Transportation Research Part E 73 (2015) 17–46

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

Long-term evolution of airport networks: Optimization model and its application to the United States

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ARTICLE INFO

Article history:
Received 12 April 2014
Received in revised form 29 October 2014
Accepted 31 October 2014
Available online 4 December 2014

Keywords:
Airports
Capacity expansion
Air transportation
Optimization model
United States

ABSTRACT

In this article, we introduce an optimization model aimed to assist aviation authorities in their strategic decisions regarding the long-term expansion of a network of airports. The objective is to maximize total system throughput for a given budget taking into account the capacity of the airports and the impact of travel costs upon demand. The results that can be obtained through the application of the model are first illustrated for a hypothetical small-size network and then in a study regarding the evolution of the network of the principal airports of the United States.

1. Introduction

World air traffic has grown at an average annual rate of approximately 5% over the last three decades. As shown in Ishutkina and Hansman (2009), this growth in air traffic is closely correlated with the level of economic activity, and, according to ATAG (2008), strongly contributes to it – "aviation's global economic impact (direct, indirect, induced and catalytic) is estimated at USD 3560 billion, equivalent to 7.5% of world Gross Domestic Product". In recent years, the air traffic growth rate was lower notably because of the economic downturn experienced in North America and Europe following the subprime crisis of the late 2000s (a rate of minus 3.5% was observed in 2009). However, in spite of conservative assumptions concerning economic growth, scheduled passenger traffic is expected to grow at an average annual rate of 4.1% over the next 20 years (ICAO, 2013).

The increase in air traffic has not been matched with an adequate expansion of infrastructure. As a consequence, the number of delayed flights has been augmenting every year. For example, in the United States (US), and despite the increase of scheduled flight times, the percentage of late arrivals grew from 13.4 to 20.3 between 1999 and 2009 (FAA 2012a, ASPM). The equivalent figures for Europe are 12.4 and 18.0, respectively (EUROCONTROL, 2000, 2010). The incidence of flight delays is especially important in some of the largest airports (over 30% of late arrivals at JFK, Heathrow, Newark, etc.).

Airport congestion problems can be – and are being – dealt with at various levels (aviation authorities, airports, airlines) and in several different forms (Hamzawi, 1992; Forsyth, 2007). In the short-term, demand management measures such as slot allocation systems and de-peaking practices can play an important role (Fan and Odoni, 2002). However, in the long term, despite the efforts that are currently being made in the improvement of control systems (e.g. US's NextGEN, see

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http://dx.doi.org/10.1016/j.tre.2014.10.016
1366-5545/

FAA, 2012b), a significant portion of air travel demand will be left unattended if some existing airports are not expanded and/or new airports are not built.

In this article, we present an optimization model for assisting aviation authorities in their strategic decisions regarding the expansion of the airport network of a country or of a community of countries willing to coordinate their investments in this type of infrastructure. The model determines in a comprehensive manner the best expansion actions to implement in each airport (or multi-airport system) for some long-term scenario used as a reference in the decision process, while complying with a given budget. Expansion actions consist of increasing the number or changing the location of runways at existing airports, and of improving terminal buildings and apron areas. The objective is to maximize total system throughput (hence, the response to air travel demand), taking into account the capacity of airports and the impact of travel costs upon demand. The model can be classified as static and deterministic since it does not determine the best timing for the expansion actions and does not address uncertainty issues (except, possibly, through sensitivity analyses). The applicability of the model is first illustrated for a small-size, hypothetical example and then in a study regarding the evolution of the network of the principal airports of the US. The results obtained in this study are presented and discussed in the light of the FACT 2 study developed by the Federal Aviation Administration (FAA) to identify airports and metropolitan areas that are likely to need additional capacity in the future (FAA, 2007).

We are well aware of the fact that the decision processes regarding the expansion of airports can be extremely complex (see Mozdzanowska, 2008 for detailed information about the US). They involve a wide variety of stakeholders – including airport administrations, local governments, and non-governmental organizations – capable of influencing decisions to some extent, but the final choices are to be made by aviation authorities and, ultimately, by central governments. These choices are expected (required) by the public to be the best possible, but they are too complex to be made and discussed without appropriate decision-support tools. The model presented in this article is, in our opinion, an example of such tools.

The article is organized as follows. We start with an overview of the literature on airport capacity expansion and related topics. Afterward, we present the optimization model developed to address airport network capacity expansion problems and, making use of the small-size, hypothetical example, show the kind of results that one can expect from its application. The method developed to solve the model is described next, being followed by a study of its computational efficiency carried out for a sample of randomly generated instances of various sizes. Then, we present the study regarding the evolution of the network of the principal airports of the US. In the last section, we provide some final remarks and indicate directions for future research.

2. Literature overview

The literature on airport capacity expansion falls into two main categories: airport expansion economics and airport site selection. The key contributions to the former subject were surveyed some years ago by Cohen and Coughlin (2003). They primarily consist of general, theoretical principles to be taken into account when making decisions on the expansion of individual airports. Very recently, Zou and Hansen (2012) extended the analysis to two airports (connected by flights of two competitive airlines). The airport site selection problems dealt with in the literature usually involve the comparison of alternative locations for building or expanding an airport in a given region. Two types of techniques are typically used for this purpose – cost-benefit analysis (see e.g. Cohen, 1997 and Jorge and De Rus, 2004) and multi-criteria analysis (see e.g. Paelinck 1977; Min, 1994; Min et al., 1997 and Vreeker et al., 2002).

In contrast, the literature dealing with airport expansion and/or construction problems at the network level – especially the optimization-based literature – is extremely meager. The consideration of network effects is important because airports are not independent both functionally and (often) managerially. To our best knowledge, Saatcioglu (1982) is the only article published in a leading journal where optimization models are applied to this kind of problems. Specifically, three models are proposed in this article. The first model determines the minimum number of airports necessary to cover a given demand from the population centers of a region within a given distance from the closest airport (thus being a set covering model). The second model considers a given budget for building (or improving) an airport network, and determines the airport locations and capacities that minimize total airport construction costs and bus transportation costs for a given demand (trips to airports are assumed to be made by bus). The third model extends the previous one by considering that demand can be assigned to different types of aircraft and buses.

Despite their merits, these models do not capture important features of air transportation – in particular, demand is assumed to be given instead of depending on demand–supply interactions. Some studies consider the impact of airport congestion on demand and on the traffic pattern within an airport network, but do not deal explicitly with airport expansion and/or construction problems. Hsiao and Hansen (2011) modeled passenger demand as a function of airport delay within the main airport network of the US and analyzed the impact of expanding Chicago O'Hare International airport. Ghobrial and Kanafani (1995) also focused on airport congestion problems within the context of an airport network, but analyzed the changes in hubbing patterns as a consequence of congestion. Evans and Schäfer (2011) focused on a network consisting in 22 airports of the US, and analyzed three different scenarios regarding its expansion. Their approach is based on an equilibrium analysis of five profit-seeking airlines that adapt their flight frequencies, aircraft size and flight network in response to airport congestion. Ferguson (2012) used a similar approach but considered a single airline with "benevolent" behavior