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Heuristic search for allocation of slots at network level

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ABSTRACT

This paper considers the allocation of slots for a network of coordinated (congested) airports, where the term "slot" refers to a time on a specific day when a carrier is given permission to use the full range of airport infrastructure for the purpose of landing and take-off at a slot-controlled airport. We take into account the existing IATA rules and guidelines: priorities of requests for slots, the capacity limitations at each airport, the minimal turn-around time between arrival and subsequent departure of the same aircraft, and allocation to series of slots rather than to individual slots. Given the complexity of the problem, we propose an approach that consists of (i) a constructive heuristic procedure to generate a feasible and coherent allocation of slots for each airport from the network, and (ii) an iterative heuristic to improve the quality of an initial feasible solution in terms of the schedule delay (time difference between allocated time slots and airline requests). To evaluate whether the approach would be practical in real operation, we perform tests on a set of generated benchmark instances that span an entire scheduling season. The instances differ by the number of airports in the network and by the distribution of requests among airports from a given network - the largest number of airports forming a network is 100, while the maximum total number of aircraft movements considered on a half-yearly basis exceeds $4.6 \cdot 10^6$. We provide computational comparisons with solutions obtained when each airport from a network is considered independently (the en-route constraint is ignored). These results reveal that the consideration of the en-route constraint, which ensures a coherent allocation of slots at origin and destination airports, introduces only a minor degradation in the schedule delay and in the number of unaccommodated requests. Furthermore, we investigate the heuristic performance for reduced-capacity scenarios.

1. Introduction

According to an air traffic growth forecast scenario that EUROCONTROL identified as the most-likely scenario for Europe (EUROCONTROL, 2013), the number of flights will increase to 14.4 millions by the year 2035, which is 50% more than in 2012 with an average annual growth of 1.8%. However, this growth will be restricted by the available airports' capacities, based on capacity expansion plans presented in a recent survey. As a result, in the most-likely scenario, around 1.9 million flights (constituting 12% of the demand) will not be accommodated in 2035. Over-stretched capacity limits will lead to a rapid increase in congestions at airports, putting added pressure on the network and resulting more delays. Although the expansion of airport capacity seems as the most obvious solution, it is often not realistic due to cost and space limitations. As an alternative way to deal with the problem, capacity allocation at congested airports is subject to strict regulations and

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guidelines that are developed and evolved under the patronage of IATA. Capacity at congested world airports (excluding the US)[1] is generally expressed in slots, where a slot can be defined as "the permission given to a carrier to use the full range of airport infrastructure necessary to operate at a slot-controlled airport on a specific date and time for the purpose of landing and take-off" (I.A.T. Association, 2015). Conforming to the IATA guidelines, requests are allocated to series of slots rather than to an individual slot, where a series of slots consists of at least five slots requested for the same time and day of the week over a specified period of time. Furthermore, each request for slots is classified within one of the three main priority groups: (i) requests with historical (grandfathered) rights; (ii) requests that qualify as new entrants; and (iii) all other requests. The allocation is proceeded hierarchically with the objective being to match as closely as possible the allocated to requested times for each priority class. Slot scheduling problems are categorized into tactical (covering a period of 6–12 h during the day of operation), pre-tactical (carried out several days before operation), and strategic (spanning 2–12 months before operation). Strategic allocation of slots is carried out twice each year, for summer and winter periods. One of the main mechanisms of the IATA allocation process are biannual, international scheduling conferences for airport and airline stakeholders. Prior to this event (pre-conference activity), airport coordinators receive confidential requests from airlines for their preferred slots. These preferences are then compiled into an initial allocation proposal by considering allocation procedures (rules) and request priorities. At the conference, airlines examine the original slot allocation outline for each airport to reach an agreement for slot allocations in the following season. In case that a schedule proves to be infeasible for an airline's network, the airline might negotiate with another airline a mutually favorable exchange of slots after the conference.

Nevertheless, according to a study performed by Airport Council International (A.C.I. Europe, 2004), IATA administrative measures have proven to be weak even for today's level of traffic resulting in unaccommodated slot requests, overbidding, late return of unwanted slots, failure to use assigned slots ('no shows') or flights operated off slot times ('off slot'). The above issues are partly due to the infeasibility in the predefined schedule which is identified shortly before the day of operations. Airport Council International estimated a loss of approximately 20 million Euros per season at large congested European airports stemming from late return of slots that cannot be reallocated to other airlines (A.C.I. Europe, 2009). In Zografos et al. (2012), the authors draw further attention to the inefficiency of the initial (pre-conference) allocation process as it produces allocations that fail to satisfy airlines' initial requests for slots. This is also due to the fact that slot coordinators are required to empirically conduct a very complex allocation process with limited availability of rule-driven support tools for slot management.

To alleviate the weaknesses in the current airport capacity management, different demand management measures (Madas and Zografos, 2006), as well as alternative solutions to congestion from an economic point of view, have received a lot of attention in the recent literature. A great volume of work focuses on the way that congestion should be controlled through congestion-based fees (Brueckner, 2002; Morrison and Winston, 2007). Other work in the area is based on various forms of congestion pricing and slot trading, while evaluating the potential gains under different demand, cost and market circumstances (Fan and Odoni, 2002; Verhoef, 2010). Furthermore, employment of market-based tools such as slot trading and auctions of (part of or the entire) slot pool have been taken into consideration (TUB, 2001; NERA, 2004). The common feature of these measures is the introduction of exceedingly new mechanisms that are not applicable in practice. Allocation of scarce airport capacity has further been tackled by means of dedicated slot scheduling approaches that can either deal with a single airport or with a network of airports. For the case of single airport allocation of slots at the strategic planning phase, the author in Kösters (2007a) presents an iterative heuristic with the aim to minimize the difference between requested and allocated slot times - for different degrees of declared capacity, demand and slot usage. However, this work does not take into account some crucial features of the problem such as series of slots and priorities of requests. To mitigate this problem, the authors in Zografos et al. (2012) develop a strategic, single-airport optimization model implementing the existing EU/IATA scheduling rules. When assessed on three regional Greek airports with up to 1824 requests on a half-yearly basis, the proposed approach showed encouraging results and demonstrated that there is a large gap for improvement in the existing airport schedule.

One of the major flaws in practice at the primary slot allocation phase is the neglection of slot coherency at origin and destination airports (Zografos et al., 2017). Allocation of slots is coherent if the arrival slot at the destination airport is approximately equal to the departure slot at the origin airport, plus the flight time between the two airports. More precisely, the assignment of a departure time interval at the origin airport of a flight constrains the arrival time interval at the destination airport. Therefore, independent determining of a feasible slot schedule at each airport of the network does not imply a feasible allocation for the entire airport network, as it has been underlined in several studies (Corolli et al., 2014; Kösters, 2007b; NERA, 2004). The consideration of the en-route constraint in the pre-conference activity would thus shorten the current (lengthy) slot allocation process, where airlines need to interact several times with coordinators, and often with other airlines, to reach an acceptable and applicable schedule. The first work that takes into account the interdependence among slots at different airports is based on a combinatorial auction mechanism for airport slot allocation (Rassenti et al., 1982), where the main focus was on the efficiency and robustness of the auction design. In Castelli et al. (2012), the authors presented an integer programming model for a network of airports with the objective to (i) maximize the number of accommodated flights and (ii) to minimize the difference between requested and allocated slot times, such that the capacity constraints of all the airports in the network are respected. As the exact method from Castelli et al. (2012) is unable to deal with instances of realistic size due to the consideration of the capacity constraint, the same authors suggest in Pellegrini et al.

[1] At the US airports, IATA rules do not apply and the demand is not managed, while a flight schedule is only influenced by the anticipated delays.