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An integrated approach for airline scheduling, aircraft fleeting and routing with cruise speed control

Hüseyin Gürkan [a], Sinan Gürel [b], M. Selim Aktürk [c,*]

[a] Fuqua School of Business, Decision Sciences, Duke University, USA
[b] Department of Industrial Engineering, Middle East Technical University, Turkey
[c] Department of Industrial Engineering, Bilkent University, Turkey

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A B S T R A C T

To place an emphasis on profound relations among airline schedule planning problems and to mitigate the effect of unexpected delays, we integrate schedule design, fleet assignment and aircraft routing problems within a daily planning horizon while passengers' connection service levels are ensured via chance constraints. We propose a nonlinear mixed integer programming model due to the nonlinear fuel consumption and CO_2 emission cost terms in the objective function, which is handled by second order conic reformulation. The key contribution of this study is to take into account the cruise time control for the first time in an integrated model of these three stages of airline operations. Changing cruise times of flights in an integrated model enables to construct a schedule to increase utilization of fuel efficient aircraft and even to decrease total number of aircraft needed while satisfying the same service level and maintenance requirements for aircraft fleeting and routing. There is a critical tradeoff between the number of aircraft needed to fulfill the required flights and overall operational expenses. We also propose two heuristic methods to solve larger size problems. Finally, computational results using real data obtained from a major U.S. carrier are presented to demonstrate potential profitability in applying the proposed solution methods.

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1. Introduction

Managing an airline is unavoidably expensive. One of the most basic costs is the price of purchasing the aircraft which range from 70 to 400 mio USD per unit Boeing (2015). Moreover, among the operational expenses, fuel has been the largest single cost term for the global airlines. According to IATA (2010) analysis on airline financial data, fuel expenses accounted for $210 billion in 2013 for global airline industry. On the other hand, unexpected delays are endemic in airline operations and to demonstrate their impact, the estimated total cost to the U.S. economy because of flight delays was as much as $41 billion in 2007 Rebollo and Balakrishnan (2014). Naturally, the efficient utilization of such expensive resources, decreasing operational expenses and higher robustness are objectives of any profitable airline. However, unfortunately these terms are inversely correlated, in other words higher utilization might cause higher operational cost, less robustness and vice versa. In this direction, generating a robust schedule with high aircraft utilization and less operational expenses at the same time is quite crucial for any airline. Therefore, in this paper, we propose an integrated model for robust schedule design, aircraft

* Corresponding author.

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routing and fleeting with cruise speed control that aims efficient aircraft utilization and robustness within the consideration of operational expenses such as fuel consumption, CO_2 emission and spill cost.

Airline schedule design problem decides where to fly and in which frequency in consideration of market demand, profitability, available resources and the competitors. Due to its broad scope, Barnhart et al. (2003) state that building flight schedules from scratch is performed manually with limited optimization in the typical airline practice. Following the construction or design of a flight schedule, fleet assignment problem tries to find the optimal assignment of aircraft types to flights by considering the number of aircraft in each fleet and coverage of all flights. After fleet assignment decomposes flight networks into subnetworks in terms of a particular fleet type, maintenance routing problem assigns individual aircraft to these flights in consideration of the maintenance requirements. For a general review on airline schedule planning problems, we refer the reader to Barnhart and Cohn (2004).

Since the different airline schedule planning problems are strongly related to each other, several integrated models are proposed that take into account combinations of these problems to improve suboptimal solutions for the entire system. Lohatepanont and Barnhart (2004) consider schedule design and fleet assignment in an integrated way in which a base schedule and two flight lists including mandatory and optional flights are given. Starting from the base schedule they consider deleting/adding flights from/to the base schedule with respect to given flight lists. In a similar fashion, Sherali et al. (2013a) propose a model that integrates the schedule design and fleet assignment processes while considering flexible flight times, schedule balance, and recapture issues, along with optional legs, path/itinerary-based demands, and multiple fare-classes. Differently, they consider the flow of passengers along itineraries over the network together with flight scheduling and fleeting decisions in order to maximize profits. Integrating three problems enables to improve local optimal solutions, however tractability worsens as much as the scope of integration expands. Therefore, these integrated problems are modeled and solved for a daily planning horizon.

In the literature, there are studies related to our work in some aspects such as daily planning horizon, passenger connection, cruise speed control or maintenance considerations. Duran et al. (2015) propose a robust airline scheduling model with controllable cruise times. In their study, the tradeoff between the costs of cruise time change and idle time insertion is considered while passengers' connection service levels are ensured by chance constraints. Speed control is quite a recent concept in solving airline scheduling problems. Aktürk et al. (2014) is the first study that makes use of speed control in the context of airline schedule recovery from disruptions. Sherali et al. (2013b) propose an approach in which they integrate the schedule design, fleet assignment, and aircraft-routing problems within the consideration of flight selection, departure timing and maintenance requirements. For maintenance requirements, they use a limit on total flight time of each aircraft that might be different for each fleet type. As a solution method, they use Benders' decomposition and enhance the model via valid inequalities. Haouari et al. (2013) propose a model for daily maintenance routing problem in which they ensure maintenance feasibility by counter constraints on flight hours, take offs and number of days since the last maintenance checks for each aircraft. They present a compact polynomial-sized representation for the general aircraft routing model and they linearize and lift that representation. Moreover, in the study of Aloulou et al. (2013), a MIP model is proposed for the robust aircraft routing problem without directly accommodating maintenance constraints however by considering that the flights start and end in the single hub where maintenance checks are achieved overnight. Aloulou et al. (2013) capture robustness by an objective function pertaining to aircraft and passenger connections.

What distinguishes our work from the studies above and makes challenging simultaneously is cruise speed control and integration. To the best of our knowledge, this is the first study in which cruise speed/time is controlled within the integrated robust schedule design, aircraft fleeting and routing problem. In our study, the fuel consumption and CO_2 emission cost functions are nonlinear functions in cruise time and involve binary variables. We have shown that these nonlinear functions with binary variables can be transformed into a set of second order conic inequalities. Moreover, even if it is a special case of our problem, Parmentier (2013) showed that aircraft routing problem by itself is an NP-complete problem. In addition to aircraft routing problem, we consider robust airline scheduling and fleet type assignment problems in an integrated fashion that involves a large number of decision variables. For that reason, when the number of flights and aircraft increases, the problem size increases drastically. We also consider passengers' connection service levels with chance constraints as well as departure timing, idle time insertion and cruise speed control different from the aircraft routing problem. Changing cruise time of flights in an integrated model enlarges the solution space and enables to construct a schedule with new flight sequences, which could not be considered previously due to fixed cruise speed/time restriction. For two flights to be connected consecutively by the same aircraft, there must be enough time gap between departure times of these flights. This time gap is the sum of cruise time, non-cruise time, turnaround time and idle time. In other studies, the lower bound for this gap is taken as fixed, however cruise speed/time change enables to control this lower bound on the gap between departure times. By this means, in our study more flight connection alternatives could be generated.

The first contribution brought by our study is that aircraft utilization could be increased and even total number of aircraft needed to cover a set of flights could be decreased while ensuring equivalent service level and maintenance requirements. Due to having more alternatives on flight connections and compression of cruise time of flights, it is possible to increase the number of flights to be performed by an efficient aircraft. While this increase in the utilization of fuel efficient aircraft could reduce the minimum number of required aircraft to perform a set of flights. There is a critical tradeoff between the number of aircraft needed to fulfill the required flights and the overall operational expenses, such as fuel consumption costs.

The second is the robustness issue. Since we have more alternatives on flight connections, it is possible to generate better flight sequences in terms of robustness. For example, on a route having a flight with a great delay probability would require

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