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The time slot allocation problem under uncertain capacity

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ABSTRACT

This paper presents two stochastic programming models for the allocation of time slots over a network of airports. The proposed models address three key issues. First, they provide an optimization tool to allocate time slots, which takes several operational aspects and airline preferences into account; second, they execute the process on a network of airports; and third they explicitly include uncertainty. To the best of our knowledge, these are the first models for time slot allocation to consider both the stochastic nature of capacity reductions and the problem's network structure. From a practical viewpoint, the proposed models provide important insights for the allocation of time slots. Specifically, they highlight the tradeoff between the schedule/request discrepancies, i.e., the time difference between allocated time slots and airline requests, and operational delays. Increasing schedule/request discrepancies enables a reduction in operational delays. Moreover, the models are computationally viable. A set of realistic test instances that consider the scheduling of four calendar days on different European airport networks has been solved within reasonable – for the application's context – computation times. In one of our test instances, we were able to reduce the sum of schedule/request discrepancies and operational delays by up to 58%. This work provides slot coordinators with a valuable decision making tool, and it indicates that the proposed approach is very promising and may lead to relevant monetary savings for airlines and aircraft operators.

1. Introduction

Congestion in air traffic causes very high expenses for airlines and aircraft operators every day. Although air traffic demand is below the pre-economic crisis levels of 2007 and 2008, costs caused by flight inefficiencies in 2011 amounted to 5.2 B€ in Europe only, as reported by EUROCONTROL's Performance Review Unit (EUROCONTROL, 2012). Despite being "fully coordinated", the most congested airports in Western and Central Europe suffer persistent congestion. Full coordination of an airport means, essentially, that the number of flights scheduled at the airport per hour (or other unit of time) is not allowed to exceed the "declared capacity" of the airport (deNeufville and Odoni, 2003). This picture is even gloomier if we consider EUROCONTROL's forecasts on the future evolution of air traffic. In fact, despite the slowdown in the air traffic market caused by the global economic crisis, air traffic is expected to double by 2035 in the most likely scenario. This will leave 12% of traffic demand not accommodated and the 20 busiest European airports heavily congested (EUROCONTROL, 2013). In the long term, planning the increase of current airport capacity is an absolute prerequisite to cope with the projected traffic

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demand. However, at least in the short-medium term, optimizing the use of existing capacity is necessary in order to alleviate congestion.

Several approaches have been proposed to alleviate congestion and resolve demand-capacity imbalances. Medium term approaches, such as the use of slot auctions or congestion pricing, are mostly administrative or economic in nature, and try to alleviate congestion by modifying spatial or temporal traffic patterns, see Brueckner (2002), Fan (2003) and Raffarin (2004), among others. Short term approaches consider the operational adjustment of air traffic flows to match available capacity, and typically span a planning horizon of less than 24 h. On short term approaches, a wide body of literature is available. The interested reader may refer to Odoni (1987), Richetta and Odoni (1994), Dell'Olmo and Lulli (2003) and Ball et al. (2010) to mention a few. In addition to the cited models, that are flight-based, i.e., they model each single flight, aggregate models that consider flows of flights have been developed with the scope of reducing computational times. Among these macroscopic models, we cite Bayen et al. (2006), Sun and Bayen (2008), Wan and Roy (2008) and Andreatta et al. (2011).

Herein, we focus on medium term initiatives aiming to allocate time slots among airlines and aircraft operators efficiently. A "time slot", or "slot" for short, is the amount of capacity needed by an aircraft to land or take-off. More specifically, it is a permission given by a coordinator for a planned operation to use the full range of airport infrastructure necessary to arrive or depart at a Level 3[1] airport on a specific date and time (Worldwide Slot Guidelines, 2012).

Slot allocation is *de facto* handled according to the guidelines of the International Air Transport Association (IATA). Since 1974, IATA has provided the global air transport community with a single set of standards for the management of airport slots, outlining policies, principles and procedures for slot allocation. These guidelines are the result of consultation between airlines and airport coordinators, reflecting the proven best practice for the coordination and management of airport slots (Worldwide Slot Guidelines, 2012). For the allocation of slots at European Union airports, IATA guidelines are enriched with further conditions aiming to encourage the efficient use of airport capacity through the optimal allocation of slots (DotEcon, 2002, see Czerny et al. (2008) for details).

European Commission regulation 95/1993 guarantees that slot allocation is based on neutral, transparent and nondiscriminatory rules. In this regulation process, each Member State has the duty of appointing a schedule coordinator at airport or national level with the ultimate mission to operationalize, coordinate, supervise, and arbitrate the slot allocation process. The fundamental principle of the slot allocation process is the *grandfather right*, i.e., the right of an airline to keep a slot of the preceding equivalent season. This right is granted if and only if such a slot was used at least 80% of the time (*use-it-or-lose-it* rule). However, this procedure is far from being efficient. Indeed, as reported by Airports Council International (ACI) Europe, unsatisfied/unaccommodated demand, overbidding, late return of unwanted slots, flights operated significantly and repeatedly off slot time ("off slot"), and failure to operate allocated slots (the so called "no shows"), are all factors pointing or contributing to the inefficient allocation and use of an already insufficient resource (see also Zografos et al. (2012)). Several amendments to the EC regulation have been adopted or proposed with the scope of ensuring the fullest and most flexible use of limited capacity at congested airports. For instance, regulation (EC) 793/2004 was adopted to strengthen the coordinator's role and the monitoring of compliance, i.e., the usage of slots with respect to the allocation, to verify that airlines do not use a slot in a significantly different way than allocated by the coordinator.

Based on the UK experience, the Commission is also considering to change the current regulation to allow for the introduction of market-based mechanisms across the EU provided that safeguards to ensure transparency and undistorted competition are established, including greater independence for slot coordinators. Several studies have been proposed to analyze the introduction of market-based mechanisms in the slot allocation process. Rassenti et al. (1982) developed a sealed-bid combinatorial auction for the allocation of time slots to competing airlines. A similar approach has been proposed by Ball et al. (2005). Kleit and Kobayashi (1996) and Fukui (2010) examined whether slot markets have resulted in anticompetitive activities with restricted market entry and service expansion by other carriers, especially rival carriers. Verhoef and pricing (2010) looked into some alternative economic instruments for managing congestion at airports, notably slot sales and slot trading. In the last few years, secondary trading has achieved a lot of attention by the research community. Some of these studies have been commissioned by the EU Commission as a guidance on the possible market and legal impacts of the introduction of such trading. For instance, Matt McDonald (2006) analyzed into details the likely effects of the introduction of secondary slot trading into Community legislation, while Starkie (1998) examined the arguments for and against a secondary market in slots, focusing on evidence from US airports. Furthermore, Pellegrini et al. (2012) proposed a market mechanism for secondary trading based on budget balanced combinatorial exchange.

In this paper, we focus on the judicious assignment of time slots to aircraft operators with the purpose of obtaining an "effective" and "reliable" airline schedule. The schedule is considered "effective" if the assigned slots respect airline preferences. Currently, slot allocations at different airports are independent, while the necessity of coherently allocating the departure and arrival slots at origin and destination for each flight is widely recognized. Furthermore, it is necessary to consider interdependencies among flights operated by the same airline. The approach we propose, based on mathematical programming, allocates slots at all airports simultaneously, considering a true network of airports thus guaranteeing the coherence of the final result, i.e., the airline schedule. We refer to the difference between airline requests and the schedule, i.e., the

[1] Level 3 or fully coordinated: airports where capacity providers have not developed sufficient infrastructure, or where governments have imposed conditions that make it impossible to meet demand. A coordinator is appointed to allocate slots to airlines and other aircraft operators using or planning to use the airport as a means of managing available capacity.