Transportation Research Part A 69 (2014) 286–298

Contents lists available at ScienceDirect

Transportation Research Part A

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

Time to burn: Flight delay, terminal efficiency, and fuel consumption in the National Airspace System

Megan S. Ryerson [a,b,*], Mark Hansen [c], James Bonn [d]

[a] Department of City and Regional Planning, University of Pennsylvania, 102 Meyerson Hall, 210 S. 34th Street, Philadelphia, PA 19104, United States
[b] Department of Electrical and Systems Engineering, University of Pennsylvania, 200 South 33rd Street, 203 Moore Building, Philadelphia, PA 19104, United States
[c] Department of Civil and Environmental Engineering, NEXTOR, Institute of Transportation Studies, University of California, Berkeley, 109 McLaughlin Hall, Berkeley, CA 94720-1720, United States
[d] Federal Aviation Administration, Office of the Assistant Administrator of NextGen, Systems Analysis and Modeling Directorate, NAS Modeling Division, Washington, DC, United States

ARTICLE INFO

Article history:
Received 22 March 2012
Received in revised form 15 August 2014
Accepted 24 August 2014

Keywords:
Aviation
Fuel consumption
Air Traffic Management

ABSTRACT

Improved Air Traffic Management (ATM) leading to reduced en route and gate delay, greater predictability in flight planning, and reduced terminal inefficiencies has a role to play in reducing aviation fuel consumption. Air navigation service providers are working to quantify this role to help prioritize and justify ATM modernization efforts. In the following study we analyze actual flight-level fuel consumption data reported by a major U.S. based airline to study the possible fuel savings from ATM improvements that allow flights to better adhere to their planned trajectories both en route and in the terminal area. To do so we isolate the contribution of airborne delay, departure delay, excess planned flight time, and terminal area inefficiencies on fuel consumption using econometric techniques. The model results indicate that, for two commonly operated aircraft types, the system-wide averages of flight fuel consumption attributed to ATM delay and terminal inefficiencies are 1.0–1.5% and 1.5–4.5%, respectively. We quantify the fuel impact of predicted delay to be 10–20% that of unanticipated delay, reinforcing the role of flight plan predictability in reducing fuel consumption. We rank terminal areas by quantifying a Terminal Inefficiency metric based on the variation in terminal area fuel consumed across flights. Our results help prioritize ATM modernization investments by quantifying the trade-offs in planned and unplanned delays and identifying terminal areas with high potential for improvement.

1. Introduction

Reducing fuel consumption and the environmental impacts of aviation are major goals across the aviation community. While much of onus for reducing fuel consumption falls on the airlines, air navigation service providers (ANSPs), such as the Federal Aviation Administration (FAA) and European Organisation for the Safety of Air Navigation (Eurocontrol), recognize their role in assisting airlines to reduce the costs and environmental impact of aviation fuel consumption. The U.S. and European efforts to modernize air navigation systems, known as NextGen and SESAR respectively, give considerable attention to such benefits (see for example, FAA, 2013). These programs are expected to reduce airline fuel consumption by both

* Corresponding author at: Department of City and Regional Planning, University of Pennsylvania, 102 Meyerson Hall, 210 S. 34th Street, Philadelphia, PA 19104, United States. Tel.: +1 215 746 8236.

E-mail addresses: mryerson@design.upenn.edu (M.S. Ryerson), mhansen@ce.berkeley.edu (M. Hansen), james.bonn@faa.gov (J. Bonn).

http://dx.doi.org/10.1016/j.tra.2014.08.024
0965-8564/

allowing more efficient flight plans and greater adherence to those flight plans in actual operations (thereby reducing delay and inefficient routings).

Nonetheless, ANSPs struggle with the importance of their role in reducing aviation fuel consumption and in setting quantitative targets for such reductions. The potential amount of fuel to be saved by improved air navigation services is unclear. Since the major source of such savings is likely to be better Air Traffic Management (ATM) and operational performance, ANSPs are working to quantify the fuel savings benefit pool—the upper limit on potential fuel savings—from such improvements.

A joint FAA/Eurocontrol (2012) study estimated this benefit pool by comparing the fuel consumed by flights on their actual trajectories against idealized trajectories. The FAA/Eurocontrol study found significant potential savings in fuel consumption on the order of 6–8%. For the en route phase, the estimates are derived from excess distances of actual routes compared to great circle ones, which are then converted into times and finally into fuel burn. For the terminal phase, the estimation procedure is more complicated, but in general is based on comparisons between actual flights and benchmark flights entering the terminal area from a similar direction and under comparable conditions.

While carefully done, the FAA/Eurocontrol study has several limitations. First, it did not have access to actual fuel burn data for the flights it analyzed. Second, it is largely based on distances flown and thus overlooks the effects of delays relative to the initial schedule or the flight plan. Third, the method for estimating the terminal area benefit pool is arguably too conservative since benchmark values assumed the same basic terminal route structures as exist in the present system.

In this study we seek to supplement the findings of the FAA/Eurocontrol study in each of the above respects. First, our analysis is based on actual fuel burn for a large set of flights. Second, we consider the impact of different forms of flight delay on fuel burn. Finally, instead of basing terminal inefficiency on comparisons with benchmarks for a given terminal, we instead identify, statistically, the most efficient terminal areas, and estimate the savings if all terminal areas could match the performance of the most efficient ones.

As noted, our analysis is based on empirical fuel burn data for a large set of flights, and exploits the substantial variation in the delays and different terminal areas of flights within this set. Careful analysis of the fuel consumption differences associated with this variation provides a basis for estimating the effects of interest. Virtually all of these flights were presumably operated in conformance to stringent safety standards, which may not be possible were all flights to fly great circle routes as posited in the FAA/Eurocontrol study. On the other hand, our analysis does not address gains from further improvements that would result from adopting more efficient trajectories. To the extent that this could be done without compromising safety, the resulting benefits could be added to the ones we estimate here.

To evaluate the potential for reduced delay as well as more efficient terminal area operations to reduce fuel consumption, we develop a statistical model of fuel consumption based on historical airline and FAA data. The model isolates the contribution of variables that capture delays, and also includes fixed effects for different terminal areas. Section 2 introduces the methodology and modeling approach and discusses the data collected. Coefficient estimates are presented and discussed in Section 3. In Section 4 we use the coefficient estimates to calculate the fuel consumed due to flight delays and terminal area inefficiencies in the terminal area and ultimately calculate the percent of total fuel consumption that can be attributed to these factors. Section 5 offers conclusions and recommendations for further research.

2. Methodology and modeling

In this section we present an overview of the fuel consumption model from which we will isolate the impact of delay and terminal area inefficiencies on fuel consumption. We then discuss the definition of the delay variables in depth, as well as the additional variables employed in the analysis. Finally, we describe the data sources used in the research.

2.1. Fuel consumption model overview

We consider airborne fuel consumption (f) for a flight n of aircraft type a to have the following form:

$$f = g_n(c, \vec{d}, q, \vec{y}, \vec{w}) + \varepsilon \tag{1}$$

where c is a baseline (simulated) airborne fuel consumption value; $\vec{d}$ is a vector of operational performance variables; q is a value representing assumed and actual take-off weights; $\vec{y}$ is the vector of dummy variables indicating the origin and destination airports of the flight; and $\vec{w}$ is a vector of airport weather variables. The key vectors of interest include $\vec{d}$, $\vec{y}$, and $\vec{w}$, as they capture the impact of delays on fuel consumption. The additional variables also influence fuel consumption and are therefore included in order to isolate the impacts of $\vec{d}$, $\vec{y}$, and $\vec{w}$.

2.1.1. Delay variables

The vector $\vec{d}$ includes the three delay variables: airborne delay (ℓ^r), which is the difference between planned and actual airborne time; departure delay (ℓ^d), the difference between planned and actual departure time; and excess planned flight time (ℓ^p), the additional planned gate-to-gate time above an estimated unimpeded value. We define departure time as dt; airborne time as at; and the three possible subscripts s, a, and i to represent planned, actual, and unimpeded time. Each of the three defined delay variables are a function of the following reported values for every flight: planned departure time