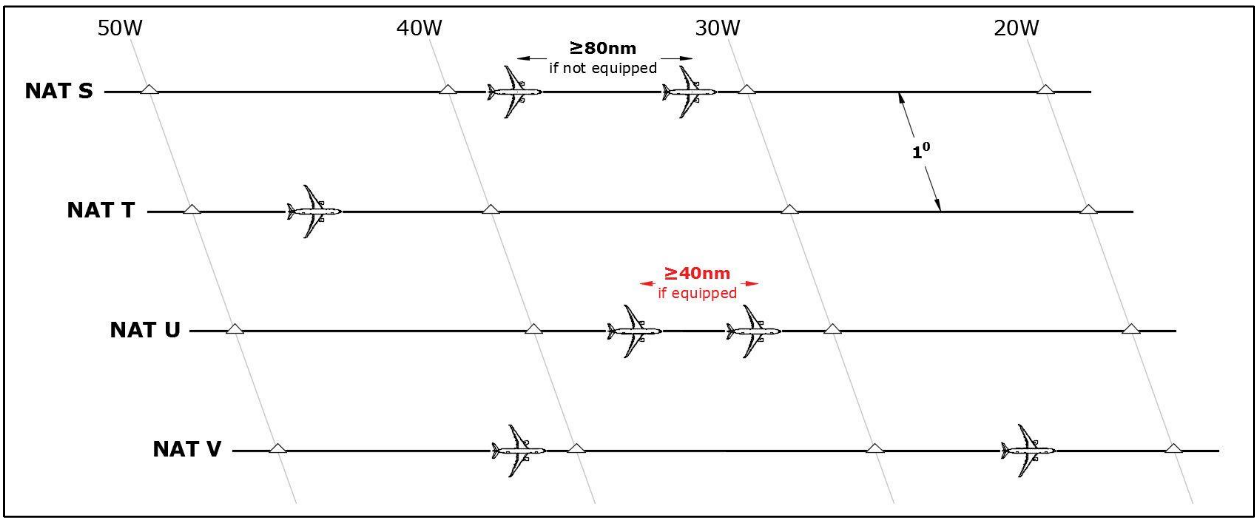

Figure 49: OTS Operations before November 2015 (Trial Implementation of RLatSM)

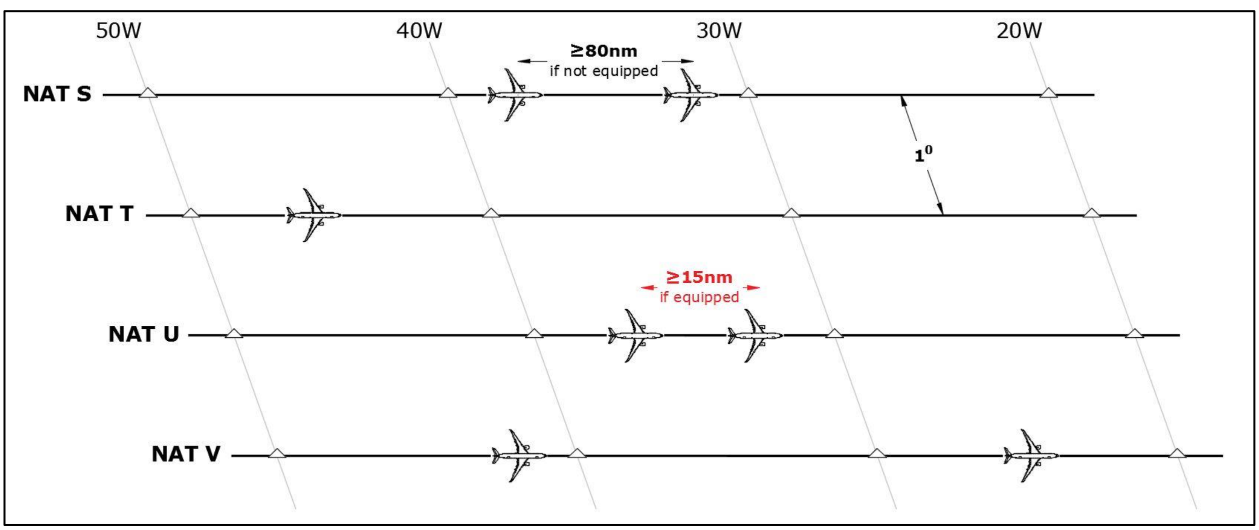

Figure 50: Whole Degree Separated Tracks with RLongSM down to 15 nm

Table 6: Simulation Scenarios

	Lateral Separation for Non-Equipped	Lateral Separation for Equipped	Minimum Longitudinal Separation for Non-Equipped	Minimum Longitudinal Separation for Equipped
Scenario 1	1 degree	1 degree	10 minutes	5 minutes
Scenario 2	1 degree	½ degree	10 minutes	5 minutes
Scenario 3	1 degree	1 degree	10 minutes	2 minutes
Scenario 4	1 degree	½ degree	10 minutes	2 minutes
Scenario 5	1 degree	½ degree	10 minutes	1 minutes

4.6.5 Simulation Parameters

The simulation for all 5 scenarios was performed using demand and OTS configuration data for August 15, 2014. The selection of the date was driven by the availability of demand data (August 15, 2014 is one of the 16 seed dates used by the FAA) and OTS data. The types of aircraft allowed to fly in each airway of the Organized Track System are defined using three parameters:

- 0: No aircraft is allowed to use this airway
- 1: Airway reserved for equipped aircraft
- 2: Every aircraft can use this airway

For the basic OTS configuration (whole degree separated tracks) these parameters were derived from the NAT Track messages of the day (see Table 7 and Table 9). For the Reduced Lateral Separation Minima (RLatSM) configuration these parameters were adjusted to reflect two basic characteristics of the RLatSM system:

- RLatSM tracks are used only between FL350 and FL390
- Tracks separated by less than 1 degree of latitude can be flown only by equipped aircraft (see Table 8 and Table 10)

Table 7: Basic Westbound OTS configuration

FL	NATA	NATB	NATC	NATD	NATE
39000	2	1	1	2	2
38000	2	1	1	2	2
37000	2	1	1	2	2
36000	2	1	1	2	2
35000	2	2	2	2	2
34000	2	2	2	2	2
33000	2	2	2	2	2
32000	2	2	2	2	2
31000	2	2	2	2	2

Table 8: RLatSM Westbound OTS Configuration

FL	NATB	NATBC	NATC	NATCD	NATD
39000	1	1	1	1	1
38000	1	1	1	1	1
37000	1	1	1	1	1
36000	1	1	1	1	1
35000	1	1	1	1	1
34000	2	0	2	0	2
33000	2	0	2	0	2
32000	2	0	2	0	2
31000	2	0	2	0	2

Table 9: Basic Eastbound OTS Configuration

FL	NATQ	NATR	NATS	NATT	NATU	NATV	NATW	NATX	NATY	NATZ
39000	2	2	2	1	1	2	2	2	0	2
38000	0	0	2	1	1	2	2	2	0	2
37000	0	0	2	1	1	2	2	2	2	0
36000	2	2	2	1	1	2	0	0	0	0
35000	2	2	2	2	2	2	2	2	2	0
34000	2	2	2	2	2	2	2	2	0	2
33000	0	0	2	2	2	2	2	2	2	0
32000	2	2	2	2	2	2	2	2	0	2
31000	0	0	0	0	0	0	0	0	0	0

Table 10: RLatSM Eastbound OTS Configuration

FL	NATQ	NATR	NATT	NATU	NATV	NATX	NATY	NATZ	NATQR	NATTU	NATUV	NATWX
39000	1	1	1	1	1	1	0	2	1	1	1	1
38000	1	1	1	1	1	1	0	2	1	1	1	1
37000	1	1	1	1	1	1	2	0	1	1	1	1
36000	1	1	1	1	1	0	0	0	1	1	1	1
35000	1	1	1	1	1	1	2	0	1	1	1	1
34000	2	2	2	2	2	2	0	2	0	0	0	0
33000	0	0	2	2	2	2	2	0	0	0	0	0
32000	2	2	2	2	2	2	0	2	0	0	0	0
31000	0	0	0	0	0	0	0	0	0	0	0	0

CHAPTER 5 RESULTS

5.1 Systematic Errors

All the results presented here were prepared for the purpose of this thesis using a version of the model that has not been validated and as a result there are errors in the calculations. The main parts of the current version of the Global Oceanic Model that have not been refined yet are the following:

- The track assignment algorithm that is responsible for assigning the best most fuel efficient route from a list of alternatives that contain a random route and OTS routes.
- The part of the simulation that is responsible for simulating and de-conflicting the Organized Track System flights.

It was not possible to address these systematic errors in the time frame of completeness of this study. Taking this into account, the results presented in this section are preliminary and cannot be used to extract valid conclusions of the operations in the North Atlantic.

5.2 Preliminary OTS Performance Metrics

5.2.1 Fuel and GHG Benefits

The five scenarios presented in section 4.6.4 were simulated using Matlab version 2015b in a 64-bit desktop computer. The simulation time of each scenario was about 2.5 hours. Table 11 presents the execution time of each main routine of the model. However, not all the routines are executed in each different scenario. This happens because the system has the ability to skip these routines (OTS Processing, Wind Processing, Demand Preprocessing) if specific input files exist.

The simulation time is substantial high because we simulate three days of demand for each run. Every demand set is cloned two times, one of which is used to warm up the system and the second one to give time to every flight of the middle day to land before we complete the simulation.

Table 11: Global Oceanic Model Execution Time per Routine

G.O.M Routine	Typical Execution Time (seconds)
OTS_Processor	11
Wind_Processor	65
Demand_Preprocessor	2012
Demand_Processor_I	95
Demand_Processor_II	843
FlightOpers_Simulator	5860
Total	8886

The performance of the system can be assessed using various metrics. The primary approach is the calculation of the average fuel consumption and Green House Gas (GHG) emission of each scenario and the comparison to the baseline scenario. These numbers should be converted to monetary values in order to be used in an extended analysis of the Net Present Value (NPV) or the Return on Investment (ROI) of the investments required to achieve the minimum performance requirements of the proposed scenarios.

The cost of jet fuel is directly connected to the oscillations of the oil price in the global market. This implies that any NPV analysis of the system involves some uncertainty due to jet fuel cost. Apart from that, the GHG cost is not defined in concrete. It is worth mentioning that there are five common types of carbon prices [17]:

1. Carbon tax: A carbon tax also internalizes the externality of carbon pollution, but instead of selling or giving away rights to pollute (the allowance approach), a carbon tax creates an obligation for firms to pay a fee for each unit of carbon that they emit.
2. Effective price of carbon: Carbon allowances and carbon taxes internalize the climate change externality by making polluters pay.
3. Marginal abatement cost of carbon: An abatement cost refers to an estimate of the expected cost of reducing emissions of a particular pollutant.

4. Average policy cost versus marginal abatement cost: Many policy analyses compare the total benefits of a policy to the total costs—this represents the net cost (or benefit) of the policy.
5. Social cost of carbon: The social cost of carbon is the societal cost of current and future damages related to climate change resulting from the emission of one additional unit of pollutant.

The conversion of fuel consumption calculated using the GOM to dollar values was performed based on the current world average jet fuel price that is equal to 465.9$/ton [18]. On average one kilogram of jet fuel accounts for 3.3125 kg of GHG that could be valued as 35$/ton. Figure 51 presents the annual fuel and GHG benefits per scenario compared to the baseline scenario. Based on the results, the reduction of longitudinal separation down to 1 minute for equipped aircraft pairs and the lateral separation down to 0.5 degrees will save around 15 million of dollars for the system. This number might be the higher calculated among all scenarios but it is less than 0.1 percent of the total fuel and GHG annual cost for the system.

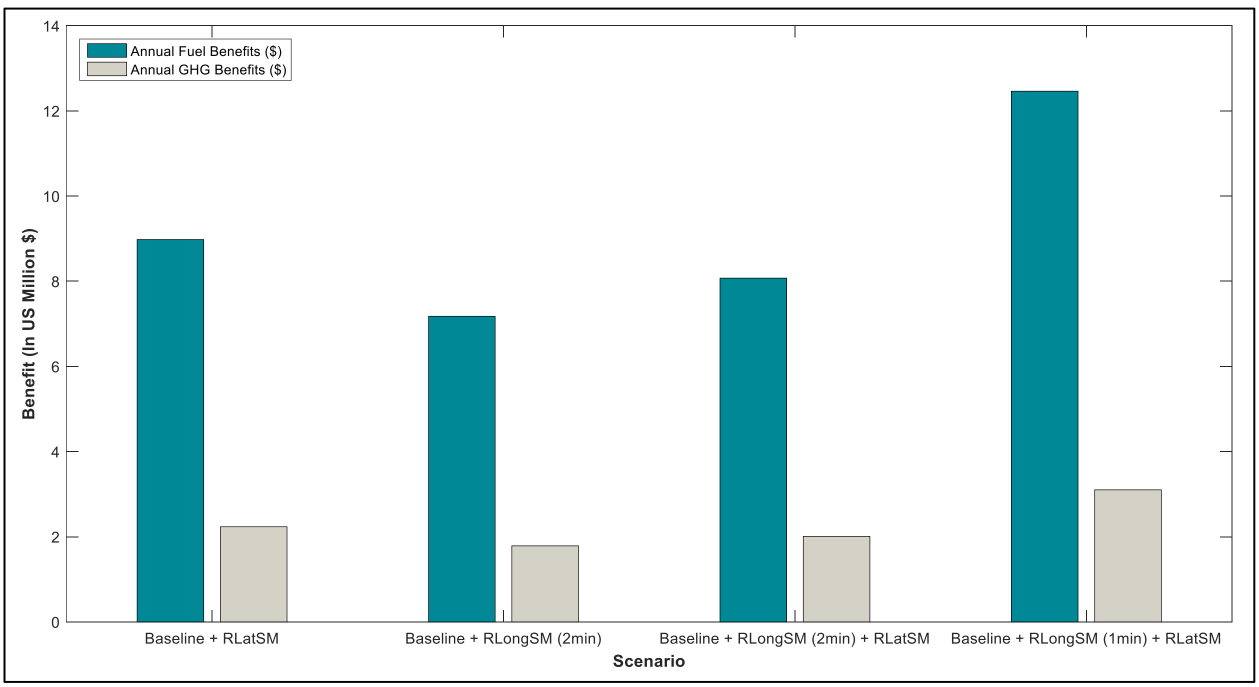

Figure 51: Annual Fuel and Green House Gas Emission Benefits

5.2.2 Level of Service (LOS)

Another important metric regarding the Organized Track System performance is the Level of Service (LOS). The LOS is the percent of flights that were assigned the track and flight level that they requested. Figure 52 shows the effect of reduced separation in the Level of Service. However, these results are not valid due to the systematic and random errors that still exist in the system. For instance, the successful flight level assignment is 100% and the successful track assignment is greater than 98% through all scenarios. Both of these indicators are not realistic.

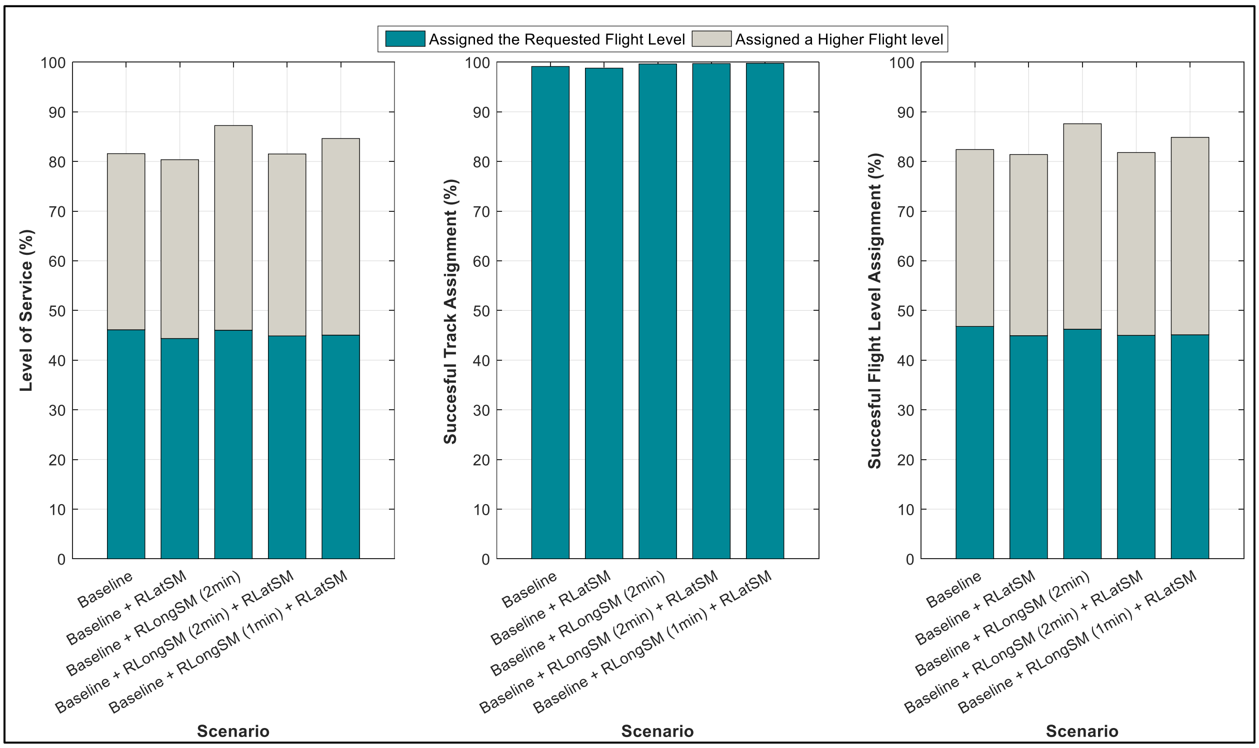

Figure 52: Organized Track System Level of Service

Figure 53 illustrates how close is the alternative track assigned to flights whose optimal track was reserved. This figure contains some anomalies as well because it shows that when we applied Reduced Longitudinal Separations down to 2 minutes then the percent of flights that were assigned the second closest track increased substantially compared to the baseline.

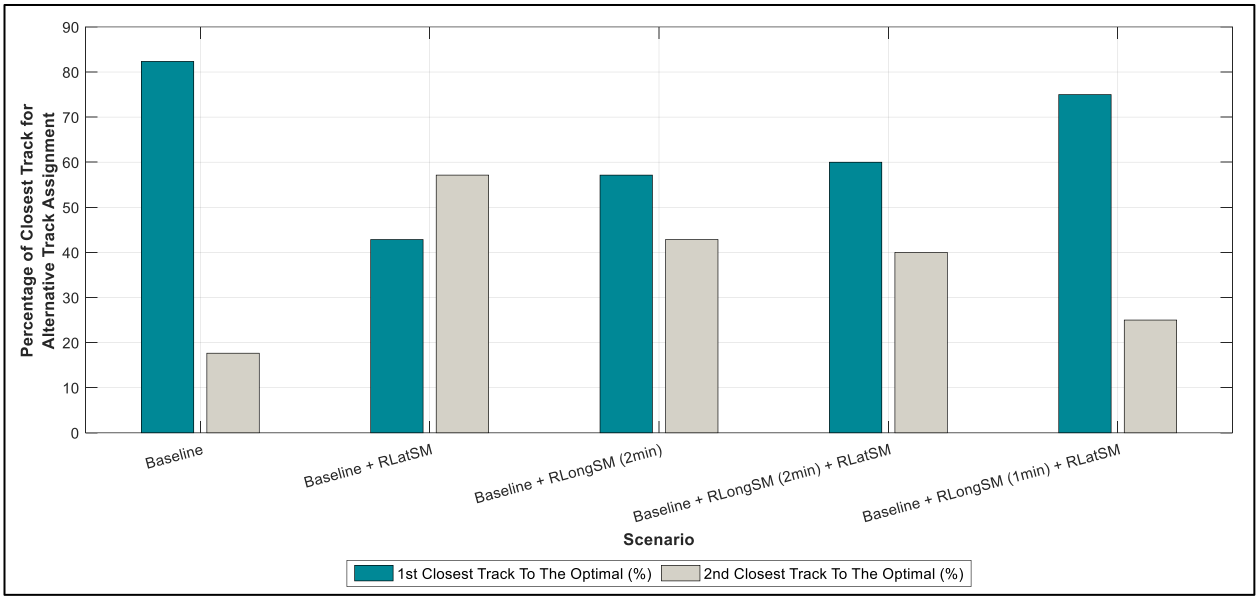

Figure 53: Alternative Track Assignment Analysis

A similar analysis was performed for flights that were not assigned the flights level that they requested (see Figure 54). All scenarios were simulated allowing aircraft to climb one thousand feet or descent up to five thousand feet when the requested flight level was not available. The analysis proves that the application of Reduced Lateral Separations allows aircraft to stay within three thousand feet from their optimal flight level. What is more, the reduction of longitudinal separations down to 2 min for equipped aircraft gives the opportunity for more aircraft to choose an alternative flight level that is closer to their optimal. Another important detail of this figure is that the highest bar is always the one that refers to aircraft that climb one thousand feet above their optimal flight level. This happens because this is the first flight level that the algorithm checks when the optimal is reserved.

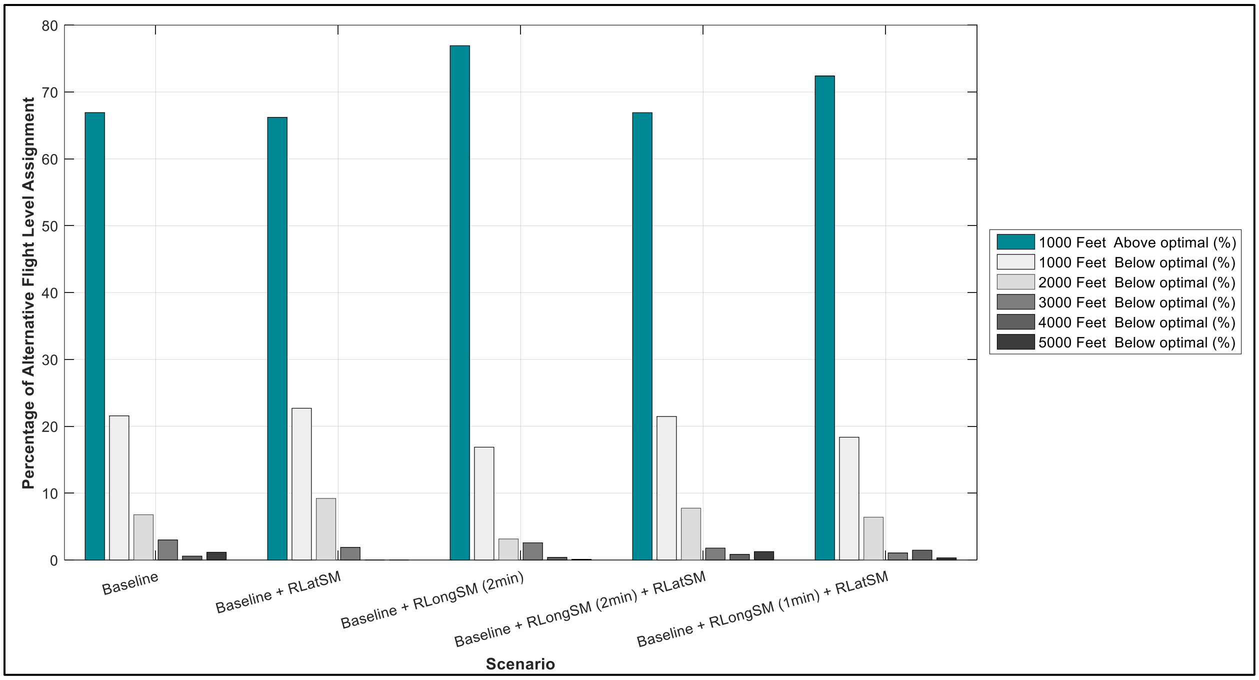

Figure 54: Alternative Flight Level Assignment Analysis

5.3 The Effect of Reduced Lateral Separations in the Organized Track System

The reduction of the lateral separation in the OTS has creates modifies the track system in two ways:

- Reduces the space reserved in the North Atlantic for the Organized Track System
- Reduces the capacity of the Organized Track System. For instance, looking at Table 7 and Table 8 the basic system offers 45 airways to accommodate the traffic whereas the RLatSM system offers 37 airways.

The reduction of the space reserved for the OTS will allow more flights to follow random flight paths. We simulated and we identified flights that used the OTS (mostly outer tracks) in the baseline and they changed to random when we applied the RLatSM. Figure 55 shows the difference of fuel consumption for these flights. However, we cannot derive safe conclusions from this chart because there are outliners like flights with bad filed flight plan data (see Figure 56).

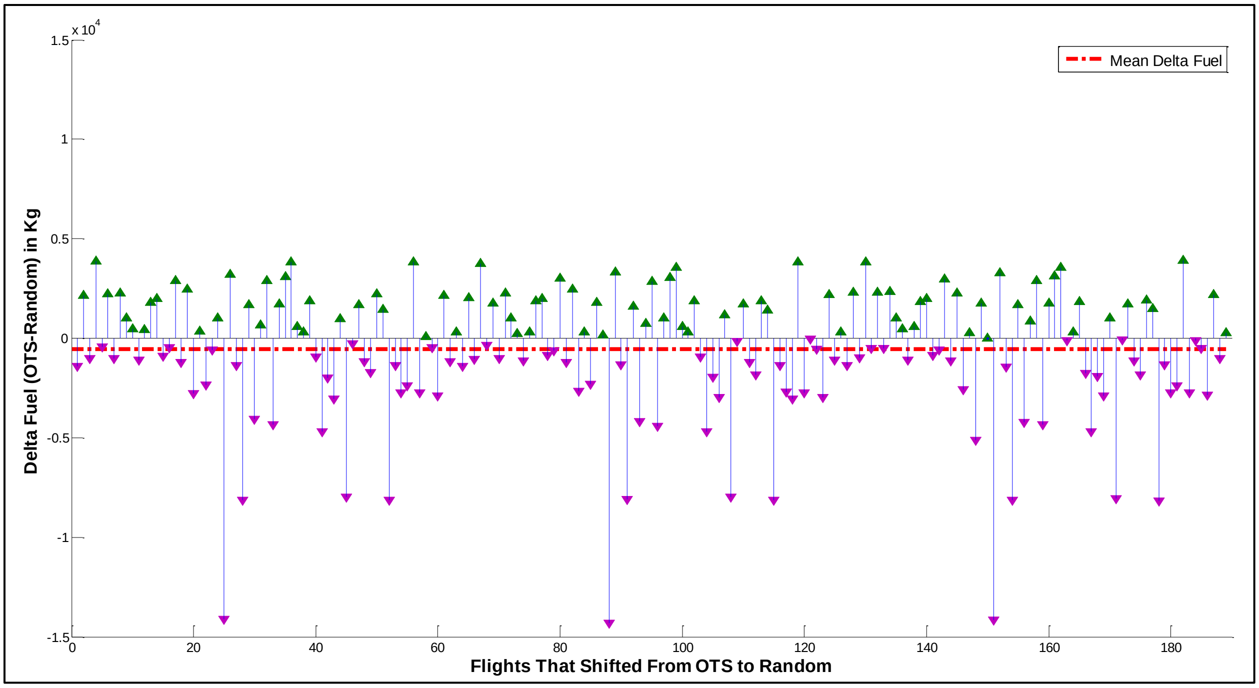

Figure 55: Delta Fuel for Flights That Shifted from OTS to Random (with anomalies)

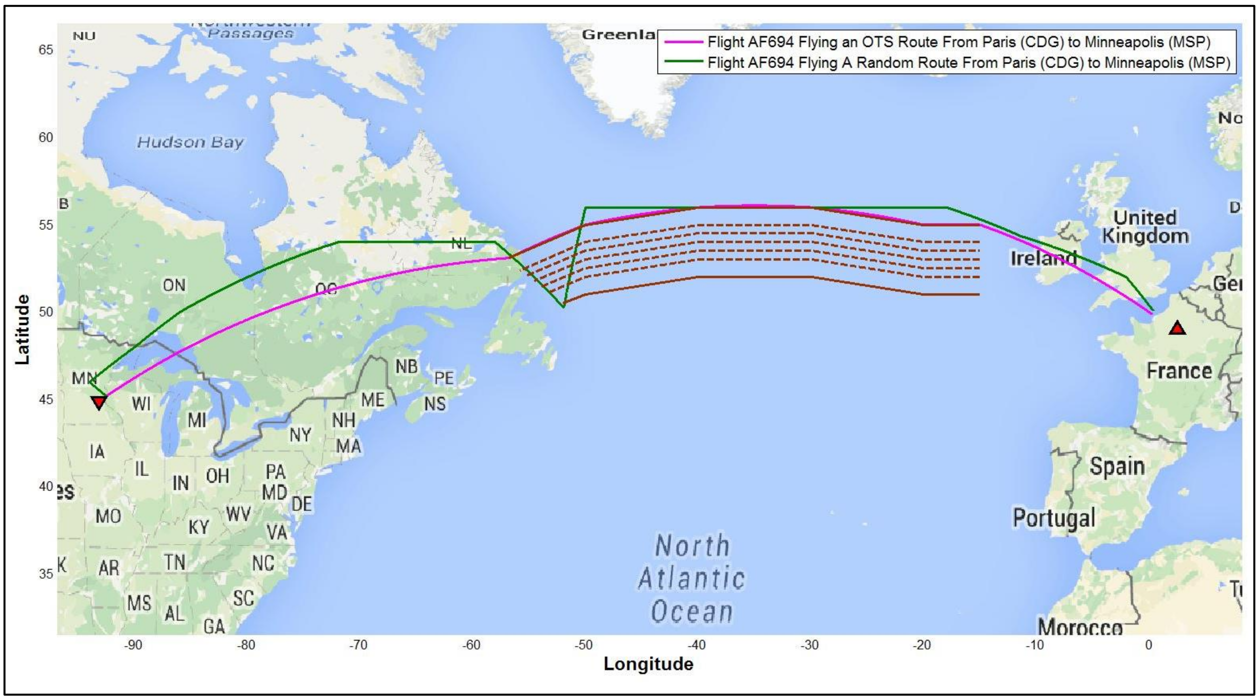

Figure 56: Example of Flight with Bad Flight Plan

Figure 57 and Figure 58 present the fuel difference and the travel time difference for flights that shifted from OTS to random because of the application of the RLatSM. These figures refer only to flights with valid flights plans (see Figure 59). A close observation to these figures reveals that there is no clear trend for the specific group of flights. Some flights have a benefit when the flight a random route whereas others receive a penalty. The mean fuel difference is positive which means that the overall impact to the system in term of fuel consumption is positive. On the other hand, the mean difference in travel time is negative.

There is a number of factors that differ between the random and the organized airspace. One of these factors is that many flights may compete for the same airspace and the way to retain the minimum separation between them is either to change the flight level of one of them, detour them or adjust their cruise Mach number. The latest factor is not adjusted during the deconfliction of flights that fly inside the Organized Track System. Another significant and variable factor over the North Atlantic that affects the travel time and the fuel consumption is the wind experienced by flights. In a typical day, westbound OTS flights should experience less headwind than random westbound flights while eastbound OTS should experience higher tailwind than random eastbound flights.

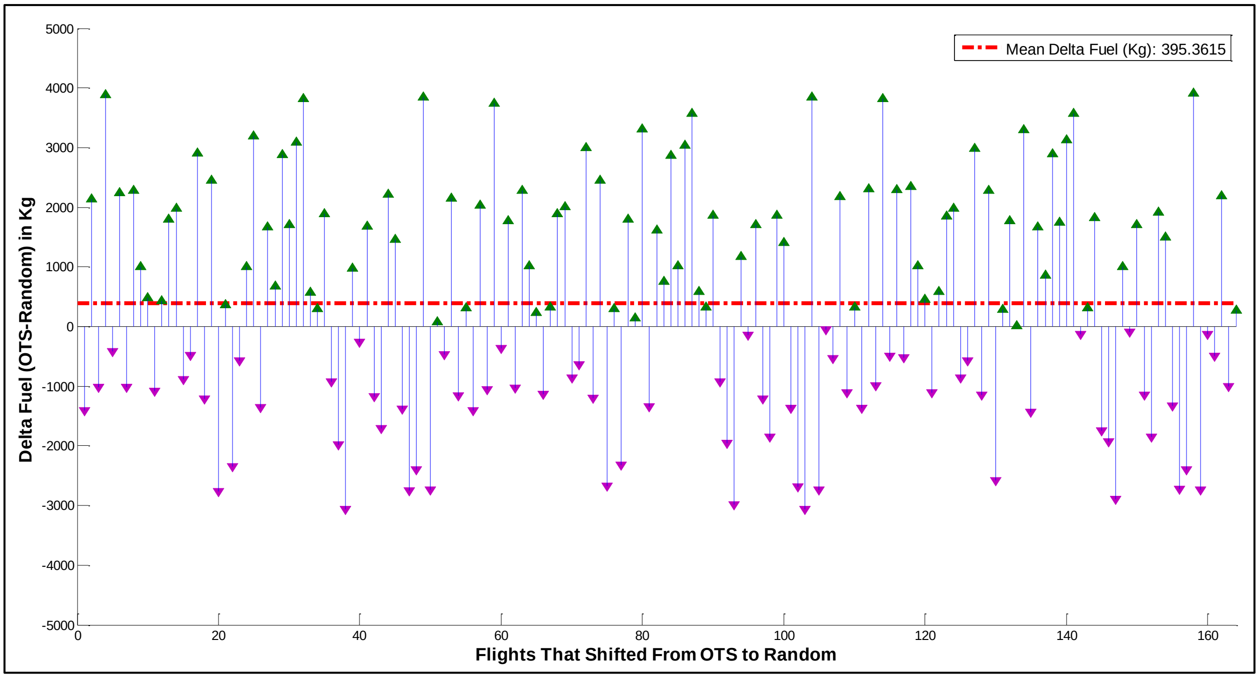

Figure 57: Delta Fuel for Flights That Shifted from OTS to Random (without anomalies)

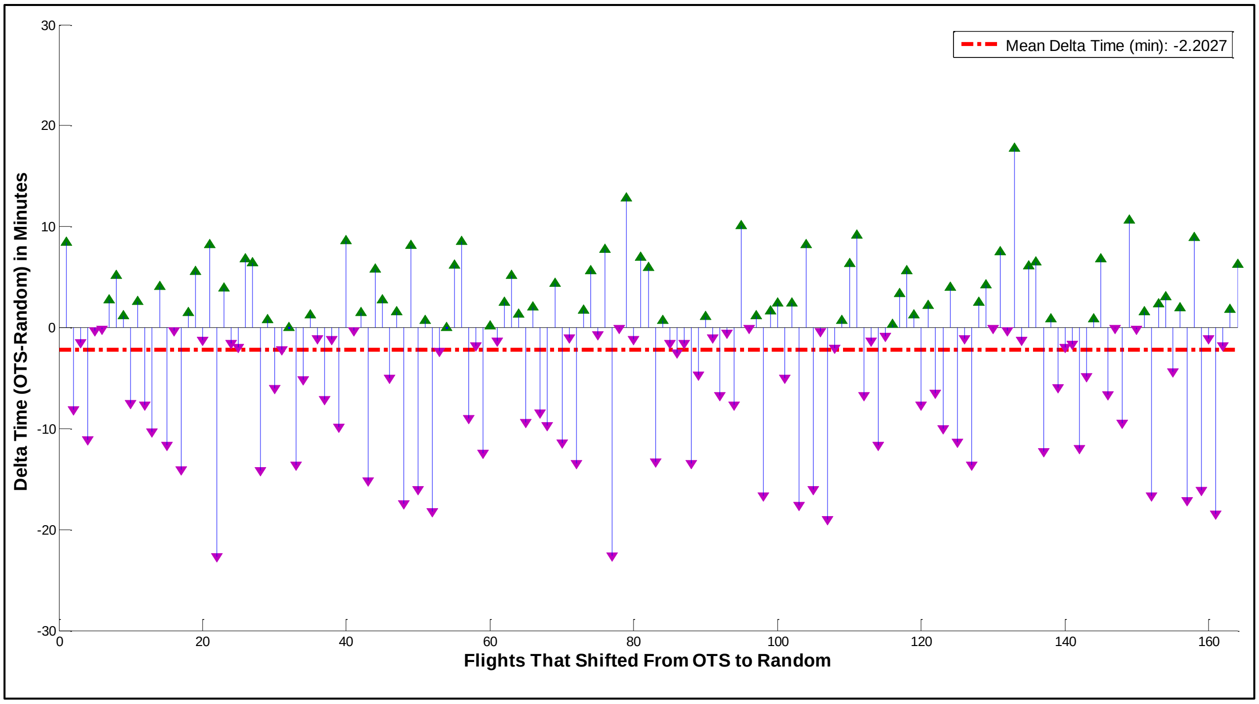

Figure 58: Delta Time for Flights That Shifted from OTS to Random (without anomalies)

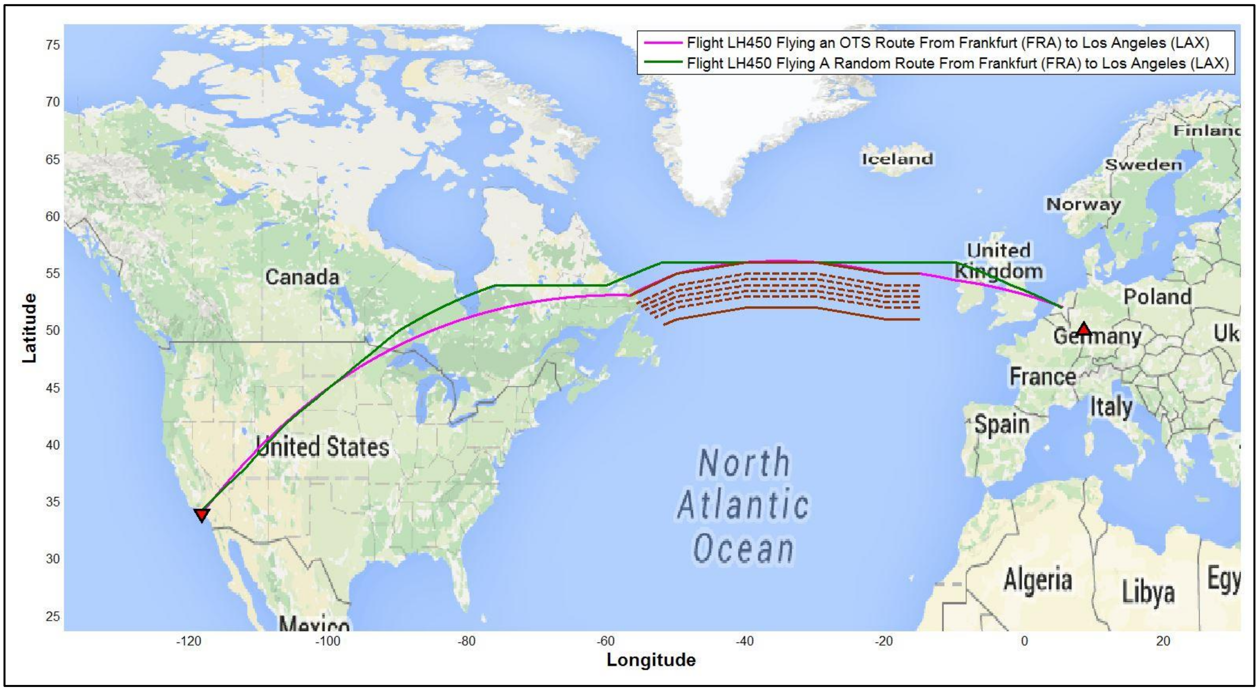

Figure 59: Flight That Shifted from OTS to Random After the Application of RLatSM

TOPIC 2: CHICAGO O'HARE INTERNATIONAL AIRPORT NOISE STUDY

CHAPTER 6 BACKGROUND

6.1 Objective of the Study

This study is focused on the replication with accuracy of noise contours prepared back in 2002 for different stages of the O'Hare Modification Plan (OMP). Another part of this analysis is the analysis and combination of different sources of data in order to build noise contours for the current state of operation at Chicago O'Hare International Airport (ORD). This information combined will be used in order to observe the effect of the reconfiguration of runways at ORD on the airport noise pollution. Furthermore, the study will prove whether the assumptions made in 2002 for the future of operation in ORD were correct or not and to what extend they affected the noise contours prepared for the final stages of the O'Hare Modification Plan.

6.2 Chicago O'Hare International Airport

Chicago O'Hare International Airport (IATA: ORD, ICAO: KORD) topped the 2015 list of the U.S. busiest airports in terms of total movements while it was ranked third in terms of total passenger enplanements. 875,136 aircraft carried 76,949,336 passengers in both domestic and international routes [19].

The high percentage of delayed flights lead the city management on 2004 to invest in a $6.6 billion (in 2001 dollars) project in order to increase the airfield capacity by 17% and decrease delays by 74% [20]. The O'Hare Modernization Plan will change drastically the runway configuration of the airport. The goal is to convert the three runway orientation into a two runway orientation with 6 parallel runways (90/270) and two crosswind runways (40/220).

6.3 Noise Modeling Scenarios

The transition from the original 6 runway airfield to the new 8 runway airfield has affected the flight paths, the distribution of operations to each runway and as a result the noise level exposure of the communities around ORD. For this reason, the Suburban O'Hare Commission (SOC) assigned JDA Aviation Technology Solutions to perform an extensive and established analysis of the Chicago Department of Aviation (CDA) and FAA Environmental Impact Statement (EIS) noise contours as well as actual noise measurement from sensors dispersed around the airport.

As part of the previously defined study our involvement in the following areas included:

I. Production of noise contours using the Integrated Noise Model (INM) to document the differences between modeled EIS noise contours and actual noise measurements,
II. Production of INM contours to evaluate the noise impact of promising procedural/operational identified in the Fly Quiet analysis paper [21],
III. Utilization of INM to quantify the geographic area and the approximate noise-impacted population around ORD International Airport.

The INM analysis presented in the preceding chapters includes:

1. Noise contours built using ORD EIS data for the following scenarios:
   - 1.1 2002 Baseline
   - 1.2 Construction Phase II Alternative C
   - 1.3 OMP Built Out Alternative C
2. Current and future contours modeled to determine current and future noise impacts and quantify the geographic area and the population impacted around ORD for the following scenarios:
   - 2.1 Modified OMP Built Out Alternative C
   - 2.2 Today: 2014-2015 ORD Noise Contour

6.4 Integrated Noise Model (INM)

The Integrated Noise Model is a computer software developed by the Federal Aviation Administration (FAA) to assess the noise impact of airport activity. The algorithms used in the model are based on the Society of Automotive Engineers Aerospace Information Report 1845 to estimate the noise level for an area or specific location around an airport. INM version 1 was released in January 1978. This study was performed using the latest version of the software, 7.0d. As of May 2015, the Aviation Environmental Design Tool (AEDT) replaced the INM [22].

The basic characteristics of INM are the following:

- The user can define a runway configuration of any airport around the world or choose one of the US airports included in the models database
- The user can model operation using built-in flight paths or create flight paths for each aircraft type
- The model calculates DNL values for a grid of points (contour), for specific user-defined locations and for population locations

Input variables for the INM are:

- Average values of local atmospheric conditions (Temperature (F), Pressure (in-Hg), Humidity (%), Headwind (Kt)
- Flight Paths
- Fleet mix
- Daytime and nighttime operations

6.5 Basic Airport Noise Calculation Information

All noise calculation values in noise modeling analyses are reported in Sound Pressure Level (dBA). Each aircraft operation creates a Sound Exposure Level (SEL) at a specific location around the airport. Combining SELs for all aircraft operations at a specific airport results in the calculation of the Day-Night average sound Levels (DNL). DNL is the standard Federal metric for determining cumulative exposure of individuals to noise except California where CNL is used instead.

Special care should be given at the number of nighttime operations at any noise study. DNL adds a 10 dB noise penalty to each aircraft operation occurring during nighttime hours (10 p.m. to 7 a.m.). The extra 10dB mean that a nighttime event weighs 10 times more in a logarithmic scale in comparison with a day-time event. DNL includes that penalty to compensate for people's heightened sensitivity to noise during this period. This penalty contributes heavily to an airport's overall noise profile [23].

Noise studies are usually focused on the calculation of the contour areas under 55 DNL and 65 DNL. The least severe exposure occurs outside the 55 DNL contour, the level at which the Federal Aviation Administration describes noise exposure as minimal. The 65 DNL is the Federal significance threshold for aircraft noise exposure (see Table 12).

Table 12: Land Use Compatibility with Yearly Day-Night Average Sound Levels [24]

Land use	Yearly day-night average sound level (L_{dn}) in decibels					
	Below 65	65-70	70-75	75-80	80-85	Over 85
RESIDENTIAL						
Residential, other than mobile homes and transient lodgings	Y	N(1)	N(1)	N	N	N
Mobile home parks	Y	N	N	N	N	N
Transient lodgings	Y	N(1)	N(1)	N(1)	N	N
PUBLIC USE						
Schools	Y	N(1)	N(1)	N	N	N
Hospitals and nursing homes	Y	25	30	N	N	N
Churches, auditoriums, and concert halls	Y	25	30	N	N	N
Governmental services	Y	Y	25	30	N	N
Transportation	Y	Y	Y(2)	Y(3)	Y(4)	Y(4)
Parking	Y	Y	Y(2)	Y(3)	Y(4)	N
COMMERCIAL USE						
Offices, business and professional	Y	Y	25	30	N	N
Wholesale and retail—building materials, hardware and farm equipment	Y	Y	Y(2)	Y(3)	Y(4)	N
Retail trade—general	Y	Y	25	30	N	N
Utilities	Y	Y	Y(2)	Y(3)	Y(4)	N

Communication	Y	Y	25	30	N	N
MANUFACTURING AND PRODUCTION						
Manufacturing, general	Y	Y	Y(2)	Y(3)	Y(4)	N
Photographic and optical	Y	Y	25	30	N	N
Agriculture (except livestock) and forestry	Y	Y(6)	Y(7)	Y(8)	Y(8)	Y(8)
Livestock farming and breeding	Y	Y(6)	Y(7)	N	N	N
Mining and fishing, resource production and extraction	Y	Y	Y	Y	Y	Y
RECREATIONAL						
Outdoor sports arenas and spectator sports	Y	Y(5)	Y(5)	N	N	N
Outdoor music shells, amphitheaters	Y	N	N	N	N	N
Nature exhibits and zoos	Y	Y	N	N	N	N
Amusements, parks, resorts and camps	Y	Y	Y	N	N	N
Golf courses, riding stables and water recreation	Y	Y	25	30	N	N

CHAPTER 7 DATA COLLECTION AND ANALYSIS

7.1 Data Sources

Various data sources were required to do this study. The first data source used was the original ORD EIS study files dating back to 2002 and published 2 years later by the FAA, CDA and their engineering contractors. All EIS data used for this study are publicly available at the FAA website [25]. Concerning the noise modeling of today's operations, CDA provided 30 days of detailed flight track data to JDA. These 30 days span over a period of a year from November 2013 to October 2014 and they include the 16 days of the National Airspace System (NAS) used in FAA studies. The detailed flight tracks (three dimensional information) include the following information:

- Aircraft Type
- Flight Identification
- Departure or Arrival Time
- Runway Used
- Flight Track Latitude, Longitude and Altitude Waypoints

The third source of data was CDA public records [26]. These reports were used to derive the runway use from May 2014 to April 2015. Table 13 summarizes the data used for each noise contour scenario presented in this study.

Table 13: Noise Study Scenarios and Associated Data Used

Noise Scenario	Data Source(s)
EIS 2002 Baseline	ORD EIS Noise Files
EIS Construction Phase II Alternative C	ORD EIS Noise Files
EIS OMP Built Out Alternative C	ORD EIS Noise Files
Modified OMP Built Out Alternative C	ORD EIS Noise Files (modified)
Today: 2014-2015 ORD Noise Contour	CDA Flight Track Data, CDA Runway Use Data

7.2 Chicago Population Data

A difference between INM 7.0 and INM 7.0d is the format of the population input data. INM 7.0d can import population data in ".pl" comma-delimited format contrary to INM 7.0 that could import ".upl" format population data. Population files are available at United States Census Bureau website [27] for 50 states plus the federal state and Puerto Rico. The input file for INM is designated as the state's abbreviation followed by "geo2010.pl" (ex. ilgeo2010.pl).

7.3 Chicago O'Hare Airport Noise Management System (ANMS)

The Chicago O'Hare Airport Noise Management System (ANMS) comprises 32 sensors scattered around the airport. The airport is the main noise source of the area so these sensors were placed strategically in order to capture the noise generated by aircraft operations at ORD (see Figure 60). The ANMS system collects aircraft flight tracks due to its direct connection to the FAA's air traffic control radar. The coordinates of the monitors were derived based on their address [28] and then they were imported into INM. The software in each run calculates the DNL values for these 32 specific locations. This information is essential in order to compare the noise levels generated by the airport activity with the actual noise levels recorded by the system because the noise detected at each sensor could also include non-aviation sources. Differences between the ANMS sensors and the INM computer model are normal.

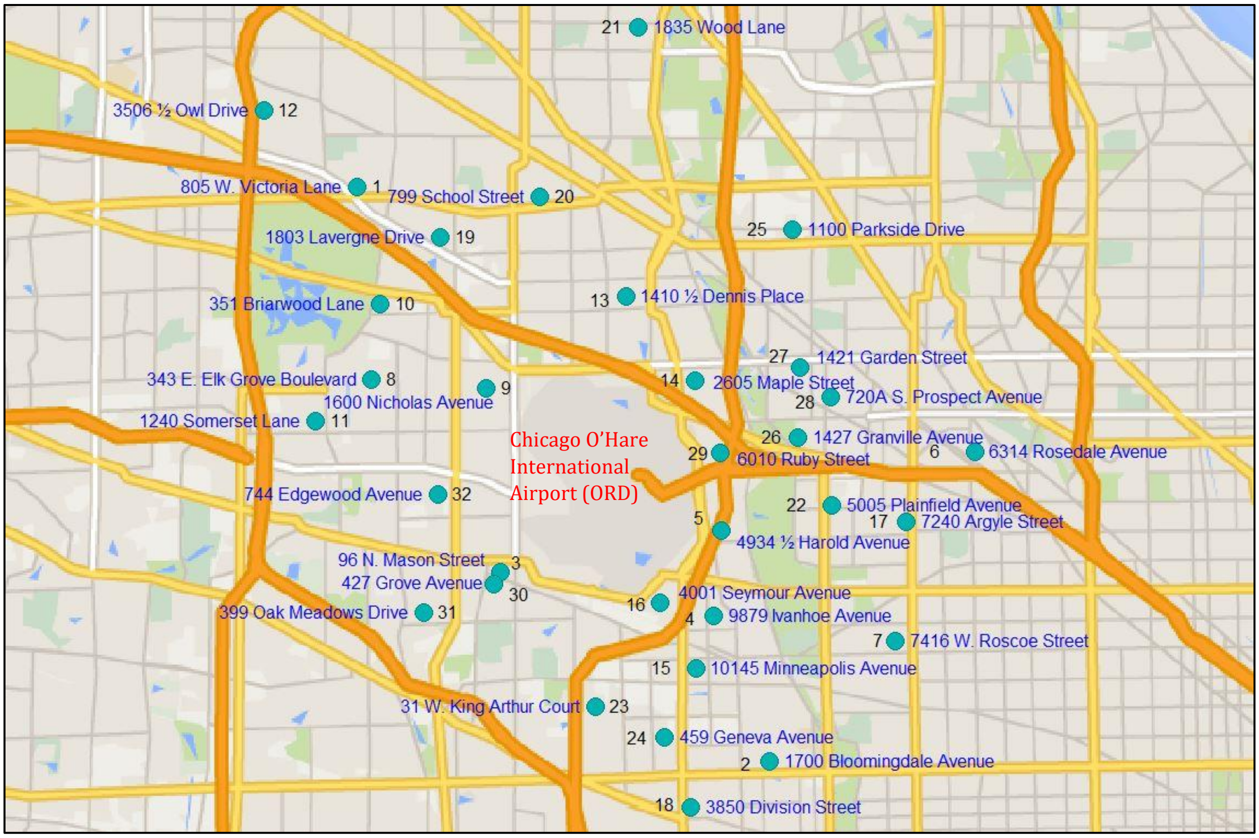

Figure 60: Chicago MNPS Sensor Locations

7.4 Data Analysis

The analysis required the understanding of ORD runway use. For this purpose, 15 days of track data from FlightAware[7] ranging between October 2013 and September 2014 were analyzed to observe the behavior of ORD operations in terms of aircraft type and runway use (see Figure 61 and Figure 62).

[7] FlightAware is a global aviation software and data services company that operates a website that offers live flight tracking and maintains a database of historical records.

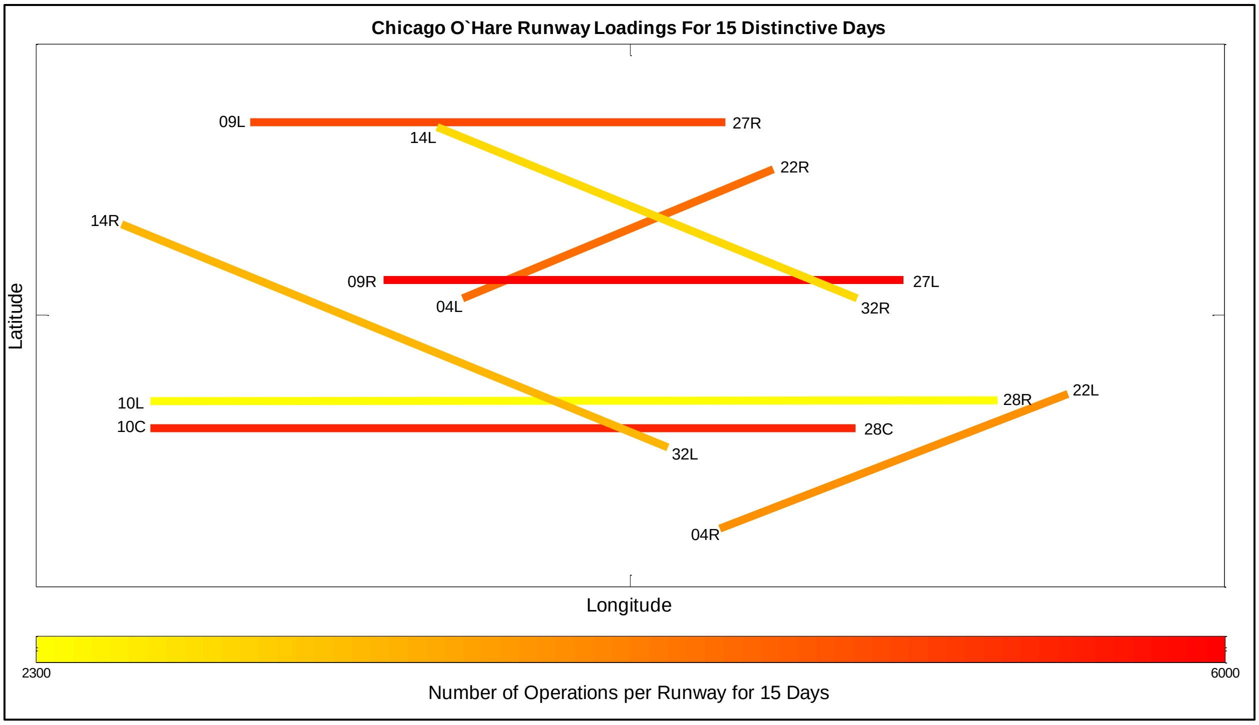

Figure 61: ORD Runway Loadings (15 Days Sample)

Runways 09L-27R, 09R-27L and 10C-28C are most heavily loaded because they are separated by more than 5,000 feet and in addition to the precision radar available at the airport they can be used for independent triple arrivals and departures. This runway utilization increases the capacity of the airfield. Crosswind runways 04R-22L, 04L-22R, 14R-32L and 14L-32R are used occasionally when required based on the wind conditions. Operationally, runways 28C-10C, 27L-09R and 27R-09L are primarily used for arrivals while 22L-04R, 28R-10L and 32R-14L are used for arrivals.

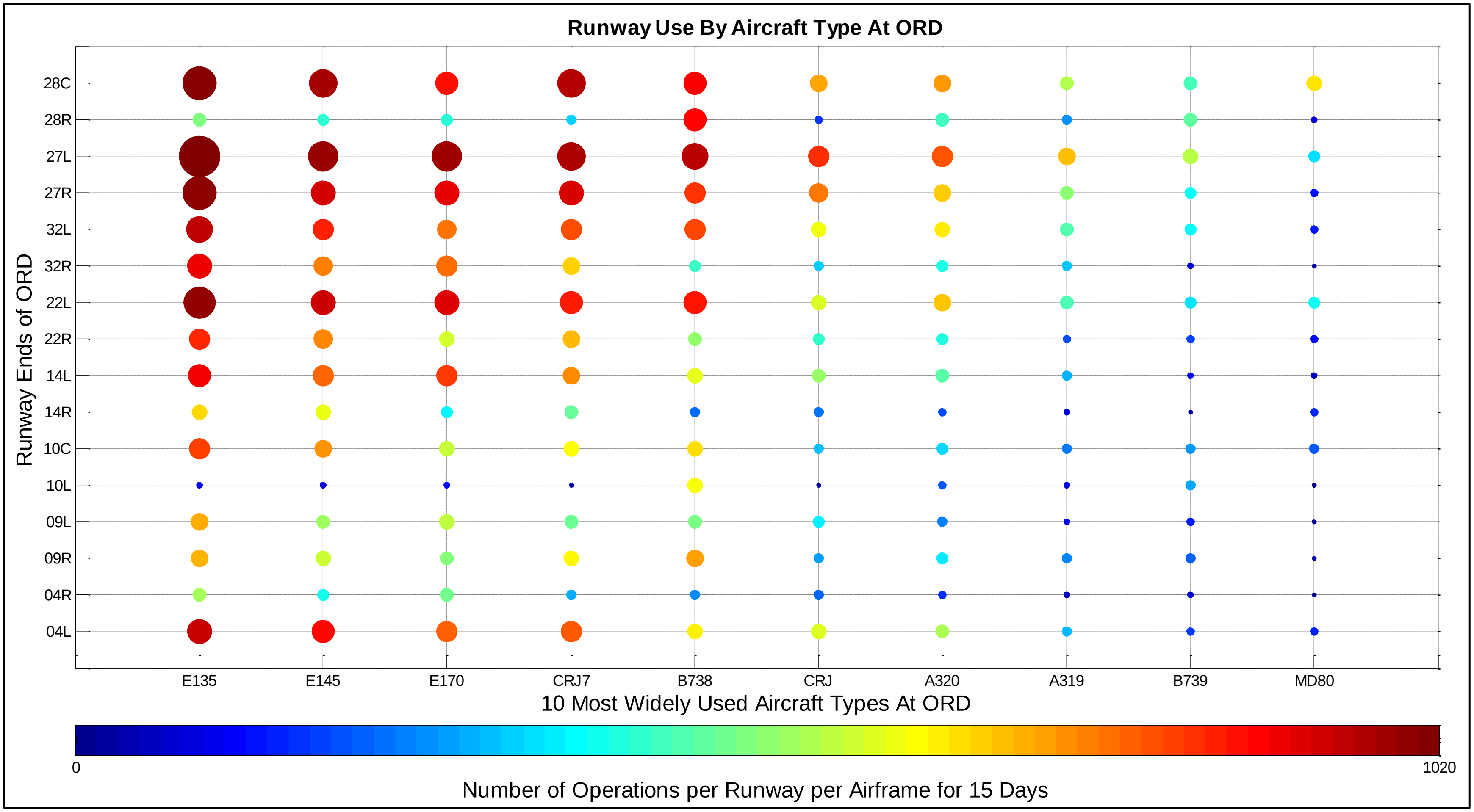

Figure 62: Runway Use By 10 Most Common Aircraft Operating AT ORD

CHAPTER 8 COMPUTER NOISE MODELING

8.1 INM Run Parameters

This section presents the noise contours developed to study noise impacts at the O'Hare International Airport. A specific set of atmospheric conditions was applied to each of the runs performed. The airport atmospheric reference values used are the following:

- Temperature: 59 ^{o}F
- Atmospheric pressure: 29.92 inHg
- Humidity: 70%
- Headwind: 8 knots

All runs were made with the Integrated Noise Model (INM) Noise Power Distance (NPD) flag turned on and the analysis used refinement level 12 with a tolerance of 0.10. These inputs provide good resolution for each noise contour.

8.2 EIS 2002 Baseline Noise Analysis

The first step of this study was a verification of the noise contours developed in 2002 by the FAA, the CDA and their engineering contractors. It's is worth mentioning that the production of exactly the same contours produced in 2004 is not possible for two main reasons. Firstly, there was need for a few changes to aircraft designations in order to make the 2002 study files compatible with the latest INM version. Secondly, an older version of INM, 6.0 was used for the noise contours of the initial version of this scenario.

The ORD runway configuration back in 2002 consisted of 2 East-West parallel runways (09L-27R and 09R-27L), 2 runways heading northeast (04L-22R and 04R-22L) and 2 runways heading northwest (14L-32R and 14R-32L). Figure 63 illustrates the noise contours produced for the specific configuration using a demand input file with 2,528 daily flights and 108 distinctive airframes. For this scenario, the model estimated the 65 DNL contour area to be equal to 21.5 square miles affecting 27,171 people (2010 Census).

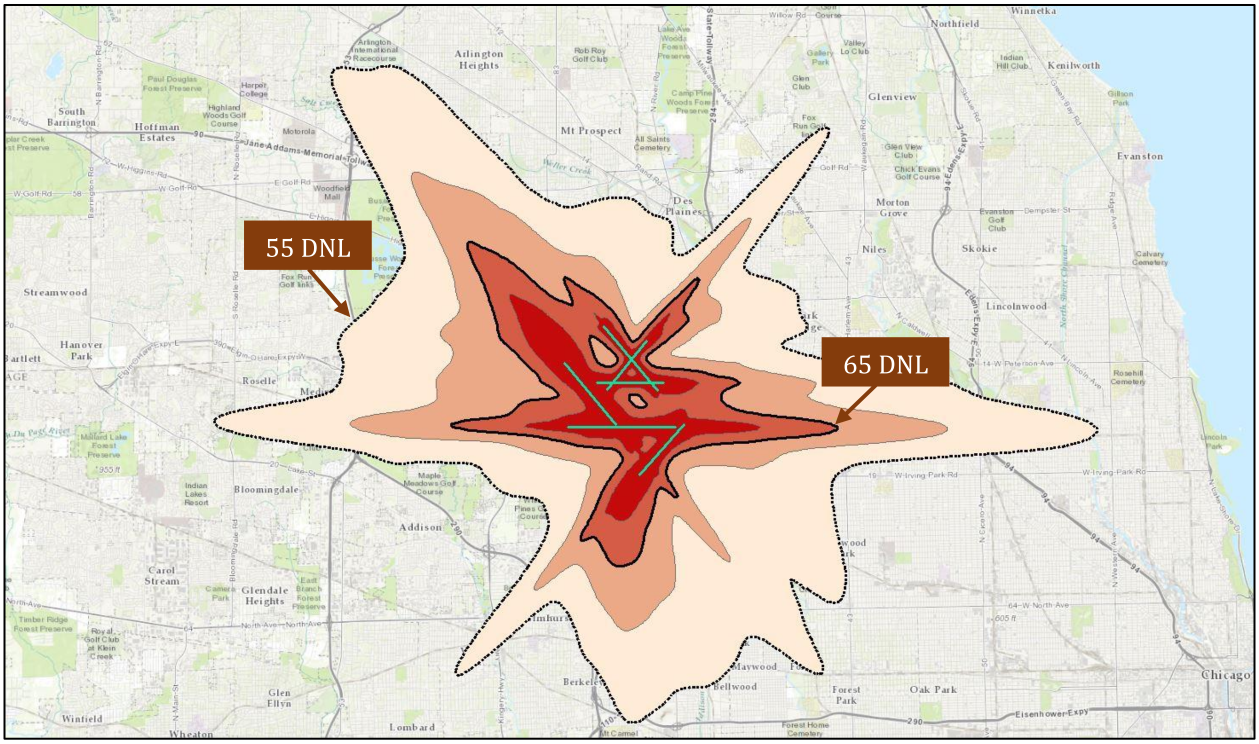

Figure 63: EIS Baseline 2002 Noise Contours at ORD Airport

8.3 EIS Construction Phase II Alternative C

Phase II of the O'Hare Modernization Plan concerns the construction of runway 09L-27R. This contours for this scenario were produced assuming that the demand in 2007 would be 2,812 flights per day. The results of our analysis showed that the 65 DNL contour area was 20.6 square miles and the 55 DNL contour area was 123.1 square miles (see Figure 64). The population affected by the 65 DNL contour was estimated to be 23,114 people based on 2010 Census population data.

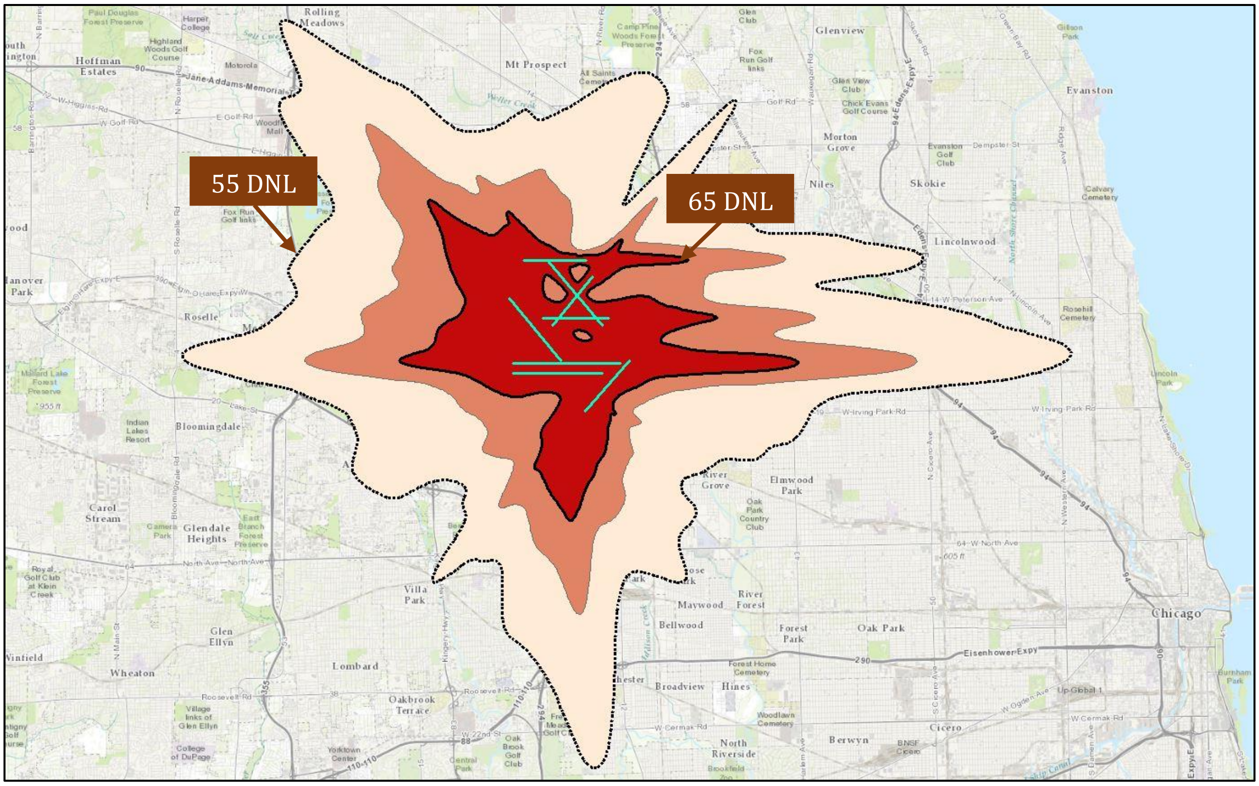

Figure 64: Phase II Noise Contours for ORD Airport

8.4 EIS OMP Built Out Alternative C

Back in 2004, the daily flight operations for ORD were predicted to be 3,070 at Fall 2015 (5.6% nighttime operations). The contours produced using this demand and the final configuration of the O'Hare International Airport (6 parallel east-west runways plus 2 crosswind runways) are shown in Figure 65. The 65 DNL contour area is 18.2 square miles affecting 24,964 people while the 55 DNL contour area covers 100.6 square miles and affects 374,606 people.

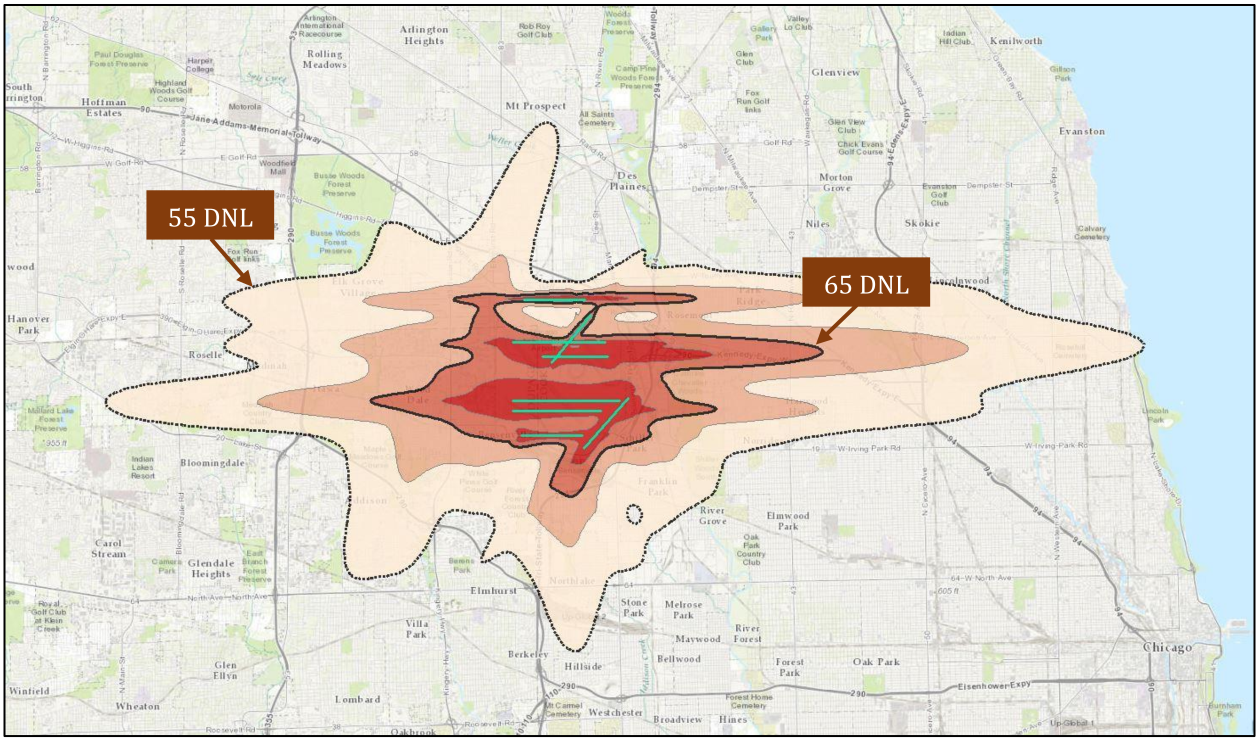

Figure 65: EIS OMP Built Out Alternative C for ORD Airport

8.5 Modified OMP Built Out Alternative C

The noise contours for the ORD final runway configuration that were developed in 2004 are not realistic today for two reasons. Firstly, the fleet mix has changed both in terms of aircraft models used (latest aircraft types produce lower noise levels) and in terms of the capacity of the aircraft operating at O'Hare International Airport. Secondly, the assumption that nighttime operations account for only 5.6% of the total daily traffic of the airport is not consistent with the average number of nighttime operations observed over the last few years (10.5%). Applying these new parameters, we prepared a revised map of noise contours for the OMP Built Out scenario (see Figure 66). The 65 DNL contour area covers 22.0 square miles around the airport where live 44,087 people and the 55 DNL contour extends over a total area of 126.3 square miles enclosing the residencies of 445,037 people.

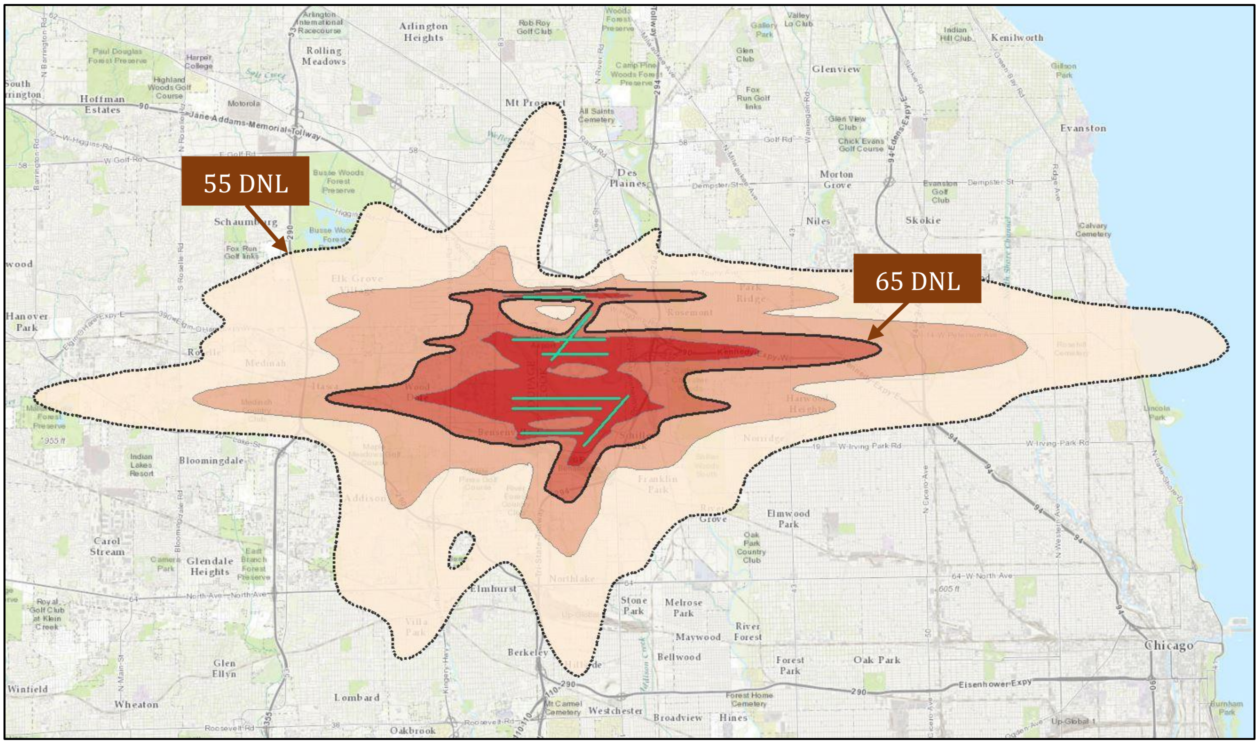

Figure 66: Modified OMP Built Out Alternative C for ORD Airport

8.6 Today: 2014-2015 ORD Noise Contour

The reconfiguration of ORD runway layout was accompanied with complaints from the surrounding communities about the increased noise levels related to airport operations. For this reason there was need to for release of noise contours based on real data. Using runway use data obtained from CDA public records we estimated the average daytime flight operations to be 2,128 and the nighttime 250 (10.5% of total daily flight demand). The 65 DNL contour area for this scenario covers 12.5 square miles around the airport and it affects 13,636 people while the 55 DNL spans over 81.4 square miles and it affects 308,031 people (see Figure 67).

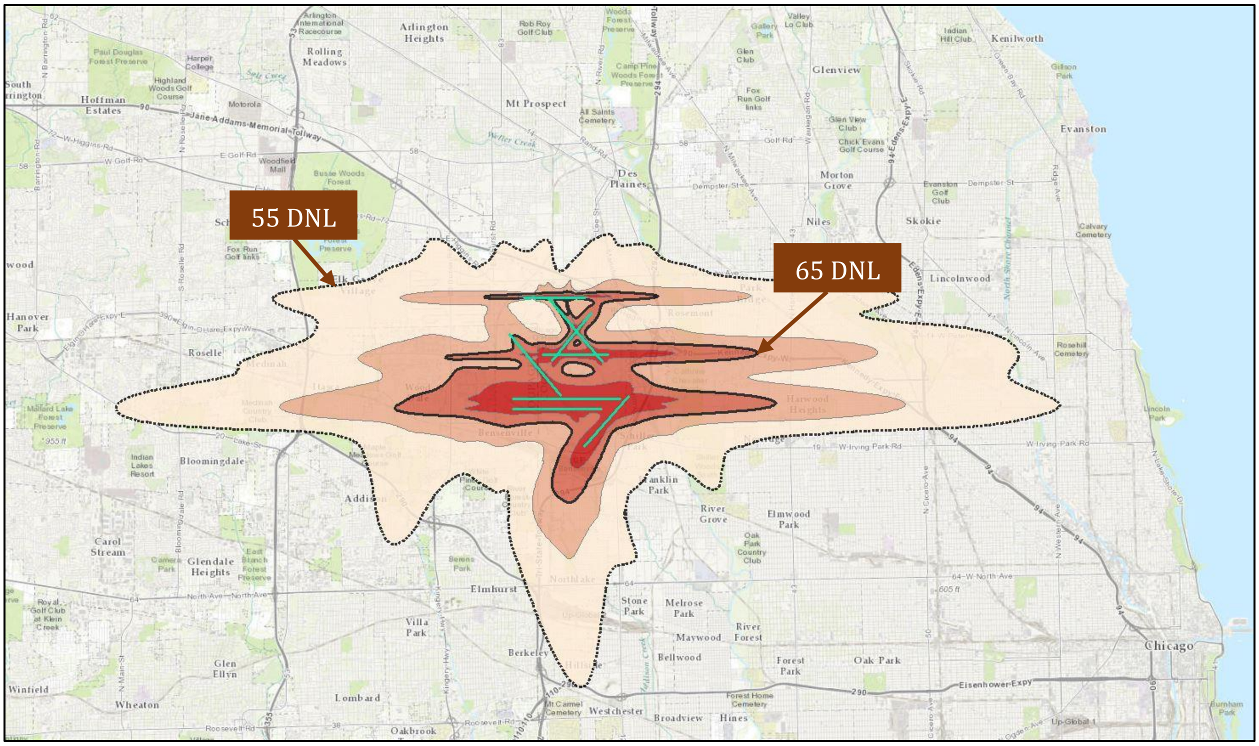

Figure 67: Today: 2014-2015 Noise Contours for ORD Airport

CHAPTER 9 RESULTS

Table 12 presents a summary of the output metrics collected from the scenarios modeled in INM. There is a clear declining trend in the area under 65 DNL and 55 DNL. The same behavior is observed in the population affected by each of the two DNL contours. However, it is worth mentioning that the effect of the O'Hare Modernization Plan in the population affected is inconclusive because the calculations for the total population under each DNL contour were performed using Census 2010 data for all five scenarios. For instance, it might seems that after the reconfiguration of O'Hare International Airport the population affected by the airport activity decreased by almost 50% but this is not certainly true because the demographic characteristics in 2002 were different than those used in the study.

Table 14: Summary Results

Scenario	65 DNL Area (sq. mi.)	55 DNL Area (sq. mi.)	Population Under 65 DNL	Population Under 55 DNL
EIS 2002 Baseline	21.5	135.5	27,171	607,255
EIS Construction Phase II Alternative C	20.6	123.1	23,114	497,758
EIS OMP Built Out Alternative C	18.2	100.6	24,964	374,606
Modified OMP Built Out Alternative C	22.0	126.3	44,087	445,037
Today: 2014-2015 ORD Noise Contour	12.5	81.4	13,636	308,031

A second significant outcome of this analysis concerns the spike of all metrics for the Modified OMP Built Out Alternative C scenario (see Figure 68 and Figure 69). This scenario proves that the assumptions used for the preparation of EIS OMP Built Out Alternative C back in 2002 drove the contour areas to unrealistic low levels. Furthermore, the substantial difference between the Modified OMP Built Out Alternative C and its modified version illustrates that nighttime operations have a considerable effect in the Day-Night Average Sound Level (DNL) experienced by the community around the airport (see Figure 70).

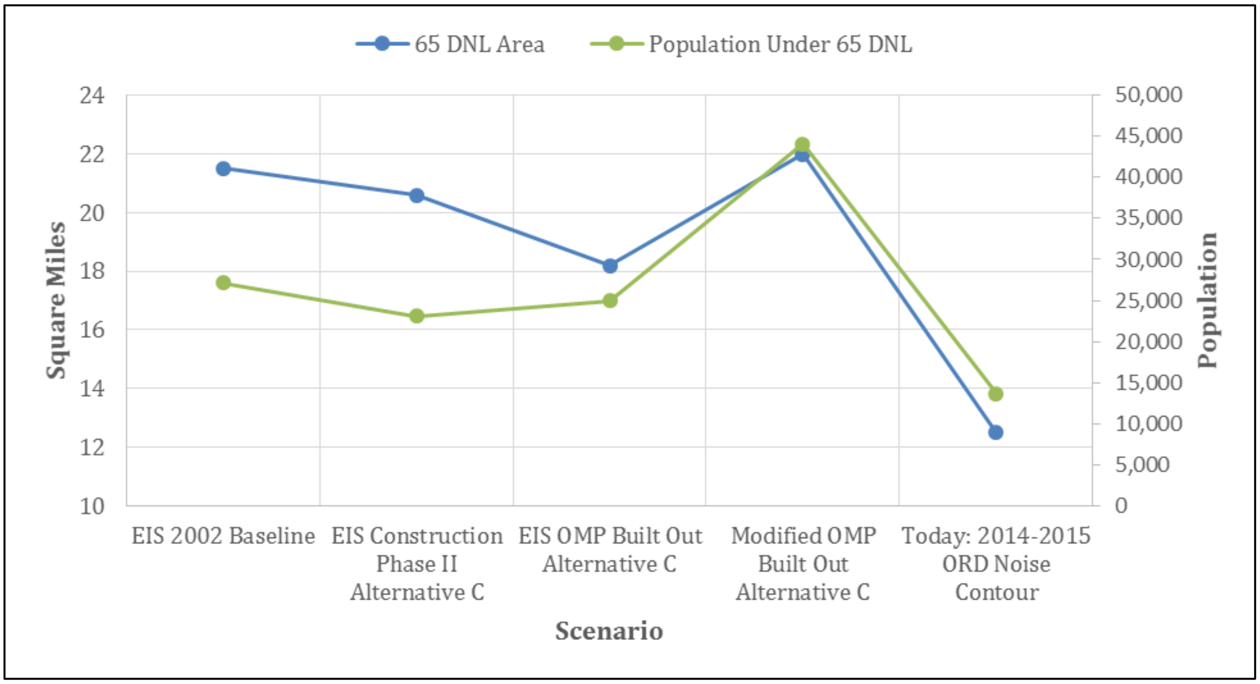

Figure 68: 65 DNL Contour Measurements

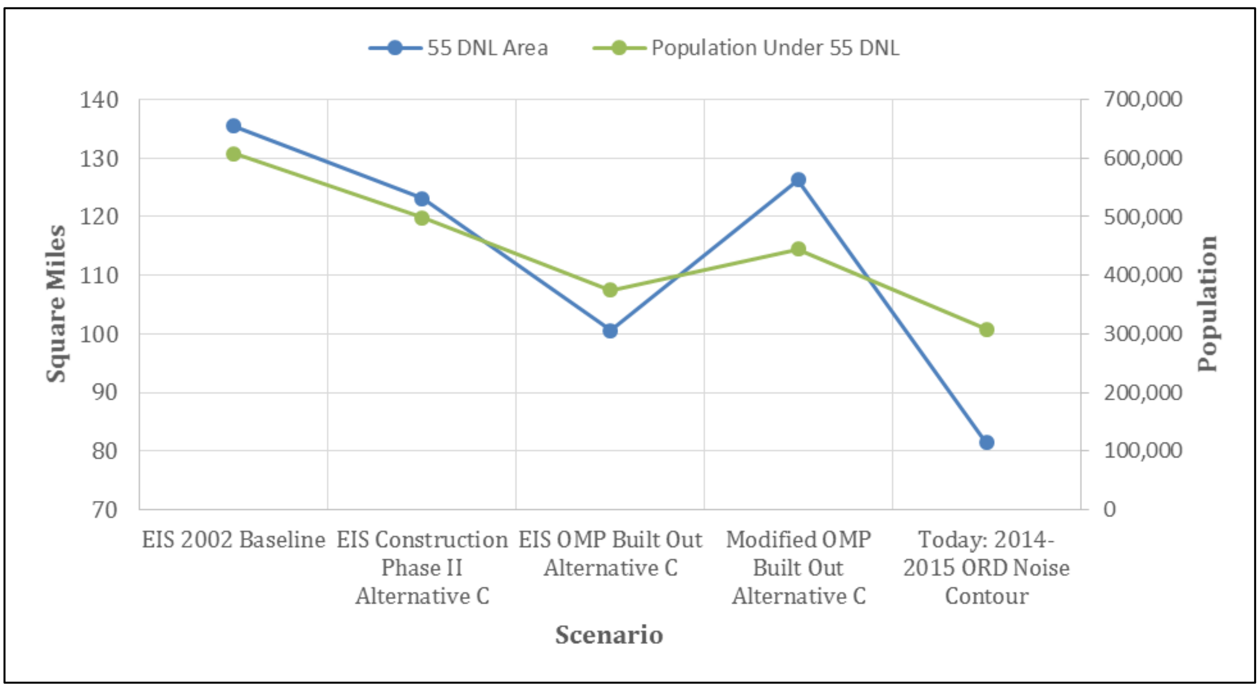

Figure 69: 55 DNL Contour Measurements

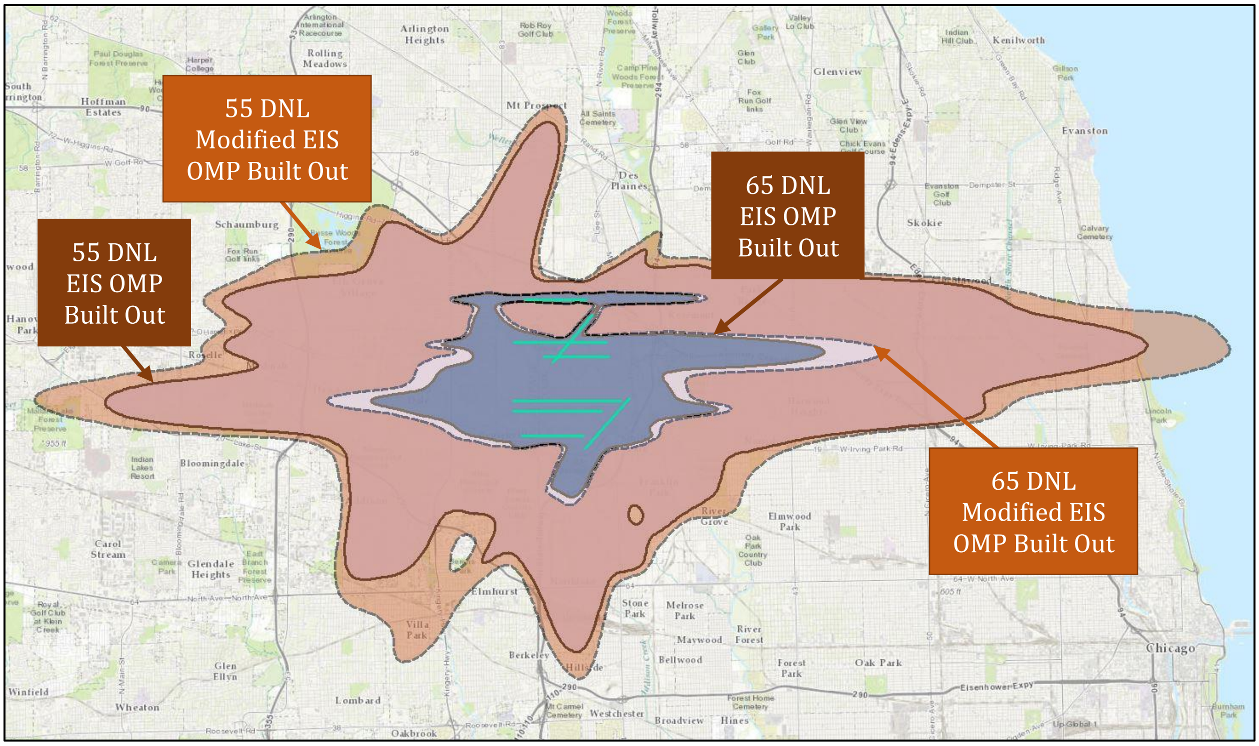

Figure 70: Comparison of 65 DNL and 55 DNL Noise Contours for EIS OMP Built Out and Modified EIS OMP Built Out

Finally, the OMP did not only increase the capacity of the airport but it also decreased the environmental impact of the airport activity (see Figure 71). The comparison between the contours in EIS 2002 Baseline scenario and Today's scenario reveal that the 65 DNL area decreased by 41.86% and the 55 DNL area decreased by 39.92%. Although the numbers might seem satisfactory, we should consider the dispersion of the contours around the airport. The decommissioning of runways 14R-32L and 14L-32L and the construction of four east-west runways shifted the operations to heavier east-west flows. As a result, there are communities around the airport that benefited while others saw the overflights to increase over time.

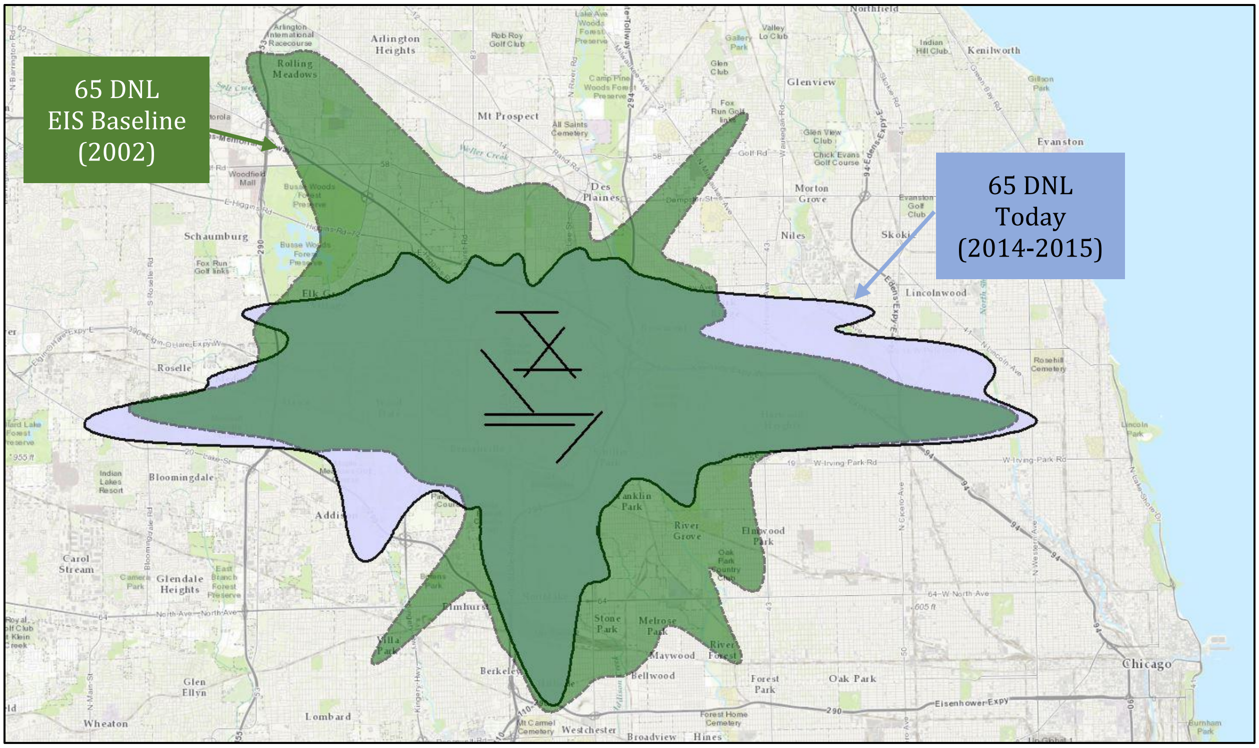

Figure 71: Comparison of 65 DNL Contours for Baseline and Today (2014-2015)

CHAPTER 10 CONCLUSIONS

This thesis assessed the current and future operations performance in the North Atlantic Organized Track System at the beginning of the era of reduced separations at the world's busiest oceanic region. The improved navigational, communication and surveillance performance of aircraft avionics allow the Air Traffic Controllers bring them as close as 8 nautical miles longitudinally and 15 nautical miles laterally in the OTS. Initially, the longitudinal separation between equipped aircraft reduced from 80 nm to 40 nm. However, the assessment of the system in a sample of 8 days of 2014 did not prove that this separation was used extensively.

Applying a demand shortfall analysis algorithm using TFMS and OAG data we identified missing Atlantic flights and we enhanced the TFMS demand sets. Then we prepared and run a cost matrix algorithm that showed that more flights use the OTS than those that have filed a track in their flight plan. Afterwards, we simulated a number of scenarios regarding the future of the separations in the OTS. We performed the simulations using the Global Oceanic Model. This fast time simulation model was not prepared to simulate OTS traffic. This process was accomplished but the model was not validated. As a result the output of the simulations cannot be used to derive solid conclusion and drive decisions.

The second topic of this thesis was the noise study that was performed for the Chicago O'Hare International Airport that undergoes a massive reconfiguration plan. We successful reproduced the Environmental Impact Study DNL noise contours of 2002, the EIS Construction Phase II contours and the EIS Built Out noise footprint. We also prepared noise contours for a revised version of EIS Construction Phase II which proved that the nighttime operations for this phase of the reconfiguration were underestimated and for this reason the noise contours were predicted substantially smaller than the actual ones. Finally, we produced noise contours for 2014-2015 using real data and we compared them with the noise contours of 2002. The comparison between the two scenarios revealed that the O´Hare Modernization Program (OMP) decreased the environmental impact of the airport operations by almost 40%.

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