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Analysis of Delay Characteristics of European Air Traffic through a Data-Driven Airport-Centric Queuing Network Model

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Abstract: In this paper, we investigate the effect of local disturbances on European airports over the global delay characteristics of the air traffic network. First, the existing traffic data is used for analyzing the busiest European airports and their connectivity to other airports in the network. Based on this analysis, an airport based queuing network model is constructed for simulating delay propagation across the network. The model is used for generating various scenarios where the capacities of airports were reduced under local disturbances (weather effects, air traffic controller strikes etc.). The consequences of these local capacity reductions on the total network delay (departure + arrival) is analyzed. In particular, it is observed that there are airport-specific critical capacity values and if an airport's capacity drops below this critical value, there can be a significant jump in the value of total delay in the network. Results also show that airports that are operating above these critical capacity values tend to have higher tolerance to disturbances, at the expense of using extra resources.

Keywords: Air Transportation, Air Traffic Modeling and Simulation.

1. INTRODUCTION

The air transportation industry and its role in modern life are rapidly growing. It is expected that the number of commercial flights will almost double from 26 million to 48.7 million and 13.5 trillion passenger-kilometer will be flown by 2030, which is almost the triple of what is flown by airlines today (see Airbus (2015)). Total number of new deliveries for both passenger and freighter aircraft are expected to be close to 32,600, while 14,000 passenger aircraft will be retired or converted to freighter (see Airbus (2015)). However, the airspaces have a fixed amount of capacity and the number of airports to be built is not large enough to accommodate such increase in the demand. Therefore, the Air Traffic Management (ATM) system must go under an operational transformation in order to increase its efficiency to deal with these challenge. Meeting the capacity demand and minimizing arrival flight delays are among the most critical challenges of Flight Path 2050 ICAO (2011).

New procedures and concepts that are being developed in SESAR and NextGen are leading to a global paradigm shift from air traffic "control" to efficient air traffic "management", which requires redesigning the ATM system. The first step to design such a complex system is to perform a thorough analysis of connectivity of the airports in the ATM network. This analysis provides a deep understanding of breaking points of the system and unexpected delay generation in the network.

In this work, we provide a data analytic approach to model the European ATM Network Flow for identifying the patterns of delay propagation across the network. To identify these patterns, EUROCONTROL's ALL_FT+ (historical air traffic) data is used for defining the airspace and the network structure through a queuing network modelling and delay propagation analysis. This work focuses on identifying the stochastic parametrization of the ATM network as to be able to predict the behavior of the network under disturbances that lead to airport capacity reduction. Several case studies are examined to understand how local disturbances are propagated across the whole network. Finally, the critical capacity reduction values, which cause significant delay generation over the traffic network are estimated.

1.1 Previous Works

Several researchers focused on queuing network modeling for propagation of local delays in the air traffic network. MITRE Corporation has 2 different National Airspace System(NAS) simulation models for simulation of delay propagation on the nationwide airport and airspace network in the United States. The first one is the National Airspace System Performance Analysis Capability (NASPAC) Frolow and Sinnott (1989) and the second one is the Detailed Policy Assessment Tool (DPAT), which is

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the successor of the NASPAC (see Wieland (1997)). When capacity of an airport is reduced due to external events, DPAT is able to propagate delays across the network, but it does not utilize the information regarding aircraft itineraries, which might lead to unreliable predictions.

On the other hand, there are also agent-based simulation models for delay propagation, such as The Future ATM Concepts Evaluation Tool (FACET) Bilimoria et al. (2001). LMINET Long et al. (1999) and LMINET2 Long and Hasan (2009), are national queuing network models that are model the airports as $M(t)/E_k(t)/1$ queues. While LMINET does not use aircraft itineraries, LMINET2 utilizes this information. The Approximate Network Delays (AND) model is another popular model Pyrgiotis (2012); Pyrgiotis et al. (2013). The modelling approach in AND model and in LMINET2 are similar. However, calculating strategies of the local queuing delays are different. The advantages of this approach are that it is computationally cheap and it can model both deterministic and stochastic effects. Modeling procedure in this paper closely follows these two approaches to analyze the European Air Traffic Network.

The paper is organized as follows. The section 2 gives an analysis of ALLFT+ data to reduce the number of airports in the European Network and validation of the applied strategy. Section 3 provides connectivities of the busiest airports for classification purposes. Next, the airport-centric queuing network model is given in section 4. Section 5 provides an estimation of critical capacity values of European airports. Finally, section 6 presents simulation results for percentile capacity reduction and operating close to breaking point in busiest airports.

2. TRAFFIC DISTRIBUTION IN EUROPE

This section gives the analysis of traffic flow and characteristics of European's airports. For these purposes, 2 months of ALLFT+ traffic data is used, which contains flights in Europe during June 2014 and November 2014.

The busiest airports in 2014 is given in Table 1. It is observed that approximately 20% of all movements in Europe originated from or arrived at these 8 busiest airports.

Table 1. Busiest Airports (June-Nov. 2014)

June 2014			November 2014		
#	Airport	Mov./Day	#	Airport	Mov./Day
1	EDDF	1394	1	EGLL	1252
2	LFPG	1385	2	EDDF	1228
3	EGLL	1340	3	LFPG	1204
4	EHAM	1325	4	LTBA	1148
5	LTBA	1232	5	EHAM	1141
6	EDDM	1096	6	EDDM	1021
7	LEMD	1000	7	LEMD	920
8	LIRF	962	8	LIRF	779
19% of all movements in Europe			22% of all movements in Europe		

It is obvious that an airport generates delays when it reaches its capacity limit. In Europe, most of the airports have daily movements under a 100. This means that most of the airports hourly movements are less than 4. If an airport has only 1 runway, then the hourly capacity of this airport will be around 30. So, this kind of airport operates far from its limit and does not cause delay in network because of capacity constraint. Because of this reason, such minor airports can be taken as an aggregated airport.

In addition to the airports in Europe, non-European airports also inject traffics into European airports. Figure 1 depicts the traffic flow over Europe in directed graphs that are generated by using the actual flight dataset. Vertices represent specific regions and weights on the edges represents the percentage of air traffic flow from one region to another. The letters in the graphs represents the regions, which are provided by ICAO, i.e. L: Southern Europe, Israel and Turkey; E: Northern Europe; U: Russia; K: United States; O: Pakistan, Afghanistan and most of Western Asia; G: Western parts of West Africa and Maghreb.

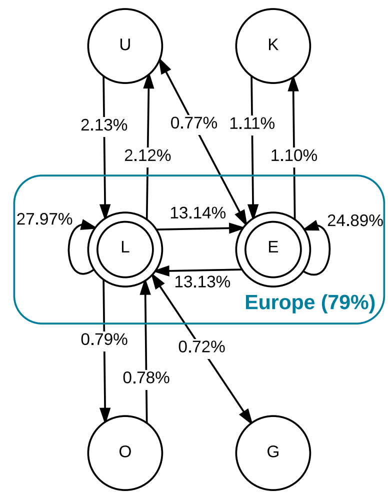

Fig. 1. Regional Air Traffic Flow in Europe in June 2014

In this study, the analysis and model development will be focused on the European region. Moreover, the all flights for non-European airports do not exist in data set. If a non-European airport is considered as an exact airport, the demands caused by European flights will operate under of its capacity limitation without its all flights. So, all of the non-European airports are considered as an aggregated airport. It can be extracted from the Figure 1 that implementing a model focusing primarily on Europe will represent a stronger model with at least 79% actual flow coverage.

After this simplification, all of the minor airports and non-European airports are considered as one aggregated airport. The total number of airports in European network has been reduced to 103 airports, including 102 European major airports and an aggregated airport for Network Model.

3. CONNECTIVITIES OF BUSIEST EUROPEAN AIRPORTS

This section gives the analysis of connectivity of the busiest European airports. The delays in European network are mainly generated by the busiest airports, therefore, the busiest airports are important in delay propagation. The characteristic of an airport can be understood by analysing its connectivity. The relation between the busiest airports and non-European airports can also be investigated and the effects of a specific busiest airport on the network