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Integrated airline planning: Robust update of scheduling and fleet balancing under demand uncertainty

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ABSTRACT

The airline schedule planning problem is defined as the sequence of decisions that need to be made to obtain a fully operational flight schedule. Historically, the airline scheduling problem has been sequentially solved. However, there have already been many attempts in order to obtain airline schedules in an integrated way. But due to tractability issues it is nowadays impossible to determine a fully operative and optimal schedule with an integrated model which accounts for all the key airline related aspects such as competitive effects, stochastic demand figures and uncertain operating conditions. Airlines usually develop base schedules, which are obtained much time in advance to the day of operations and not accounting for all the related uncertainty. This paper proposes a mathematical model in order to update base schedules in terms of timetable and fleet assignments while considering stochastic demand figures and uncertain operating conditions, and where robust itineraries are introduced in order to ameliorate miss-connected passengers. The proposed model leads to a large-scale problem which is difficult to be solved. Therefore, a novel improved and accelerated Benders decomposition approach is proposed. The analytical work is supported with case studies involving the Spanish legacy airline, IBERIA. The presented approach shows that the number of miss-connected passengers may be reduced when robust planning is applied.

1. Introduction

The airline schedule planning problem is defined as the sequence of decisions that need to be made to make a flight schedule operational. Given the high level of competition in the airline industry, effective decision making is crucial to the profitability of an airline. However, this decision making should not be only based on the available airline's resources. Passenger demand fluctuations arising from stochastic market demands could affect the actual performance of the planned schedules. In practice, the performance of an optimal plan could be reduced when applied to actual operations where passenger demand fluctuations occur. In other words stochastic disturbances arising from variations in daily passenger demand could affect the optimality of the fleet assignments and timetables. Therefore, to set a good flight schedule, not only the fleet and related supply have to be considered, but passenger demand fluctuations arising from stochastic market demands in actual operations also have to be taken into account. This is the motivation for this study in which we focus on the integration of the decision making process. Our goal is to achieve simultaneous rather than sequential solutions, all while accounting for uncertain environment conditions such as demand fluctuations and operating conditions. Note that a simultaneous

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solution will generate more economical solutions and create fewer incompatibilities between the decisions and that a greater robustness degree may be achieved, obtaining smoother solutions, which in case of incidents may be recovered in an easier way.

Note that stochastic disturbances not only may come from the passenger demand side. Operating conditions are highly uncertain and may also have heavy impacts on schedules. In this paper, although uncertain conditions are addressed from two points of view, namely passenger demand realization and flight connection time, all those aspects regarding aircraft routing and crew scheduling are out of scope.

Designing an airline network is an extremely complex task due to the huge number of variables affecting the design, i.e. passenger demand, ground facilities and capacity, competition, etc. These issues are not always easily modeled and usually result in huge models. Here, the type of network to be operated is decided (i.e., hub and spoke network, point to point network, linear network). Legacy airlines usually use hub and spoke networks, which is the case for the case studies presented in this paper. Arithmetically adding a flight in a hub and spoke network creates geometric market additions via flight connections. Consequently, airlines are able to attend more markets than with other types of networks. Hub and spoke networks also permit to get lower operating costs because some infrastructures such as resources needed for maintenance may be concentrated in hubs. Once the network is known the route and fleet planning must be done where the routes to be operated and the fleet types to be bought are decided, respectively (Cadarso and Marín, 2013). The order in which these problems are solved may be different from the one presented here. They may also be solved partially integrated with other problems to be presented next: the schedule planning (Lohatepanont and Barnhart, 2004).

1.1. Schedule planning

The schedule planning process typically starts from an existing schedule with a well-developed route structure and fleet composition. In the construction of each new schedule, changes are introduced to the existing schedule to reflect changes in demands and the market environment. Due to the enormous size and complexity of the problem, schedule planning is a multi-step process, usually separated into four, sequentially solved subproblems: schedule design, fleet assignment, maintenance routing, and crew scheduling (Barnhart and Cohn, 2004; Belobaba et al., 2015; Cadarso et al., 2017).

1.1.1. Schedule design

Given available resources, the objective of schedule design is to develop a profit-maximizing schedule, defining an origin, a destination, a departure time, and an arrival time for each flight leg. It is a critical stage of an airline's planning process, as a major proportion of costs and revenues are fixed once a flight schedule is determined. Schedule design is typically composed of two sequential steps: frequency planning and timetable development (Lohatepanont and Barnhart, 2004).

Frequency Planning is the problem of determining the number of flight departures over a specified time period or interval (e.g., over a week) for each route. This is a critical factor in an airline's ability to compete for passengers, whose flight selection is primarily influenced by the frequency of flights, timetable, fares and quality of service. Increasing flight frequencies reduces wait time between flights, improves the convenience of air travel for passengers and increases the airline's market share relative to that of its competitors (Belobaba et al., 2015). This last effect results in an airline's market share being dependent not only on its own service but also on the services provided by other airlines in the market.

Timetable Development involves constructing a flight schedule that matches the frequencies determined in solving the frequency planning problem. Numerous factors must be considered in generating a timetable, including the trade-off between maximization of aircraft utilization (block hours per day) and schedule convenience for the passengers; minimum 'turnaround' times at each airport to deplane and enplane passengers, refuel and clean aircraft; and convenient passenger connections at hub airports (Belobaba et al., 2015).

Hub and spoke networks usually feature a high percentage of connecting passengers. In order to fly from one spoke to a different one, a connection must be performed in the network hub and, the time needed to accomplish these connections must be established. But whether this time is enough in order to avoid miss-connected passengers will be uncertain due to stochastic events, such as operating and weather conditions. Also the amount of connecting passengers will depend on final demand figures, which are not known until the day of operations.

Lan et al. (2006) consider passengers who miss their flight legs due to insufficient connection time and develop a new approach to minimize passenger miss-connections by re-timing departure times. Although they consider arrival time uncertainty, they account neither for demand uncertainty nor for re-fleeting. Jiang and Barnhart (2011) maximize the number of potentially connecting itineraries weighted by their respective revenues but lacks of similar issues as before.

1.1.2. Fleet assignment

The fleet assignment problem is to determine the type of aircraft to be flown on each flight, given a planned flight network and specified timetable. The solution has a tremendous impact on an airline's profits, as it directly affects flight operating costs and passenger revenues. Important factors in assigning fleet types to flights include passenger demand, aircraft seating capacities, aircraft operating costs, and fleet size and composition (Hane et al., 1995). Sherali et al. (2006) present a tutorial on the basic and enhanced models and approaches that have been developed for the fleet assignment problem, including integration with other airline decision processes.