Economic Impact Analysis of Data Link in the North Atlantic Region

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ABSTRACT

This paper investigates the economic impact of North Atlantic (NAT) region Data Link mandate and implementing Reduced Lateral separation (RLatSM) in the NAT oceanic airspace. A detailed cost analysis is carried out to estimate the Data link mandate cost for all NAT operators based on a survey of 44 commercial operators. A computer simulation model North Atlantic Track System Analysis Model (NATSAM) was developed and used to assess fuel and time savings derived from implementing Data link mandate and reduced lateral separation across the NAT oceanic airspace.

1. OBJECTIVE

This paper examines the likely economic costs and benefits to commercial aircraft operators derived from the introduction of a data link mandate in the North Atlantic oceanic airspace as well as the benefit mechanisms available through the reduction of lateral and longitudinal separation minima.

2. BACKGROUND ON NORTH ATLANTIC OPERATIONS

Nine States provide air traffic services in the NAT: Canada, Denmark, France, Iceland, Ireland, Norway, Portugal, the United Kingdom and the United States [4]. Commercial traffic represents the majority of operations in the NAT, with International General Aviation (IGA) primarily operating at high altitudes. A significant portion of traffic in the NAT takes place along a system of 5-7 nearly parallel tracks known as the Organized Track System (OTS), which includes traffic flows between North America (excluding Alaska) and Europe (and Middle East). The exact location of these tracks is updated twice a day (one for eastbound and one for westbound traffic) according to projected wind and meteorological conditions [3].

Most of the NAT airspace is out of the range of Very High Frequency (VHF) and radar. The majority of communications take place using High Frequency (HF) voice, which is subject to disruption, atmospheric effects, ambiguity in accents, frequency congestion, and a third-party relay between pilots and controllers.
One position report using HF voice is usually done every 10 degrees of longitude, or roughly once every hour during the flight. Due to the lack of surveillance and timely controller intervention capability, safety in the NAT is maintained by imposing large longitudinal (10 minutes) and horizontal (60 NM or 1 degree of latitude) separation standards [3].

3. BACKGROUND ON DATA LINK MANDATE

The implementation of the Future Air Navigation System or FANS-1/A started in the NAT in the 1990s. The FANS-1/A system has three main functionalities [6]:

- **ATS Facilities Notification (AFN):** used to initiate logon between aircraft and Air traffic Services (ATS) facility
- **Controller Pilot Data Link Communication (CPDLC):** enables direct data link communication between pilot and ATS facility using either pre-defined or free text message formats. Used for clearances, requests, acknowledgements, negotiations, etc.
- **Automatic Dependent Surveillance - Contract (ADS-C):** automatic report of position, velocity, intent, and other information via a contract established between aircraft and ATS facility. It provides an alternative to voice reporting by sending automatic position reports via SATCOM.

The International Civil Aviation Organization (ICAO), NAT Systems Planning Group (NAT SPG), identified the need to mandate the use of data link equipment on the basis of safety, to reduce the vertical risk in the NAT below the Target Level of Safety (TLS). A high number of Large Height Deviations (LHDs) in the region has been the main factor for not meeting the TLS in the vertical plane for some time. The FAA defines a LHD as “any vertical deviation of 300 feet or more from the expected flight level.” ADS-C conformance monitoring could be used to detect deviations in the lateral and vertical planes from the cleared route and flight level.

The data link mandate plan specifies that all aircraft conducting flights in the airspace defined below shall be equipped with and shall operate CPDLC and ADS-C equipment as follows (meeting the requirements specified in RTCA DO-258A/EUROCAE ED-100A or equivalent, capable of operating outside VHF data link coverage):

- **Phase 1** - From 7 February 2013. The limits in the vertical plane have been defined from flight level 360 to flight level 390, inclusive, and in the horizontal plane, no more than two tracks within the NAT OTS designated as core tracks. The specified tracks shall be identified when the NAT Organized Track message is published.

- **Phase 2** - From 5 February 2015. In specified portions of the NAT Minimum Navigation Specification (MNPS) Airspace. The lateral and vertical extent of airspace that phase 2 will cover is still under definition.
4. COST ANALYSIS

4.1 Major Data Sources

Current and planned data link equipage levels were gathered through a survey of major commercial operators. CSSI, Inc. led the effort, in collaboration with the International Air Transport Association (IATA) and the U.S. Federal Aviation Administration (FAA), to collect input on data link avionics equipage for 2010, 2013, 2015, and beyond. This was an unprecedented study, capturing information for 44 major airlines (representing 81.6 percent of NAT MNPS operations and 88.2 percent of commercial operations).

Costs to meet the requirements of the data link mandate were estimated based on equipage levels provided by aircraft operators and cost data from manufacturers. Cost data was gathered through a cost focus group of industry representatives, which included over 40 participants representing aircraft and avionics manufacturers, commercial airlines, International General Aviation (IGA) representatives, and all of the NAT Air Navigation Service Providers (ANSPs). This cost focus group provided first-hand cost information related to the equipment with data link avionics.

Researchers at MIT’s International Center for Air Transportation (ICAT) developed a traffic forecast and fleet mix analysis for 2013, 2015, and 2020. Projections were developed using data samples from OAG Aviation and the Enhanced Traffic Management System database (ETMS). Baseline traffic operations for 2010 were derived from an ETMS sample from May to September. Finally, the OAG BACK Aviation World Aircraft Registry for June 2010 was used to make estimates of the fleet composition for those airlines that did not respond to the data link survey.

4.2 Major Assumptions

- Airspace where mandate applies will be exclusionary. Only aircraft equipped with the technologies and systems described will be allowed to operate in that airspace
- This study is based on the Proposal for Amendment of Regional Supplementary Procedures – Doc 7030/5 approved by the ICAO Council on January 4, 2012
- The cost analysis covers a five-year period, beginning with January 1st, 2010 and ending with December 31st, 2014. It is assumed that costs began to accrue in 2010 and that airlines will equip gradually while trying to comply with the data link mandate before phase 2 comes into effect, as this will be the more stringent phase
- All costs are presented in 2010 USD
- A discount rate of 7 percent is applied [2]
- Projections of costs and data link equipage availability from manufacturers are current as of 2012
- Projections of commercial and general aviation fleets and data link equipage plans are current as of 2010
- All avionics retrofits take place during scheduled maintenance to avoid prohibitive costs of taking an aircraft out of service to retrofit.
- Assumed that 52 airlines not responding to CSSI / IATA equipage survey (10.1% NAT MNPS operations) show the same equipage trends as the 44 airlines responding to the survey (81.6% NAT MNPS operations)

4.3 Description of Costs

Initial costs are the largest costs for commercial operators, particularly costs for equipment, installation, and loss of revenue due to airplane downtime. Recurring costs were negligible in comparison. Recurring costs include maintenance, communications, training, and manual revision. For example, communication costs vary greatly depending on the type of contract that each carrier has with the communication service provider. Some airlines may pay per data link message, others per flight, or others may bundle additional services, such as Airline Operational Communications (AOC). This analysis focuses on initial costs due to equipment and installation.

4.4 Fleet and Data Link Equipage Assessment for Commercial Operators

To understand the number and types of flight operations in the North Atlantic MNPS airspace, a sample dataset of recorded operations spanning from May to September 2010 was used. This dataset included 213,219 flights with an average of 1,394 flights per day. 92.6 percent of the flights were commercial operations, 4.8 percent of the flights were IGA operations, and 2.6 percent were military. In 2010, approximately 50 percent of all flights in MNPS airspace were fully equipped to comply with the mandate. By 2013, almost 70 percent of flights in MNPS airspace are projected to be in compliance. By 2015, this number is expected to increase to 80 percent or more.

4.5 Status of Equipment Availability

In 2010, there were five commercial aircraft types which did not have a commercially available ADS-C and CPDLC solution. These included the Airbus 310, Boeing 747-100, Boeing 747-200, Boeing 747-300, and Boeing Douglas DC-10. In 2010, these aircraft types accounted for three percent of flights in NAT MNPS airspace.

4.6 Results of Cost Analysis for Commercial Operators

This analysis estimates the costs that would result from aircraft gradually adopting the technologies necessary to meet the requirements of the data link mandate before phase 2 comes into effect on February 5, 2015. Equipage levels for 2010 (the first year of the analysis period) are used as the baseline for comparison.

A net present value (NPV) approach was used to distribute the costs of the mandate program for U.S. commercial operators as follows:

- 2010 – 0 percent costs
- 2011 – 10 percent costs
- 2012 – 10 percent costs
- 2013 – 20 percent costs (mandate phase 1)
- 2014 – 60 percent costs
- 2015 – 0 percent costs (mandate phase 2)

Prior experience implementing regulatory measures, such as Reduced Vertical Separation Minima (RVSM), shows that most operators willing to equip would wait until shortly before the rule enters into effect to retrofit. Therefore, the majority of the costs in the NPV analysis were allocated in preparation for phase 2 of the mandate in 2015.
Avionics procurement was the most significant cost for aircraft operators. Retrofit costs for commercial operators range from $50,000 USD to over $1 million USD per airframe depending on the original level of aircraft equipage. Most airframes needing retrofit are somewhere in between these two extremes. Three aircraft types (Boeing 767-300, Boeing 757-200, and Boeing 747-400) account for most of the total commercial retrofit costs (Figure 1). This is because such legacy aircraft are heavily used in the NAT and usually have low levels of equipage (Figure 2).

![Figure 1: Total Undiscounted Equipment Costs per Aircraft Fleet Type. 44 Commercial Operators Responding to Data Link Equipage Survey, 81.6% NAT MNPS Operations.](image)
Most commercial airframes needing retrofit fall within one of the following cost categories (Figure 3):

a) Those needing only FANS-1/A retrofit (cost per airframe from $50,000 USD to less than $200,000 USD)

b) Those having a medium level of equipage (cost per airframe from $400,000 USD to less than $600,000 USD)

c) Those needing a full retrofit with FANS-1/A and pre-requisite systems (GPS, SATCOM, and Flight Management Computer - FMC - upgrade capable of supporting FANS-1/A). In this case, cost per airframe could be over one million USD.
Another significant cost for operators is aircraft downtime and installation. Downtime costs also vary greatly depending on the aircraft type and pre-existing equipage. For commercial operators, if an aircraft only needs installation of the FANS-1/A package, only a few hours of downtime are needed. Pre-requisite systems, such as an FMC upgrade would require an extra day of aircraft downtime. A complete SATCOM or GPS installation would take approximately 5 days and a full retrofit with all the systems would take 6 to 10 days.

In the cases when installation and labor are not included in the equipment costs, an additional $15,000 dollars for one day of airplane downtime to $90,000 dollars for a full retrofit will need to be added. Commercial operators would try to do their extensive retrofits during scheduled maintenance checks to avoid putting an aircraft out of service, which could be very expensive.

There are approximately 2,152 commercial airframes operating in the NAT. After accounting for those airframes that cannot be retrofitted due to lack of equipment commercially available, there are approximately 838 airframes that need some level of retrofit (Figure 4). For all commercial carriers, total retrofit costs are estimated to be $464 million (2010 USD). This includes costs for equipment, installation and downtime. Avionics is by far the largest cost (Figure 5).

![Figure 4: Total Retrofit Needs in 2010. Includes airlines responding to equipage survey (81.6% NAT MNPS Operations) and assumptions for airlines not responding to survey (10.1 % NAT MNPS Operations).]
If Iridium is used instead of Inmarsat when a SATCOM retrofit is needed, total retrofit costs are approximately 12 to 14 percent less. The ICAO NAT SPG concluded that “FANS 1/A (or equivalent) data link communications conducted over Inmarsat I3 Classic Aero, Iridium Short Burst Data and Very High Frequency (VHF) sub-networks have demonstrated acceptable performance for the use of data link services [5].”

Table 1 shows a detailed cost breakdown for U.S commercial operators, differentiating between avionics costs and the cost for downtime and installation.

<table>
<thead>
<tr>
<th></th>
<th>Total number of airframes</th>
<th>Number of equipped airframes</th>
<th>Number of airframes needing retrofit</th>
<th>Number of airframes with no equipment commercially available by 2013</th>
<th>Number of airframes to retrofit</th>
<th>Total avionics cost (2010 USD)</th>
<th>Total downtime cost (2010 USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSSI / IATA Equipage Survey</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(44 Carriers, 81.6% NAT MNPS</td>
<td>1,740</td>
<td>1,062</td>
<td>678</td>
<td>48</td>
<td>630</td>
<td>$305.3M</td>
<td>$28.4M</td>
</tr>
<tr>
<td>Operations)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Operators,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(52 Carriers, 10% NAT MNPS</td>
<td>412</td>
<td>175</td>
<td>237</td>
<td>29</td>
<td>208</td>
<td>$118.7M</td>
<td>$11.8M</td>
</tr>
<tr>
<td>Operations)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>2,152</td>
<td>1,237</td>
<td>915</td>
<td>77</td>
<td>838</td>
<td>$424 M</td>
<td>$40.2M</td>
</tr>
</tbody>
</table>

Table 1: Detailed Cost Breakdown for U.S. Commercial Operators.

4.7 Potential Impact of Fleet Retirements

In addition to providing equipage information for their 2010 NAT fleet, airlines responding to the data link survey gave projections for the years 2013, 2015, and beyond. These projections carry a lot of uncertainty, as there are many economic and business factors that may affect final fleet decisions. The farther out these projections are, the more uncertain they are. The 44 NAT carriers responding to equipage
survey indicated that they expect to retire or replace 121 airframes by 2015. If this projection materializes, it would represent a cost avoidance of $31.9 million (2010 USD) in data link retrofits.

5. BENEFITS ANALYSIS

5.1 North Atlantic Performance Benefits Model

A computer simulation model called the North Atlantic Track System Analysis Model (NATSAM) was developed to assess fuel and time savings (or penalties) derived from implementing a data link mandate and reducing lateral separation to 25 NM in the NAT. The model consists of three modules:

a) A continuous simulation module to model the aircraft performance across the complete flight from an origin airport to a destination airport;

b) A track assignment module to perform heuristic or optimal assignments of flights entering the NAT track boundaries; and

c) A wind module to account for wind conditions along the complete route

5.1.1 Aircraft Performance Module

The benefits model employs the Euro control BADA 3.9 aircraft performance model that has been widely adopted in many airspace cost/benefit studies by FAA and Euro control [1]. The aircraft performance considers a typical flight across the North Atlantic as shown in Figure 6. The model estimates fuel and travel time cost matrices for each flight for various available routes. This process replicates a flight planning activity as it considers wind and fuel costs involved in the selection of optimal versus non-optimal NAT OTS tracks.

The performance calculations are carried out using numerical integration of the BADA 3.9 model with small numerical steps sizes in climb and descent (20 seconds) and a moderate step size in the cruise phase of the flight (3 minutes). The “to NAT Route” segment shown in Figure 6 consists of a climb and a cruise phase to reach the NAT track boundary. Typical detour factors for the first and final segments of the flight are obtained using the Enhanced Traffic Management System data (ETMS) and they are used to model realistic flight tracks from each origin airport to the NAT boundary points. The “NAT Route” segment shown in Figure 6 is flown at constant Mach number optimized for each aircraft. The “Beyond NAT Route” segment considers typical climbs performed by flights crossing the North Atlantic before reaching their destination (Figure 7). The aircraft performance module considers airline operational practices such as takeoff mass distributions as a function of stage length flown. The airline fuel and takeoff mass data was obtained from a survey of 779 flights collected by Airlines for America.
5.1.2 Wind Module

The NATSAM model uses data from the National Center for Atmospheric Research (NCAR) Reanalysis Wind Model developed by the Physical Sciences Division of the Earth System Research Laboratory at the National Oceanic and Atmospheric Administration (NOAA). The Reanalysis model contains 6-hour and daily wind patterns over the North Atlantic using a 2.5 degree grid shown in Figure 8. The model provides winds from sea level conditions to 15,000 meters with a total of 19 pressure levels available. The NCAR wind model implemented in
NATSAM is interpolated in three-dimensions to obtain winds at any altitude flown by the aircraft in the North Atlantic OTS system. Figure 8 shows the winds aloft in the North Atlantic Region for the 250 mb pressure level (~34,000 feet). Seven Eastbound NAT OTS tracks are shown for the simulation day.

Figure 8: Wind Representation in NATSAM Model. Wind Data Source: NCAR Reanalysis Model. Map Source: Google Earth.

5.1.3 NAT Track Assignment Module

The NATSAM model has a track assignment module that assigns flights to NAT OTS tracks based on their relative costs compared to a wind-optimal track selected as preferred alternative. Whereas the aircraft performance module calculates fuel and travel times for all tracks and all flight levels likely to be used in the North Atlantic crossing, the track assignment module coordinates the assignment of tracks to each flight considering the demand levels for each requested track and flight level combination (Figure 9).

Currently, a simple heuristic algorithm assigns the least costly (fuel-based) track to a flight subject to track capacity constraints. For example, a flight requests a desired track and cruise flight level combination as it departs the origin airport. As the flight approaches the NAT OTS track boundary (Figure 9) air traffic controllers provide an updated track-cruise flight level combination that considers other traffic entering the NAT boundary at the same time. Each flight modeled has a wind-optimal fuel track as well as dozens of other sub-optimal solutions for the flight. These sub-optimal solutions are used when capacity constraints prevent the flight using its best wind-optimal solution.
5.2 NATSAM Model Outputs

The NATSAM Model produces numerous outputs that can be used to understand the benefits of the data link mandate and RLaSM. The model produces time-space events of NAT track assignments, summaries of flights assigned to a track-cruise flight level combination for a given day, and summaries of fuel and travel time metrics comparing equipped vs. non-equipped aircraft using the NAT OTS system.

The model produces detailed tables with results at the individual flight level including fuel used statistics, travel time statistics, airline, aircraft type, etc. Finally, the model can also produce summaries of statistics relevant to air navigation service providers. For example, summaries of the number of flights assigned to their requested tracks and cruise flight levels for a given simulation period. These statistics provide valuable insight on how many flights get their wind-optimal tracks and provide an opportunity to gauge system performance of the NAT OTS region.

6. RESULTS

Benefits of the data link mandate (cases 5a and 7a) and reduced lateral separation (cases 5b and 7b) have been studied for two equipage levels. The current level of equipage in the NAT fleet is approximately 50% and Cases 5a and 5b represent a low level of equipage (55%) whereas Cases 7a and 7b represent high level of equipage (90%). The fuel consumption in these two cases is compared against the baseline scenario where there is neither data link mandate nor reduced lateral separation. Table 2 shows the assumed traffic levels and equipage for all modeled scenarios. The benefits and penalties for cases 5a, 7a (data link mandate scenarios) and 5b and 7b (reduced lateral and data link mandate scenarios) are shown in Table 3.
<table>
<thead>
<tr>
<th>Case #</th>
<th>Operational Strategy</th>
<th>Traffic Level</th>
<th>Equipage Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>5a</td>
<td>Data link mandate Phase 2 – all OTS tracks; FL360, FL370, FL380, FL390; from 2015. Only data link equipped aircraft allowed to operate in this airspace</td>
<td>2017</td>
<td>55%</td>
</tr>
<tr>
<td>7a</td>
<td></td>
<td>2017</td>
<td>90%</td>
</tr>
<tr>
<td>5b</td>
<td>Reduced lateral separation – ½ degree spacing in all OTS tracks; FL360, FL370, FL380, FL390; from 2017. Only data link equipped aircraft allowed to operate in this airspace</td>
<td>2017</td>
<td>55%</td>
</tr>
<tr>
<td>7b</td>
<td></td>
<td>2017</td>
<td>90%</td>
</tr>
</tbody>
</table>

Table 2: Modeling Scenarios.

<table>
<thead>
<tr>
<th>Case 5a</th>
<th>Case 5b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefits</td>
<td>$56,630,704</td>
</tr>
<tr>
<td>Penalties</td>
<td>($114,167,562)</td>
</tr>
<tr>
<td>Net Penalties</td>
<td>($57,536,858)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case 7a</th>
<th>Case 7b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefits</td>
<td>$76,229,803</td>
</tr>
<tr>
<td>Penalties</td>
<td>($66,624,673)</td>
</tr>
<tr>
<td>Net Benefits</td>
<td>$9,605,130</td>
</tr>
</tbody>
</table>

Table 3: Benefits and Penalties for Case 5a, 7a, 5b and 7b.

As observed in Table 3, when the level of equipage is low (Case 5a at 55%) and a exclusionary zone is introduced where only data link equipped aircraft can operate, most of the unequipped aircraft are forced to take lower cruise altitudes compared to their wind optimum cruising altitudes. These translate into penalties of $57.5 million in the year 2017. Case 7a represents a higher level of equipage (90%) which translates into a net benefit of $9.6 million. This transition from penalties in Case 5a to benefits in Case 7a is due to the fact that more equipped aircraft are now able to operate in the exclusionary zone. 45% of aircraft in Case 5a have restrictions on cruising altitudes whereas only 10% of aircraft are restricted in Case 7a. Therefore most of the aircraft enjoy benefits in Case-7a whereas most of the aircraft are penalized in Case-5a. Most of the penalties in both Cases are the result of Data link mandate which precludes unequipped aircraft to cruise at altitudes from 36000 ft. to 39000 ft, which is the most optimum altitude range. The results underscore the need to increase the equipage in the future, as the mandate is implemented.
Introducing reduced lateral separation allows the tracks to be spaced at ½ degree separation and facilitates the location of tracks in a more wind optimum fashion. This allows aircraft to fly more efficient profiles than ever and reduces their fuel burn and travel time. As observed in Table 3 when reduced lateral separation is implemented together with Data link mandate, the net penalties for Case 5b are $34.9 million and for Case 7b there is a net benefit of $9.9 million. In both low equipage cases (5a and 5b), unequipped aircraft are vulnerable to heavy penalties if they are excluded from optimal altitudes.

Introducing reduced lateral and longitudinal separations in the NAT OTS increases the capacity and can help mitigate some of the penalties associated with the exclusionary airspace of the data link mandate, generating more benefits for data link equipped aircraft. Since reduced longitudinal separation is outside the scope of this study it is not discussed here.

7. CONCLUSIONS

Costs and benefits have been calculated on a preliminary basis. These results indicate that a holistic approach to implementation of the data link initiatives is necessary and is similar to the portfolio approach being implemented under FAA's NextGen program. All in all, the data link initiative will provide safety and qualitative benefits to aircraft operators and ANSPs. Quantitative benefits in terms of fuel savings can be possible through initiatives such as reducing lateral and longitudinal separation minima, allowing more aircraft to achieve optimal flight profiles. Similarly, penalties for unequipped aircraft are mitigated with increasing data link equipage.

8. REFERENCES

[1] Base of Aircraft Data (BADA) version 3.9
[3] ICAO, April 1999