Local TBS delay reduction effect on global network operations

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Abstract – A flight may be late departing or arriving from an airport because of the delays that occurred earlier on that day. From a small amount of initial delay, it can propagate and compromise on-time performance of the overall operations of the same aircraft. It can propagate on the next legs and compromise other flights as well which causes disruption in the network. A lot of research has been done in the area of flight delay propagation and many models were created to help airlines and operators reduce that very same effect.

The Time Based Separation (TBS) project has brought new methods for separation of arrivals by time instead of distance. It's a promising method for reducing flight delays. In this paper, by collecting flight records data from the Central Office for Delay Analysis in EUROCONTROL, we’ve observed a significant decrease in delays in case of strong headwinds, which proves the very point of TBS’s effectiveness in optimizing runway throughput and network operations. The dataset consisted of around 60,000 flights at London Heathrow airport. By using that data, a few analyses are executed which show us the overall effect on the network.

Keywords: airport delays; delay propagation; network of airports; TBS

I. INTRODUCTION

Flight delay is a major problem facing the air transport industry. It represents a very important burden in the aviation since it has massive impact on global operations. As delays increase so do airline and airport resources (e.g. fuel, crew) i.e. additional resources are needed to compensate for the lost time. Any kind of delay costs the industry, especially the airline, billions of dollars. With the continuous growth of traffic and its forecast for the next upcoming years, flight delays will substantially increase. For that reason the network will become too congested and the airport and airspace capacity will reach their limits very soon if no measures are taken. With respect to that this paper will focus on a promising measure, a runway throughput enhancement (RTE) concept - the Time Based Separation (TBS). In case of strong headwinds while the standard Distance Based Separation (DBS) method is applied, it results in causing delays. The TBS concept however, makes it possible to safely reduce the distance between aircraft thus reducing the delays and overall flight times and workload, resulting in more efficient flight operations. TBS dynamically adjusts the separation between arriving aircraft, maintaining the time separation at a constant equivalent to the distance separation required in a headwind and safely reduces approach separation to recover most of the capacity otherwise lost during strong headwind conditions. During severe weather conditions airport capacity is reduced. One of the most significant issues is the delayed arrivals since it’s taking longer for the aircraft to touch down in high headwind using the standard DBS method for separation.

The situation where the delays present a problem could become worse in the next decade since the air traffic is foreseen to increase. Commercial flight movements increase by 1.7% annually in Europe [1]. Delays harm the stability of the companies due to higher operation costs. In the most-likely future scenario 1.9 million flights cannot be accommodated (12% of total demand) by 2035 within the plans that airports have reported [2]. According to the Central Office for Delay Analysis’s (CODA) report, the average delay per delayed flight increases annually but it is almost negligible. However, in terms of number of flights affected, it continued to increase in the last 5 years reaching 43% in 2016 [3].

A. Related work

To get a deeper understanding of flight delays and flight delay propagation, some research papers have been reviewed and studied. Most of the research is focused on the US air transportation system since the data is accessible much easier than the European. Nevertheless, all these can be implemented and used as a reference in the air transport globally.

Beatty, Hsu did a study on flight delay propagation by analyzing the airline schedule with a concept called ‘delay multiplier’ [4]. Belkoura et al. studied the “airport-mediated propagation of delays by reconstructing a richer metric for delay multiplications” [5]. Schaefer and Millner use the
Detailed Policy Assessment Tool (DPAT) which models the flight delay propagation throughout a system of airports and sectors, to present the effects of simulated changes in capacity due to inclement weather [6]. Pyrgiotis, Malone and Odoni developed the Approximate Network Delays (AND) model using analytical queuing approach to study the propagation of delays in a large network of major airports [7]. The model is still in development so that it can be used to study the impacts of different system-wide programs (e.g. NextGen, SESAR) on a network of airports. Ivanov et al. introduced new methodology to reduce flight delay propagation and improve airport slot adherence [8]. Hansen et al. use three queuing models to determine the 4D trajectory precision (i4D) impact on delay reduction. The analysis focuses on the US air transportation system and the models show promising results. It is found that there is about 35% of delay savings on average [9].

All these models and studies are closely related to reduction of delays and delay propagation. The results obtained in this paper could be inserted in the AND model or DELAYS model [9] to determine the effect on network of airports, but it hasn’t been tested though. NATS and EUROCONTROL have done analysis on the delay reduction as a result of the TBS at London Heathrow (LHR) which showed promising results [15].

B. Aim

The primary objective of this study is to quantify and model a potential delay reduction improvement on a network of airports. This paper will demonstrate the preliminary results obtained.

The sub-objectives of this paper are to:
- Reveal the effect of the TBS implementation on delays
- Demonstrate the flight delay mitigation in the network – for one and two flight legs initially
- Rationalize the obtained results.

C. Overview of flight delays

The departure delay is classified into two main groups, primary and reactionary delay.

Primary delays are the departure delays that occur to different number of variables such as weather, airport operations, airline operations, safety measures, ATFM etc.

Reactionary delay – also known as propagated flight delay or a knock-on delay is the delay that is caused by other delays that occurred the same day. Reactionary delay contributes 45% of the total delay. For every 1 minute of primary delay there is 50 seconds of reactionary delay [3].

In this study the all-cause delay has been considered as it is most feasible. Since reporting delays is voluntarily, in the flight records data some are missing, incomplete or non-feasible. That’s why we’ve taken into account the all-cause delay which is equal to primary delay + reactionary delay. There is no specific delay that can be singled out as a direct effect to the TBS, and if the reactionary delays were the ones taken into account the dataset would have been really small and not feasible enough. Other methods can be considered as well, which are discussed later in the paper.

According to figure 1, the all cause delay is the difference between Actual OUT (actual off block time) and STD (the scheduled off-block time). And for the arrival delay, it’s the difference between Actual IN (actual in-block time) and STA (the scheduled in-block time).

D. Key Performance Indicators

For better understanding of the delays and their propagation and mitigation in the network, specific KPIs will be used in this study.

The KPIs in this paper are total delay indicator in minutes (TDI) and number of delays indicator (NDI).

- TDI – total delay indicator is the amount in minutes (\(\sum_{delay}\)) of all-cause departure delay and arrival delay respectively, which was used in this study. It is used to determine the overall impact on delays.
- NDI – number of delayed flights indicator actually measures the count of delayed flights with one minute of delay or more. In many studies and reports a delayed flight is considered delay if it is delayed by 5 minutes or more (EUROCONTROL), or 15 minutes or more (FAA).
II. DATA COLLECTION

All data for this study were acquired from EUROCONTROL. Since most delays occur in major hub airports and with that having a significant impact on the entire network, in this study only 6 major airports are examined. The scope of the data requirements is:

- Weather data for period before and after TBS implementation
- Airport network – to be as congested as possible
- Flight records data – to match the given criteria in terms of time intervals (periods) and airports.

For this study, flight records data is required for specific days. According to the requirements, before the actual flight records data are requested from CODA and extracted, it is required to define the historical weather data for London Heathrow (EGLL). As TBS is only effective, by the analysis and claims from NATS and EUROCONTROL, in weather conditions with strong winds, for this study 15 days with strongest headwind on a daily average were selected in period before TBS implementation at EGLL and in period after the implementation. The Pan-European Repository of Information Supporting the Management of EATM (PRISME) has access to all the historical weather data and provided a list with days that match the criterion – top 15 days with strongest headwind on average in period before TBS and top 15 days after the TBS implementation. For the second requirement, the network to be as congested as possible, PRISME provided us with a list of airports that are most connected to London Heathrow and in this study we selected the first 5 airports in the European Civil Aviation Conference (ECAC) area. These are: Paris CDG (LFPG), Munich (EDDM), Frankfurt (EDDF), Amsterdam Schiphol (EHAM) and Dublin (EIDW). And as for the wind data, the average wind speed for the days selected before TBS is 17.5 knots and 20 knots after. More detailed data are shown on figures 2 and 3. Based on data from the Airport Unit in EUROCONTROL, these airports didn’t have any notable change in their operation during this time period that could affect the flight delays. This suggests that any kind of effect observed during the selected days must be a direct result from the TBS.

III. CASE STUDY

The analysis is divided in 2 scenarios accordingly. The first scenario is composed of only one relation – all departures out of one airport and all arrivals into that airport respectively. It is subdivided in 6 parts for every airport individually (figure 4).

To better understand the flight delay propagation that occurs across the European air traffic network, another scenario is taken into account. In that scenario, there is a pattern that is being introduced. We’ll define the pattern with an example. Flight “A1” departs LHR and arrives at one of the 5 airports already defined e.g. Paris CDG. This flight is reserved as a first flight leg. The same aircraft, now flight “A2”, departs Paris CDG and arrives at any other airport in ECAC area (figure 5). It can be Prague, Vienna, Madrid, Rome etc. except LHR i.e. doesn’t return to London Heathrow. The reason behind that is that if it returns then will absorb the delay directly by using the TBS’s effect. Anyhow, that’s reserved as a second flight leg. These two legs, however, must occur on the same day.
From the flight data acquired by CODA, there are around 60,000 flights with almost all the information within the time period requested. However, for this study only flights that match specific criteria are required. In order to filter out the required data, a software tool is used. The most reliable and easy to use for this kind of task is Microsoft Excel. The data is sorted out in chronological order and the flights with missing crucial data for measuring delays such as registration number of aircraft, standard time of departure (STD), have been excluded. Only 6 (including LHR) have been selected as departure airports for the analysis in this paper.

For further analysis, since Excel is not powerful enough, MATLAB is coming in place. MATLAB doesn’t have a built-in tool to extract the needed data for further analysis, which requires a custom-made algorithm to filter out the data. The approach used is data mining, more specifically a sequential pattern mining.

Since there are two distinct scenarios, each scenario requires specific conditions thus slightly different algorithms. For the first analysis, data mining algorithm is created to search for all flights departing LHR under specific criteria, to be in the selected network with less than 120 minutes of a departure delay. The only reason by choosing the departure delay to be less than 2 hours is that we are not interested in the cancelled flights and flights which have advanced technical and operational problems that take more than 2 hours. All these can manipulate with the results that we are expecting to obtain. Furthermore the TBS wouldn’t have noticeable effect on long delayed flights. The filtered-out data is laid out in tables, one before TBS and another after TBS. A statistical analysis is done on all departures within the network and results illustrated accordingly. The results in this scenario will give us an answer for the TBS effect on the network.

The other data mining algorithm which is a little bit modified, searches for flights that are in a specific two flight leg pattern departing LHR. For example, if a flight departs LHR, the destination must be one of the other 5 airport hubs and the second leg is subsequent with destination anywhere in the ECAC area except LHR. This will define the effect TBS has on flight delay propagation and their mitigation outside the selected network and demonstrate how other airports benefit in delay mitigation, if there is any.

V. RESULTS

The results obtained from the analysis for both scenarios are presented on charts to demonstrate the overall effect. The factor between the flights analyzed before TBS and after TBS is 1.05. It means that the number of flights in the dataset before and after TBS was almost the same – with around of 5% difference.

Only the first scenario’s results, as origin airport being London Heathrow, are shown on charts with both KPIs respectively. The number of delayed flights has been analyzed and represents the NDI KPI. In figure 6, first series show all departures that have been delayed (DLY_1 > 0) and second series all departures that had arrival delay (DLY_2 > 0). DLY_1 represents all-cause delay first leg and DLY_2 arrival delay first leg. It is quite interesting to see that as departure delays decreased so did the arrival delays which makes other airports benefit in delay mitigation, not only LHR.

To see overall effect on delays, total amount in minutes of delay are being analyzed (figure 7) and a KPI derived, the TDI. This analysis is being used for a sole purpose to observe the delays mitigation in simplest and most comprehensible way. The series represent the sums of all-cause departure delays and arrival delays respectively (∑DLY_1, ∑DLY_2). A total improvement of 38% in departure delay and 44.6% in arrival delay is observed.

Figure 8 and 9 show good improvement too. From 953 departure delays prior to 838 post, which is around 12% reduction on average, is a major change if taking into account all other factors such as traffic, congestion, weather, capacity and so on. As for arrival delays, it is pretty obvious since the
capacity at London Heathrow is improved due to the better landing rate thus less delays (reduction of 16.5%) (figure 8).

As for the other sub-scenarios where the origin airport being other than London Heathrow, promising results were observed for NDI from 14% to 20% of reduction in flights with departure delay and flights with arrival delay – only departures. And for the arrivals from 11.2% to 30.4% delay reduction. Most beneficial was Amsterdam Schiphol where least beneficial was Munich. For the TDI KPI, in case of departures the reduction observed was between 9.8% and 40.8% and in case of arrivals 16.1% to 43.9%. The most beneficial airports analyzed were Amsterdam Schiphol and Paris CDG and least beneficial were Munich and Dublin.

As for the second scenario, when looking at the number of flights affected, there is an improvement in both – all-cause and arrival delay as well (figure 10).

As the figure 10 shows, there is a significant improvement in the total amount of delayed flights in both legs. It is interesting to see reduction in the second leg since it wasn’t expected to get such results. For instance, there are 233 flights with departure delay on their second leg. It is not certain if the previous flight leg had any delay or not. As for the number of arrival delays it is meant for the flights that are delayed at second leg’s destination airport. The airports defined in the analysis are only within the ECAC area.

In the same figure we notice something strange. The number of departure delays in the second leg is higher than the number of arrival delays from the first leg which is logically unexpected. The dataset analyzed consists of all the flights, delayed and on-time. If a flight arrived on-time, it doesn’t mean that same aircraft will fly-out without a departure delay on the next leg. There are many factors for the flight delays and are unpredictable.

Figure 11 represents the total amount of delays in minutes (TDI). Almost 30% of improvement in the departure delay and 40% in the arrival delay is observed which is quite remarkable,
despite the other factors that contribute to delays. In this figure we notice opposite of the figure 10. The simple explanation is that the duration of the delay differs. For example the arrival delay is 3 minutes and the departure delay is 2 minutes, thus clarifies the contradiction between the two figures.

![Figure 11: TDI for all departures – scenario 2](image1)

The subsequent two figures (figures 12 & 13) present the results from the analysis done on flights that are delayed at both airports i.e. with departure delay on both flight legs. Per figure 12, 72 flights were delayed at London Heathrow (first leg) and same 72 flights i.e. aircraft, didn’t recover the delay and got delayed on departure for their second leg as well. Out of these 72 flights only 68 had arrival delay. Comparing the NDI before and after TBS, there has been an improvement of about 30% in number of delays, both departure and arrival.

Figure 13 poses some unclarity when we pay close attention to the relation between departure and arrival delay. The arrival delay should be less than the departure delay, but instead we see a contradiction. Flight delays as explained before are hard to predict and we can’t know the exact reason when all-cause delays are taken into account. The arrival and departure delay have no “relation” at all. Any flight that has a departure delay may or may not have an arrival delay and any flight that departs on-time or before schedule may have an arrival delay. It all depends on the situation of the other airports. The main objective in these figures is to see the overall reduction and observe this mitigation in delay propagation as a result of the TBS which is implemented on one key airport.

![Figure 12: NDI for double delayed flights – scenario 2](image2)

![Figure 13: TDI for double delayed flights – scenario 2](image3)

VI. CONCLUSION

With this paper a better understanding of flight delay propagation in a network of airports and its reduction as a result of a runway throughput enhancement (RTE) concept is established. It contributes to a future RTE concept methodology. Hopefully this research will stimulate further RTE concept studies, especially TBS. A lot more results and details are presented in the master thesis [10] where a mathematical model (DDR – Departure Delay Reduction model) is introduced.

From all the analyses done, it can be concluded that the KPIs have improved significantly as a result from the RTE concept especially in the first scenario. It is obvious that the TBS has a significant reduction effect on delays in severe weather conditions with that reducing the flight delay propagation in global network operations. This concept doesn’t
only benefit the airport it’s implemented on but every airport that is connected to it either directly or indirectly, benefits in delay mitigation. As the delays reduce at these airports, the capacity improves. By inserting these results in a mathematical model such as DELAYS, AND or custom made prediction model, it can be anticipated that the same or similar effect will be applied in a different network of 6 airports.

It has to be noted that the second scenario’s results are based on general assumption since the delays weren’t thoroughly studied.

Furthermore, in addition to these findings, NATS has already made analysis on all the flights departing and arriving at LHR for some time periods after the TBS implementation [15]. It is interesting to point out that 25’000 minutes of delay was saved as result of the TBS based on analysis on 15 days with strong headwinds. In a period of three months, May – July 2015, on average 2.9 additional movements per hour were observed in conditions with strong headwinds and 1.2 movements per hour in all wind conditions.

A. Next steps and recommendations for further work

For further work, a larger network and bigger time frame are going to be taken into account.

As a next step, the following criteria will be considered:

- 30 days before TBS and 30 days after TBS, with strongest headwind on average.
- Network consisting of top 20 most connected airports to London Heathrow.

As the delays are really complex and not so reliable since they come from different sources, it is a good idea to do an analysis on reported delays only where the reactionary delays will be considered or specific delays according to the IATA delay codes. For that to be done, a larger dataset will be needed. According to NATS, around 90 days or more in the year have high headwinds which is a good idea to take into account more days with high headwinds thus larger data.

It is also a good idea to have an analysis on annual basis for the same network of airports and even extend it to the new criteria of 20 hub airports.

As the RTE has been mentioned many times, a delay analysis on Paris CDG is also good idea since the RECAT-EU has been implemented. With these two concepts combined, an index can be derived for the impact it has on flight delay propagation and using that it can be of a great help to build the prediction model for an RTE concept effect on delays [10]. It has to be noted that TBS improves the landing rate in strong wind conditions thus improving the efficiency of the flight operations. The other RTE concepts improve the landing rate and efficiency of operations. That said it should be expected that these concepts will have massive impact on global network operations.

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