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An integrated flight scheduling and fleet assignment method based on a discrete choice model

Zhang Dong [a], Yu Chuhang [a,*], H.Y.K. Henry Lau [b]

[a] Room 8-23, Haking Wong Building, University of Hong Kong, Hong Kong
[b] Room 8-15, Haking Wong Building, University of Hong Kong, Hong Kong

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ABSTRACT

The airline industry is capital intensive and operates on a thin profit margin. Optimal and flexible flight schedule is essential for airlines to survive in such competitive market. In this study, we focus on the integrated flight scheduling and fleet assignment problem based on a discrete choice model. Two mixed integer programming models are proposed: the first model solves the integrated flight scheduling and fleet assignment problem and the second model further considers the itinerary price elasticity. A heuristic algorithm is also proposed to efficiently solve the second model. In numerical studies, a micro market is simulated to evaluate the performance of our proposed models and algorithms. Experimental results reveal that our models can achieve a significant profit improvement under a reasonable computation time.

1. Introduction

Traditionally, the airline industry is capital intensive and often operates on a thin profit margin and the intense competition from low-cost airlines. As a result, it is essential for an airline to maintain an optimal and flexible flight schedule plan in order to survive in a competitive market. An airline schedule planning process typically consists of five steps: flight scheduling, fleet assignment, aircraft rotation, revenue management and crew scheduling (Belobaba, Odoni, & Barnhart, 2015).

The first step of the airline schedule process is flight scheduling. In practice, the flight scheduling can usually be further decomposed into two sequential steps: frequency planning and time table development. The frequency planning mainly determines the optimal service frequency for a certain origin–destination market, and the time table planning determines the specific departure time and arrival time for each flight leg subject to resource balance constraints in the network.

The next step is fleet assignment based on the obtained flight schedule. The fleet assignment is to assign appropriate fleet types to each flight leg such that the seat capacity assigned to each flight closely matches the expected demand. If a large aircraft is assigned to a flight leg with a small demand, the resource wastage is incurred. On the contrary, if a small aircraft is assigned to a flight leg with a large demand, a significant amount of profit may be lost.

Following the fleet assignment, aircraft rotation problem is then solved. The aircraft rotation is to find the maintenance feasible rotation for each aircraft. Typically, a maintenance feasible rotation consists of several flights satisfying aircraft maintenance requirements.

The last two steps are the revenue management and crew scheduling. Since they have little interaction with each other, they can be solved independently. The revenue management is to maximize the revenue based on the given flight schedule and fleet assignment plan. A revenue management system typically consists of two distinct but closely related components: differential pricing and seat inventory control. The differential pricing is a pricing strategy of charging different prices for the same flight class. The seat inventory control is the process of allocating seats among varies fare classes on a flight to maximize the expected revenue. The crew scheduling is to assign flight legs to each crew with the objective of minimizing the whole crew operating cost. The schedule assigned to each crew must satisfy regulations laid down by the airline and relevant government authorities.

Among all these five steps, the flight scheduling and fleet assignment are the two most important steps that determine an airline's profitability and service level. Traditionally, these two problems are solved in a sequential manner. The flight scheduling problem first decides flight legs to fly and the schedule for each selected flight leg. Then, the fleet assignment problem is followed to determine the best assignment of aircraft fleet types to each

* Corresponding author.
E-mail addresses: zd.pony@gmail.com (Z. Dong), ych1102@gmail.com (Y. Chuhang), hyklau@hku.hk (H.Y.K. Henry Lau).

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flight leg. The objective of flight scheduling and fleet assignment is to maximize the profit that equals to the total expected revenue minus the total operating cost.

As computing technologies and optimization theories improved dramatically in recent years, it is possible to integrate these two problems in finding a global optimal solution. In literature, there are already some efforts for solving the integrated flight scheduling and fleet assignment (Lohatepanont & Barnhart, 2004; Pita, Adler, & Antunes, 2014; Pita, Barnhart, & Antunes, 2012; Sherali, Bae, & Haouari, 2010, 2013; Zhang et al., 2015, 2016; Yu et al., 2015). One essential step in solving the integrated flight scheduling and fleet assignment problem is to estimate the market share of airlines in a specific market. To simplify modeling and computing, one common way adopted in those works (Lohatepanont & Barnhart, 2004; Pita et al., 2012; Pita et al., 2014; Sherali et al., 2010, 2013) is to set a constant market share for a specific market. A spill and recapture process is then considered. Since a lot of passengers might select one itinerary, ***spill*** is defined as a process of spill several passengers because of insufficient aircraft capacity. ***Recapture*** is defined as a process to recapture those spilled passengers by other possible itineraries. Two limitation of such setting are that (1) it cannot reflect the actual market share since it ignores the impact of flight schedule and fleet assignment solutions on the market share and (2) huge number of decision variables and constraints exist in model. In recent years, passenger discrete choice models are incorporated to circumvent this limitation. The passenger discrete choice models do not focus on the specific process of the passenger spill and recapture, however, they focus on the number of passenger finally choosing one itinerary after the spill and recapture process. The distribution of passengers among different itineraries is proportional to itineraries' attractiveness value to passengers. There are three advantages of passenger discrete choice models. First, the impact of different flight schedule and fleet assignment plans on the market share can be considered; second, the number of decision variables is decreased to $O(n)$ from $O(n^2)$ (n is the number of total itineraries) since the only final market share of each itinerary is regarded as the decision variable; Third, more accurate passenger behavior is simulated. However, non-linear constraints are usually incorporated in such models which cause the models difficult to be solved.

To the best of our knowledge, there are only three studies proposed in literature for solving the pure flight scheduling problems or the integrated flight scheduling and fleet assignment problems. Yan, Tang, and Lee (2007) and Di Wang, Klabjan, and Shebalov (2014) proposed models for pure flight scheduling design problem based on passenger discrete choice models. The fleet assignment issue is overlooked in these two works. Atasoy, Salani, and Bierlaire (2014) considered the integrated flight scheduling and fleet assignment problem and proposed a model based on a discrete choice model. However, the nonlinear elements of Atasoy et al. (2014)'s model makes it computationally intractable. To the best of our knowledge, there is no mixed integer programming model, which is much more computationally contactable, proposed for the integrated flight scheduling and fleet assignment problem. It deserves more attention to propose more efficient models to solve the integrated flight scheduling and fleet assignment problem.

To fill this gap, we propose two mixed integer programming models for the integrated flight scheduling and fleet assignment problem based on a passenger discrete choice model. There are three contributions in this study:

- First, a mixed integer programming model for the integrated flight scheduling and fleet assignment problem is formulated in which more practical constraints are considered.
- Secondly, a mixed integer programming model is proposed to further incorporate itinerary price elasticity into the integrated flight scheduling and fleet assignment problem. It can provide some managerial implication for itinerary pricing in practical applications.
- Finally, various simulation studies are conducted to evaluate performances of our models and explore some managerial implication.

1.1. Literature review

There are an increasing number of literatures looking at flight schedule and fleet assignment problems together by adopting overall integrated approaches. Levin (1971) pioneered to propose an integrated model for flight scheduling and fleet assignment problem. In their work, only a single fleet type is considered and several flight departure copies are created to represent different departure options for flight legs. For each original flight leg, exactly one departure copy can be selected and it represents the selected schedule for the flight legs. Based on this work, Desaulniers, Desrosiers, Dumas, Solomon, and Soumis (1997) and Rexing, Barnhart, Kniker, Jarrah, and Krishnamurthy (2000) further extended it to deal with multiple fleet types. Lohatepanont and Barnhart (2004) proposed another integrated flight scheduling and fleet assignment model in which the assumption of fixed and known flight legs is relaxed. All the flights are divided into two sets, mandatory and optional set. Flights in the mandatory set must be covered in the optimal solution while flights in the optional set could either be selected or not. Pita et al. (2012) and Pita et al. (2014) proposed two integrated flight scheduling and fleet assignment approaches, considering airport congestion and social factor respectively. Sherali et al. (2010, 2013) proposed efficient benders decomposition algorithms for the integrated flight scheduling and fleet assignment problems.

In studies of flight scheduling and fleet assignment, the passenger spill and recapture effects modeling is a very important issue. In practice, the total passenger demand on a given flight can exceed the allocated aircraft capacity; in this case, it might be inevitable to spill some passengers. The spilled passengers are either lost or recaptured by the other itineraries provided by the same airline. The percentage of spilled passengers in itinerary i being recaptured by itinerary j is defined as the recapture rate from i to j. The consideration of spill and recapture effect can significantly improve the resource allocation; therefore, the expected profit will also be improved. Kniker, Barnhart, and Lohatepanont (1999) proposed the Passenger Mix Model to consider the spill and recapture effect in the fleet assignment problem. Based on the Passenger Mix Model, Barnhart, Kniker, and Lohatepanont (2002) further proposed an itinerary based fleet assignment model, in which the passenger spill and recapture effect is considered based on airline network effect.

There are two limitations of the Passenger Mix Model. First, the market share of target airline is assumed to be constant. Airline's market share is closely related to its flight schedule and fleet assignment plan. For example, a good timetable that takes passenger reactions into consideration will attract more passengers; on the other hand, an inferior timetable will lose more passengers. Secondly, with regards to computational tractability, the huge number of decision variables in the Passenger Mix Model makes it hard to be solved. In the Passenger Mix Model, the passenger can either choose their original itinerary or recaptured by one of other candidate itineraries. Each possible selection corresponds to one decision variable. Let n denote the degree of the itinerary set. The total number of decision variables is $O(n^2)$. For a typical large airline,