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Airline flight schedule planning under competition

Ahmed Abdelghany[a,*], Khaled Abdelghany[b], Farshid Azadian[c]

[a] *College of Business, Embry-Riddle Aeronautical University, Daytona Beach, FL 32114, United States*
[b] *Department of Civil and Environmental Engineering, Southern Methodist University, P.O. Box 750335, Dallas, TX 75275-0340, United States*
[c] *College of Business, Embry-Riddle Aeronautical University, 600 S. Clyde Morris Blvd., Daytona Beach, FL 32114, United States*

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ABSTRACT

This paper presents a modeling framework for airline flight schedule planning under competition. The framework generates an operational flight timetable that maximizes the airline's revenue, while ensuring efficient utilization of the airline's resources (e.g. aircraft and crew). It explicitly considers passenger demand shift due to the network-level competition with other airlines. It also considers minimizing the needless ground time of the resources. The problem is formulated in the form of a bi-level mathematical program where the upper level represents the airline scheduling decisions, while the lower level captures passenger responses in terms of itinerary choices. A solution methodology is developed which integrates a meta- heuristic search algorithm, a network competition analysis model, and a resource (e.g. aircraft and crew) tracking model. The performance of the framework is evaluated through several experiments to develop the schedule for a major U.S. airline. The results demonstrate the success of the framework to develop a competitive schedule with efficient resources.

1. Introduction

The current airline industry is extremely competitive and operates under a diminutive profit margin. Airlines are striving to develop profitable flight schedules that maximize their revenues and exploit their available resources (e.g. aircraft and crew). The airline schedule planning problem (ASPP) is a part of the larger airline planning problem (APP) that entails developing a schedule for flights, fleet, crew, and other operational resources. The APP is a complex process that typically consists of several interdependent tasks including demand forecasting, capacity planning, flight frequency, departure time optimization, and resources assignment and scheduling. A common practice is to break the planning process into several modules that are usually solved sequentially and hence separately (Abdelghany and Abdelghany, 2010; Barnhart and Cohn, 2004). The quandary here is that an optimal solution for one module is not necessarily optimal for the integral process. In some cases, the solution for one module is not even feasible for its subsequent module(s). Accordingly, several iterations are usually required until an acceptable solution is obtained, with no global optimal solution guaranteed. Moreover, these processes often need to be solved months in advance, where many critical inputs such as passenger demand, competitor's schedules, and fares are uncertain and can only be approximately estimated based on historical data.

Several sources of complexity are inherited to the ASPP. First, the problem is highly non-linear due to the mutual interdependency between the airline's flight scheduling decisions and the expected demand share in the different travel markets. Second, the problem entails a complex network-level evaluation of the flight schedule in terms of capturing the trade-off between serving local markets and maximizing the network coverage through providing efficient connecting services. Furthermore, the network-level evaluation should also be extended to ensure that different itineraries (including connecting itineraries) serving the same city-pair are not competing with one another but instead complementing each other to attract more passengers to the airline. Moreover, the schedule should be able to stand the competition with other airlines. In addition, the problem is NP-hard as the number of solutions is expected to grow exponentially with the increase in the size of the problem. Finally, the problem sometimes involves conflicting objectives as the flight schedule should not only maximize the airline's market share but should also allow for maximizing the utilization of all operational resources (e.g. aircraft, crew, gates).

Considering these complexities, major airlines typically adopt an incremental schedule updating approach, in which a preceding flight schedule is modified to accommodate recent changes in demand, competition with other air carriers, and any changes in the available resources (Lohatepanont and Barnhart, 2004). The incremental approach usually results in a solution with conservative

* Corresponding author.
E-mail addresses: abdel776@erau.edu (A. Abdelghany), khaled@lyle.smu.edu (K. Abdelghany), azadianf@erau.edu (F. Azadian).

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changes to the initial schedule. This approach is desirable as it limits the changes to the existing schedule that is already adopted by the airline and is computationally tractable. Nonetheless, this approach only provides an improvement in their limited context and does not necessarily guarantee global optimality over all possible schedules. Moreover, starting from an existing schedule may not always be practical, especially in scenarios of major changes in the market conditions (e.g., merging of major airlines). Considering the mounting pressure to improve revenue and reduce operational cost, and with the recent major changes in airlines' network due to airlines mergers and acquisition, airlines might be interested in the so-called clean-sheet flight scheduling approach. Under the clean-sheet flight scheduling approach, the developed flight schedule could be independent of (or significantly different from) any previously implemented schedules. Nonetheless, when adequate constraints are considered, the clean-sheet approach could be used to develop incremental schedule update to a previous schedule.

The current practice followed by most major airlines in developing the flight schedule for a target month starts by adopting a historical schedule that represents this target month. For example, if the airline is developing a schedule for the month of January of next year, the airline may use the schedule of the month of January of the current year as a starting point. Next, a model similar to the one presented in Lohatepanont and Barnhart (2004) is applied to generate the fleet assignment of this schedule and to simultaneously adjust this flight schedule. The timetable adjustments are typically applied to a limited number of flights in the form of flight deletion, addition, and departure time adjustment. Optimizing the departure time decision for all flights is avoided due to the computational intractability of the problem. Nonetheless, the output of this process could be considered as an input to the model presented in this paper. This output consists of a preliminary flight schedule (or flight frequency) with a fleet assignment. The model presented in this paper further enhances the flights' departure times and generates itineraries that are more attractive and competitive. The model also guarantees that there are feasible aircraft and crew turns at all stations. Thus, the successive steps of aircraft rotation and crew scheduling are easier to solve.

The flight scheduling framework integrates an iterative search technique in the form of a Genetic Algorithm (GA) on the top of 1) a network competition analysis model, and 2) a resource-tracking model. The GA searches for the optimal (or near-optimal) schedule, while the competition analysis model and the resource-tracking model measure the competency of each generated schedule. The competition analysis model evaluates the attractiveness of each generated schedule by replicating passengers' itinerary choice behavior as a function of the attractiveness of the itineraries. Thus, it accurately captures the competition between the target airline and the other airlines, and estimates the market share and associated revenue of the generated schedule. The resource-tracking model determines the number of efficient rotations and the corresponding ground time of the resources. It is worth mentioning that the framework is not intended to generate the aircraft or crew line of flying. However, it constructs efficient flight turns at the different airports for each fleet type to facilitate developing an efficient line of flying for the aircraft and the crew.

As such, the research work presented in this paper contributes to the existing literature in several aspects: (1) developing a flexible modeling framework for the ASPP that can provide incremental schedule update or clean-sheet scheduling; (2) presenting a mathematical formulation to the problem that provides a decision support tool for evaluating the trade-off between schedule profitability and resource utilization; (3) capturing important airline scheduling constraints such as departure time windows and slot-constrained flights; (4) explicitly considering competition among airlines and passengers' demand elasticity by integrating an airline competition analysis model in the scheduling process which captures the passengers' itinerary choice behavior to enable evaluation of the profitability of the developed schedule; and (5) presenting an efficient solution methodology that is applicable to large-scale airline networks and presenting results for an application that replicates a real-world example.

This paper is organized as follows. Section 2 provides a review of major research effort related to the airline schedule planning problem. Next, the problem formulation and a description of the overall modeling framework are presented in Sections 3 and 4, respectively. Section 5 describes the airline competition analysis model used in the flight-scheduling framework. Sections 6 and 7, respectively, present an example and a real-world application that illustrates the application of the model for a major US airline. Concluding comments and possible research extensions are finally given in Section 8.

2. Literature review

Considerable research effort has been devoted to studying the ASPP. Most of this research has emerged as an extension of the conventional fleet assignment models (FAM). The goal of the fleet assignment problem is to optimally assign scheduled flights (i.e. with known departure time) to the most profitable aircraft type in terms of appropriate capacity and performance (see Abara, 1989; Barnhart et al., 2002; Hane et al., 1995; Sherali et al., 2006; Subramanian et al., 1994). Two main approaches are considered to extend FAM to represent flight scheduling decisions. The first approach has emerged from the fact that airlines need to reduce or expand their schedules to respond to seasonal changes in demand. In this approach, optional flights with defined departure times are introduced. Then, a solution approach is used to eliminate unnecessary flights and maintain the set of flights that optimizes a pre-defined objective (Lohatepanont and Barnhart, 2004; Sherali et al., 2010,2013). The second approach defines a time window for each flight, in which each flight is represented by several copies. Then, the most optimal time in this time window is selected, given that one copy of the flight is to be included in the schedule and all other copies are left uncovered and eliminated. The time window is used to specify how much a flight can be shifted from its original departure time to enhance a pre-defined objective (Ahuja et al., 2004; Belanger et al., 2006; Desaulniers et al., 1997; Levin, 1971; Mercier and Soumis, 2007; Rexing et al., 2000).

The flight schedule decision is also considered in several different contexts for small size airlines. The problem of developing a flight schedule that promotes robust operation has been studied by several researchers including Aloulou et al. (2010), Burke et al. (2010), Lan et al. (2006), Vaze and Barnhart (2012) and Dunbar et al. (2014) Another version of the problem is represented by the work of Yan et al. (2006) which presented a model for air cargo fleet routing and timetable setting with multiple on-time demands. Tang et al. (2008) presented an integrated model and solution algorithms for passenger, cargo, and combi flight scheduling. The model extends the work of Yan and Young (1996) and Yan and Tseng (2002). Yan and Chen (2007), introduced coordinated scheduling models for allied airlines. Jiang and Barnhart (2009) introduced the concept of dynamic flight scheduling with the objective is to match the passenger demand and aircraft capacity for all flights. Pita et al. (2012) developed a model that integrates flight scheduling and fleet assignment considering airport congestion. Atasoy et al. (2014) presented an integrated model for airline scheduling, fleeting, and pricing for a monopolized market. In another work, Pita et al. (2014) presented a flight scheduling and fleet assignment optimization model for subsidized air transport networks, especially in remote areas.