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Robust Scheduling: An Empirical Study of Its Impact on Air Traffic Delays

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ABSTRACT

We develop an econometric model to analyze the real-life impact of two robust scheduling approaches, namely limiting hub connectivity and implementing swap opportunities, based on a broad dataset of the U.S. domestic market. Our analysis is from a novel aircraft routing perspective. We confirm a delay-driving effect of direct hub connectivity and a delay-reducing effect of swap opportunities. Indirect hub connectivity provides airlines with another approach to limit delays. We furthermore contrast that the business model of Southwest Airlines cannot leverage the delay-reducing effects resulting from swap opportunities.

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1. Introduction

Delays are a serious problem in air transportation reaching far beyond the immediate inconvenience experienced by passengers. In studies issued by the Joint Economic Committee (Schumer and Maloney, 2008) and the National Center of Excellence for Aviation Operations Research (NEXTOR, 2010) the total cost of U.S. air transportation delays in 2007 was estimated to be in the range of US$31.2 billion to US$40.7 billion. The U.S. Bureau of Transportation Statistics (BTS) classifies delays into five categories. In 2015, the most common causes of delay were aircraft arriving late (36.23 percent), followed by air carrier delays attributable to maintenance, crew or baggage loading problems (30.43 percent), delays associated with the national aviation system (29.78 percent), extreme weather (3.39 percent), and security delays (0.2 percent) (BTS, 2015).

Airline delays have been studied from a policy-guiding perspective with respect to whether airlines internalize the congestion cost at airports they dominate (Brueckner, 2002; Mayer and Sinai, 2003; Brueckner and Van Dender, 2008; Daniel and Harback, 2008; Santos and Robin, 2010). Delays have furthermore been perceived as an element of airline service quality and, thereby, a result of the airlines' strategic and tactical decisions. Among others, the relation between delays and competition has been studied but results are not fully consistent. Greenfield (2014) finds indications that airlines strive for high on-time performance in order to increase market share on routes. Bubalo and Gaggero (2015) investigate delays when low cost carriers enter a market and empirically show that the increased competition has a delay-reducing influence. Bendinelli et al. (2016) address airline delays by separating the market-based level of competition and the airport-based dominance of an airline. They equally find a decrease in delays as competition on an origin-destination-market increases, whereas delays decrease as competition at an airport decreases. In contrast, Prince and Simon (2015) analyze U.S. domestic on-time performance and observe that when low cost carriers threaten to enter or actually enter an origin-destination-market, legacy car-

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riers tend to worsen their on-time performance. Baumgarten et al. (2014) point out that airlines that offer connecting services have a better on-time performance than those offering direct connections – even though direct connections require simpler operations. Our work complements the line of research on delays as an indicator of airline service quality. We are interested in which decisions of an airline will lead to a change in its own delays and thus have an impact on service quality. We focus our analysis of delays on daily aircraft routings instead of the more common airport or flight perspective. We can hence observe effects that accumulate during a day of aircraft operation. As mentioned above, 'aircraft arriving late' is the most common cause of delay observed by the BTS and our analysis allows to integrate this aspect.

Many airline networks are structured as so called hub-and-spoke networks. Airlines operate their flights from a multitude of spoke airports to few hubs where passengers may connect to flights, either for their spoke destination airport, or to a long distance flight to another hub airport. Hub-and-spoke networks typically involve peak hours at hubs at which flights arrive and depart in so called waves (Martín and Voltes-Dorta, 2009). Hub airports allow to avoid capacity shortages at specific airports, increase spatial coverage, and serve thin markets (Tretheway and Oum, 1992). Furthermore, aircraft routings that connect different hubs are usually characterized by high load factors, since there is a high passenger demand for these markets (ITF, 2013). Each hub-and-spoke airline has individual hubs and some airports serve as hubs to multiple airlines. Apart from offering connecting services at hub airports, hubs also fulfill operational requirements for airlines. Standby crew and aircraft are based at hubs and maintenance facilities are oftentimes located at hubs. A clear downside of flight schedules involving hubbing activities is their sensitivity to disruptions, since hub airports are likely to have high volumes of traffic, and are susceptible to congestion.

Point-to-point networks are constructed from direct flights between airports and primarily cater to the local market than to connecting traffic. Point-to-point carriers feature so called focus cities that are of particular commercial interest and that may serve as home or technical bases for crew, aircraft, and maintenance.

Fig. 1 displays two airline networks in the first week of July 2013. The US Airways network is depicted on the left side (flights to Alaska and Hawaii are omitted for presentation reasons). One easily identifies the hubs at Phoenix Sky Harbor International Airport as well as Charlotte Douglas International Airport. Together with the two additional hubs at Ronald Reagan Washington National Airport and Philadelphia International Airport these four airports offer the highest number of connections in the network. The comparable network of Southwest Airlines is depicted on the right side of Fig. 1. Southwest Airlines operates its network with ten focus cities, for instance, Denver International Airport, Chicago Midway Airport, and Dallas Love Field. However, US Airways' hub-and-spoke network shows by far less direct connections than the point-to-point network operated by Southwest Airlines.

If airlines are confronted with disruptions they may apply short-term recovery tactics to recover the delay – at least in part. It is, however, more promising to construct airline schedules in such a way that they "perform well under operational irregularities" (Lee et al., 2007, p. 1949). These schedules are referred to as robust schedules. Robust airline operations are an important field of research. Lee et al. (2007) identify two paths in constructing robust airline schedules: first, to create schedules that are less sensitive to disruptions and, second, to build more flexibility into schedules. Both approaches are intended to reduce the impact of disruptions in operations and, thus, to reduce delays. Our work focuses on two approaches from the latter category, namely *hub connectivity* (Rosenberger et al., 2004) and *swap opportunities* (Ageeva, 2000). Based on U.S. domestic air traffic data, we empirically test the effect of reducing hub connectivity and implementing swap opportunities on air traffic delays.

We develop an empirical model to analyze the impact on airline delays of implementing two robust scheduling strategies into flight schedules. We focus on the robust aircraft routing concepts of *hub connectivity* and *swap opportunities* because, despite numerous references to them in literature, knowledge on their impact on a comprehensive real-life operations dataset is very limited. Atkinson et al. (2016) find a delay-reducing effect when airlines operate more aircraft of the same type in close temporal proximity from an airport. This is a precondition for swap opportunities that we investigate in more detail. We analyze the aircraft routings to unveil at least two such meetings in routings, allowing for the swap back to the regular routing. In order to gain detailed insights into how hub connectivity influences delays, we operationalize the hub connectiv-

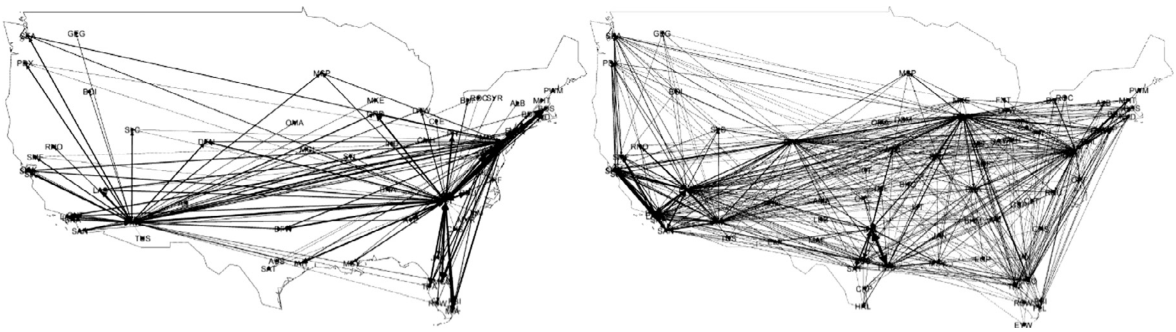

Fig. 1. The networks of operated connections of US Airways (omitting flights to Alaska and Hawaii) and Southwest Airlines.

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