Transportation Research Part E 118 (2018) 355–375

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

# The integrated aircraft routing problem with optional flights and delay considerations

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ARTICLE INFO

*Keywords:*
Flight scheduling
Fleet assignment
Aircraft routing
Stochastic demand
Column generation

ABSTRACT

In this paper, we integrate flight scheduling, fleet assignment, and aircraft routing decisions, which are the most prominent decisions in airline planning, while considering the stochasticity of the demand. In addition, optional flights, delays and deadhead flights are considered as they are crucial elements that significantly affect airline profits. Due to the complexity of the formulated problem, three different column generation-based algorithms are developed. The results show that our algorithms can solve the problem in a fraction of the time a commercial solver takes with an optimality gap of less than 0.1%.

## 1. Introduction

The revenues and costs of airline companies are mostly affected by their flight scheduling and fleet assignment decisions. These decisions should be made 10–12 weeks prior to the flight date in order to fulfill the scheduling requirements of the cabin crews. The third decision in airline planning processes is aircraft routing. The importance of integrating aircraft routing with flight scheduling and fleet assignment lies mainly in the fact that additional realistic aspects such as delays and related costs can be considered. Indeed, a common misconception about airline companies is that they build their flight schedule without any consideration of delays that may occur. It is noteworthy that delays in the schedule are usually caused by delays from the crew, weather conditions, congested runways and terminals, referred to as independent delays, or simply because delay propagates downstream to the remaining flight legs in the aircraft route. The loss of revenue for the airline industry, because of delays, may exceed $6.3 billion per annum and, additionally, the sum of crew overtime pay, passenger disruption compensation, loss of passenger welfare and other factors may exceed $11.8 billion (Administration, 2017). To assist the decision making in reducing delays and their associated costs, optional flight legs are introduced during the planning phase. This will increase the flexibility of the flight schedule by allowing to choose the combinations of flight legs that result in minimized delays and delay costs.

Recent data from the Department of Transport in the U.S.A. shows that the majority of delays are caused by the late arrival of aircraft (38.9%). This means that most delays are a result of delays that happen upstream in the route of an aircraft and propagate down the route. In March 2018, in the U.S.A. alone, a total of 5,691,103 min of delay occurred, of which 2,214,996 were related to late arrivals (DOT, 2018). These numbers result in huge costs since they translate into increased working hours for the crew, higher fuel consumption, loss of passengers, and thus loss of goodwill. Markedly, these figures highlight the potential of reducing delays and related burden through the consideration of propagated delays in airline planning.

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https://doi.org/10.1016/j.tre.2018.08.002
Received 23 April 2018; Received in revised form 4 August 2018; Accepted 6 August 2018
1366-5545/ 

Furthermore, the International Air Transport Association (IATA) expects a 3.6% annual compound growth in air traffic reaching around double the current 4 billion annual travelers by 2036. This should lead to air traffic management making urgent reform to cut delays, costs and emissions (Anon, 2017). Thus the consideration of delays in flight scheduling becomes of great concern to many airline companies. This raises the urgency to come up with permanent solutions to minimize these delays which will, in turn, contribute to cost reduction. The main airline planning process that directly tackles the issue of delay is the aircraft routing.

At this level it is important to note that there are four main processes that govern the airline industry and they are all interdependent. The three first processes have been mentioned above and are flight scheduling, fleet assignment and aircraft routing, respectively. Flight scheduling, involves creating the schedule of flights the airline company will serve. Fleet assignment, dictates which aircraft type will be assigned to which flight leg. Aircraft routing indicates the flights included in each aircraft rotation. This assists in knowing the exact route that an aircraft follows from the time it departs at the beginning of the planning horizon until it lands at the end of the planning horizon. Such information is essential because it keeps track of the number of hours and the distance each aircraft flew and thus maintenance considerations are made accordingly. Finally, the fourth process is crew scheduling where it will be decided which crew will serve which flight leg while respecting the different restrictions imposed by labor unions.

Integrating all four processes will indeed give an optimal solution but at the expense of additional computational complexity. However, solving each process alone and feeding the solution to the next process will yield sub-optimal solutions. The consideration of delay in aircraft schedules requires the integration of aircraft routing with other processes involved in airline operation planning.

Fleet assignment determines which aircraft will serve which flight leg in order to achieve the match between aircraft seating capacity and demand that maximizes the profit. However, this assignment can result in aircraft routes with high delays given the scheduled flight departure times, turnaround times and independent delays. Evidently, these delays result in many disruptions and in some extreme cases might cause flight cancellation. These delays are costly and affect airline company reputation and passenger retention. Hence, on one hand, the integration of fleet assignment and aircraft routing here aims at finding the match between aircraft capacity and demand that maximizes the profit while accounting for penalty costs incurred by aircraft delays in addition to operating costs and deadhead flight costs. Thus, the objective function allows for reducing delays. This cannot be achieved without the integration of fleet assignment and aircraft routing. On the other hand, the integration of flight scheduling with fleet assignment and aircraft routing allows for using flight scheduling as another lever to mitigate the delay. Flight scheduling aims at selecting the optional flight legs to serve in addition to the mandatory ones in order to maximize the profit. Therefore, the aim of integrating flight scheduling, fleet assignment and aircraft routing is to determine based on the demand, the available fleet and the independent delay, the flight legs to include in the schedule, the aircraft to perform each served flight leg and the route of each aircraft that maximize the profit while trying to reduce the delay. Without this integration, it is possible to observe excessive delays because the flight schedule includes a large number of optional flight legs.

The planning horizon is a crucial issue in this integrated problem because at the end of the planning horizon each aircraft must land at an airport with maintenance facilities to undergo regular maintenance checks. In some cases, the planning horizon may be one day; thus, it is enough to ensure that the aircraft ends at the same airport it started from. In other cases, the planning horizon may be three or more days, so routing decisions must be made to ensure the aircraft lands in an airport with maintenance facilities at specific points in time during the planning horizon.

In this work, the integrated flight scheduling, fleet assignment and aircraft routing problem is formulated. To make the model more realistic, delays and deadhead flights are considered. Maintenance routing is implicitly considered by ensuring that the route of each aircraft ends at the same station it started from, which is a maintenance station. Two different fare classes are modeled, namely Economy class and Business class. Due to the large number of constraints, the model is of very high complexity and in order to overcome this issue, column generation is used as a solution approach to obtain near-optimal solutions with insignificant optimality gaps. This was done by reformulating the problem from one with many constraints to one with many variables. The main advantage of column generation is that only a small set of these many variables is needed to start the algorithm. As the algorithm proceeds, additional variables are generated as needed. A near-optimal solution can be, therefore, constructed after generating a subset of the remaining variables.

The rest of this work is divided as follows. In Section 2 a literature review is conducted, that covers related work in the fields of fleet assignment, flight scheduling, aircraft routing and propagated delay including both those that develop deterministic and stochastic models. Section 3 explains the model and presents the formulation used. Section 4 presents the proposed solution approach. The results obtained from the computational experiments carried out using a case study involving a medium-sized airline company are reported in Section 5. Finally, Section 6 concludes this work and gives recommendations for future research.

## 2. Literature review

Various papers have been devoted to study airline planning processes with a recent trend, during the last few years, toward developing models that integrate two or more of these planning processes in an attempt to enforce decision consistency and achieve significant savings with respect to the sequential decision approach. However, because of their complexity, many works in the literature have integrated the planning problems while not sufficiently investigating some of their realistic features. For instance, despite being a very significant component of the airlines planning process, the amount of work in the literature that integrates aircraft routing with flight scheduling and fleet assignment is sparse, and even rarer are those that consider propagated delay.