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The impact of airport capacity constraints on future growth in the US air transportation system

Antony Evans*, Andreas Schäfer

Aviation Integrated Modeling Group, Institute for Aviation and the Environment, University of Cambridge, 1-5 Scroope Terrace, Cambridge CB2 1PX, UK

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ABSTRACT

This paper simulates airline strategic decision making and its impact on passenger demand, flight delays and aircraft emissions. Passenger flows, aircraft operations, flight delays and aircraft emissions are simulated for 22 airports in the US, under three airport capacity scenarios. The simulation results indicate that most system-wide implications for operations and environmental impact seem to be manageable, but local impacts at congested hub airports may be significant. The response of the air transportation system to avoid airports with high delays could significantly impact passenger demand and air traffic for these and directly dependent airports. The simulations also suggest that frequency competition effects could maintain flight frequencies at high levels, preventing a significant shift toward larger aircraft, which would otherwise reduce the impact of the capacity constraints.

1. Introduction

Between 1960 and 2005 scheduled passenger air travel grew from 109 billion passenger-km travelled to 3.7 trillion. Forecasts for future growth are also high; Airbus (2007) and Boeing (2007) predict a growth rate of 5% per year over the next two decades, while Schäfer et al. (2009) suggest this growth could continue to at least 2050. Airlines are expected to respond by increasing the number of aircraft movements and aircraft size. Airport and airspace capacity already constrain flight operations at many major airports in Europe and the US; in 2006, the average arrival delays were greater than 15 min at 10 European airports (EUROCONTROL, 2007) and at 23 US airports (US Federal Aviation Administration, 2008). Despite the NextGen requirement to accommodate up to three times the 2004 air traffic by 2025, existing airport capacity expansion plans at major US airports will only increase capacity by an average of 25% (US Federal Aviation Administration, 2008).

Airlines are likely to respond to capacity constraints by adjusting operations so as to maximize profits; e.g. by changing flight frequencies, aircraft size, and flight networks. Such responses may have significant effects on the distribution and levels of aviation emissions across the air transportation system. However, existing aviation-environmental systems' models do not simulate such operational responses. As a result, the projected future levels of air transportation demand may be exaggerated or the capability of the air transportation system to adjust under changing conditions may be ignored, resulting in potentially misleading forecasts of travel demand, traffic growth, and other air transportation system characteristics.

2. Modeling approach

To simulate changes in airline flight frequencies, aircraft size, and flight network in response to airport capacity constraints within a competitive environment, a one-stage Nash best response game is simulated in which airline profit is maximized by each airline (Evans, 2010). An integrated framework, presented in Fig. 1, is applied to capture the effects of passenger demand responses, airline competition, airport capacity constraints, changes in fleet performance, and changes in airline cost.

Profit maximization using a large scale mathematical programming approach is used to model individual airline network, frequency and fleet responses to changes in cost, demand and fares. Optimization is done separately for each airline using a sequence of network optimizations (lower part of Fig. 1) solved within an iterative scheme simulating a myopic best response dynamic until convergence to a Nash equilibrium, which captures the effects of frequency competition between airlines. The airline objective function, equation (1), consists of one revenue and two cost terms, the latter representing airline costs per flight and passenger.

* Corresponding author.
E-mail address: ade26@cam.ac.uk (A. Evans).

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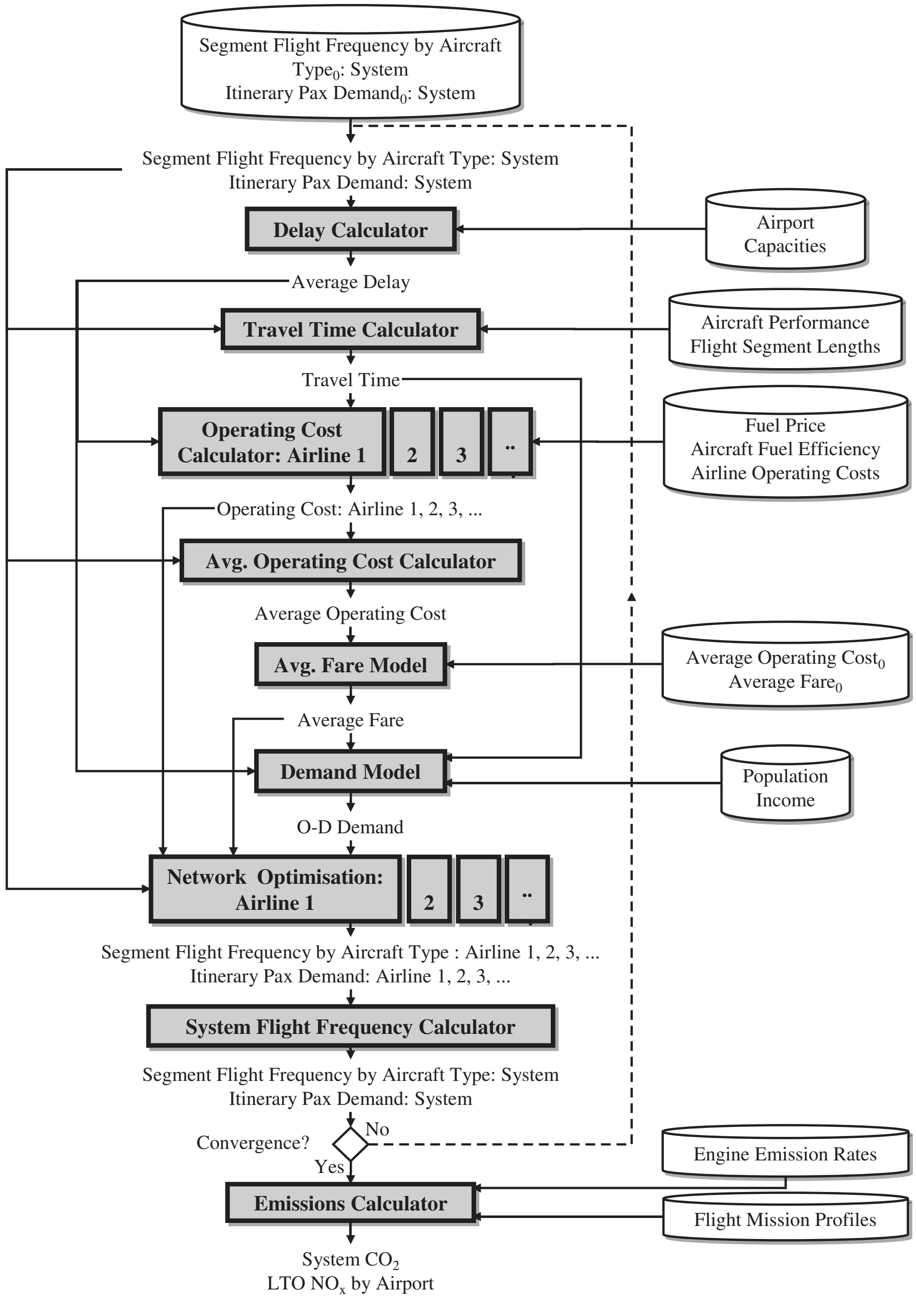

Fig. 1. Modeling framework for simulating airline operational responses to airport capacity constraints.

$$\max\left(\sum_{i\in Cities_a}\sum_{j\in Cities_a}\sum_{p\in P_{i,j,a}}\overline{Fare}_{i,j}\cdot Pax_{i,j,p,a}-\sum_{m\in Airports_a}\sum_{n\in Airports_a}\sum_{k\in SizeClasses_a}Cost_{f_{m,n,k,a}}\cdot Fltfreq_{m,n,k,a}\right.$$
$$\left.-\sum_{i\in Cities}\sum_{j\in Cities_a}\sum_{p\in P_{i,j,a}}Cost_{P_{i,j,a}}\cdot Pax_{i,j,p,a}\right)\quad\forall a\in Airlines \tag{1}$$

where $\overline{Fare}_{i,j}$ represents the fare between true origin–ultimate destination (O–D) city pair i and j, averaged over all itineraries and airlines; $Pax_{i,j,p,a}$ is passenger demand between O–D city pair i and j, on itinerary p, for airline a; $Cost_{f_{m,n,k,a}}$ is average cost per flight on the flight segment between airports m and n, for aircraft type k, for airline a; $Fltfreq_{m,n,k,a}$ represents the average number of flights per day on the flight segment between airports m and n, using aircraft type k, for airline a; and $Cost_{P_{i,j,a}}$ is average cost per passenger between O–D city pair i and j, for airline a. $P_{i,j,a}$ is the set of all passenger itineraries p between cities i and j operated by airline a; $Cities_a$ represents all cities served by airline a; $Airports_a$ is all airports served by airline a; $SizeClasses_a$ is all aircraft types operated by airline a, and $Airlines$ represents the set of all airlines modeled.

Because fare competition is not a key driver of flight frequency, network, and aircraft size choice, average O–D fares are determined exogenously to the optimization, and are input from an average fare