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A math-heuristic algorithm for the integrated air service recovery

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ABSTRACT

A sophisticated flight schedule might be easily disrupted due to adverse weather, aircraft mechanical failures, crew absences, etc. Airlines incur huge costs stemming from such flight schedule disruptions in addition to the serious inconveniences experienced by passengers. Therefore, an efficient recovery solution that simultaneously decreases an airline's recovery cost while simultaneously mitigating passenger dissatisfaction is of great importance to the airline industry. In this paper, we study the *integrated airline service recovery problem* in which the aircraft and passenger schedule recovery problems are simultaneously addressed, with the objective of minimizing aircraft recovery and operating costs, passenger itinerary delay cost, and passenger itinerary cancellation cost.

Recognizing the inherent difficulty in modeling the integrated airline service recovery problem within a single formulation (due to its huge solution space and quick response requirement), we propose a three-stage sequential math-heuristic framework to efficiently solve this problem, wherein the flight schedules and aircraft rotations are recovered in the first stage, Then, a flight rescheduling problem and passenger schedule recovery problems are iteratively solved in the next two stages. Time-space network flow representations, along with mixed-integer programming formulations, and algorithms that take advantages of the underlying problem structures, are proposed for each of three stages. This algorithm was tested on realistic data provided by the ROADEF 2009 challenge and the computational results reveal that our algorithm generated the best solution in nearly 72% of the test instances, and a near-optimal solution was achieved in the remaining instances within an acceptable timeframe. Furthermore, we also ran additional computational runs to explore the underlying characteristics of the proposed algorithm, and the recorded insights can serve as a useful guide during practical implementations of this algorithm.

1. Introduction

Flight scheduling has always been of paramount importance to the airline industry because it directly affects the profit and service level of an airline in current competitive market. A plethora of optimization methods have been proposed to help airlines generate good flight schedules. However, even sophisticated fight schedules are often subject to frequent disruptions, which can be primarily attributed to two main causes (Bratu and Barnhart, 2006): (i) Airline resource shortages, such as aircraft mechanical

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failures or an unexpected absence of a crew member; and (ii) Airport and airspace capacity limitations, such as a reduction in runway capacity due to adverse weather conditions. Such unforeseen events can severely disrupt initially generated (steady-state) flight schedules, inevitably leading to flight delays and cancellations. In such situations, huge cost can be incurred if efficient and timely recovery solutions are not readily available. An Airline Operations Control Center (AOCC) is primarily responsible for centrally controlling airline operations , resources and customers (such as aircrafts, crew members and passengers). Operation controllers can invoke a myriad of options to deal with the disruptions, including but not limited to holding (delaying) flight legs, cancelling flight legs, swapping schedules between aircraft pairs and/or crew members.

Generating a comprehensive service recovery solution for an airline is a complex task due to the large number of variables involved and short response time requirements. Note that it is virtually impossible to describe the entire airline service recovery problem within the confines of a single optimization model (even a very large one) and solve it via a commercially available solver. Therefore, in practice, an airline service recovery solution is generated in a sequential manner, wherein the aircraft schedule is recovered first, followed by the crew schedule recovery, and finally, the passenger re-accommodation requests are fulfilled. Considering that an aircraft is an airline's most valuable (monetary) resource, typically an airline first initiates an aircraft schedule recovery solution, which only includes rescheduling of flights and rerouting of aircrafts. This solution must satisfy several constraints including airport capacity limitations, maintenance requirements, station departure curfew restrictions, and aircraft balance requirements. Objectives of the aircraft schedule recovery problem consist of three parts, namely, minimizing aircraft operating costs, minimizing the disutility costs to passengers, and minimizing the deviation from the initial schedule. Aircraft operating cost includes the fuel cost, the maintenance cost, and the ground service cost. The disutility cost is the cost perceived by passengers because of flight delays and cancellations, and the cost of deviation is a penalty cost aimed at minimizing the proximity of the recovered solution from its initial schedule. While passenger re-accommodations are currently assigned the lowest priority within the schedule recovery framework, it ought to be noted that the passenger service satisfaction is of utmost importance to an airline, and moreover, the cost of passenger re-accommodation accounts for an appreciable percentage of the total recovery cost. The currently followed sequential recovery framework reduces the overall passenger satisfaction due to a number of reasons, such as: (i) Delays for certain passenger segments might end up being very large; (ii) A number of passengers transferring at hub airports might miss their onward connections; (iii) Passengers might be downgraded to lower class cabins because of insufficient (remaining) aircraft capacities; all of which contribute towards significant costs for an airline.

Simultaneously considering aircraft schedule recovery and passenger re-accommodations is one possible way to improve passenger satisfaction while maintaining the overall recovery cost within its permissible limits.. The main advantage of such integrated viewpoint is that a more passenger friendly recovery solution can be achieved, while also minimizing any incrementally accrued operating costs.. In this paper, the joint aircraft scheduling and passenger itinerary recovery problem is decomposed into three stages, and a novel three-stage math-heuristic algorithm is proposed. In the first stage, the aircraft schedule recovery problem is considered, and a mixed-integer programming formulation is presented to determine new aircraft rotations and flight schedules, with the objective of minimizing the flight cancellation costs and delay cost. In the second stage, given the aircraft rotations from the first stage, a flight rescheduling problem is formulated to minimize the cost of disrupted passenger connections. Finally, in the third stage, a passenger recovery solution is advocated to explore new itineraries for the remainder of the disrupted passengers, with the aim of minimizing passenger itinerary delays and cancellation costs.

The proposed algorithm was tested on realistic data sets provided by the ROADEF 2009 Challenge (Palpant et al., 2009), which was a competition that specifically catered test instances for solving the integrated aircraft and passenger recovery problem. A black-box solution checker and cost evaluator are also provided by ROADEF 2009 Challenge to check the feasibility status and cost of a given recovery solution. Our computational experience reveals that the proposed framework performs exceedingly well when compared to existing approaches in the literature, and the algorithm determines the the near-optimal solution to all test instances within the time limit specified in the challenge guidelines.

Although several heuristic algorithms have been proposed previously in literature to solve the integrated aircraft and passenger schedule recovery problem, the algorithmic framework presented here offers several advantages:

(1) In previous attempts in the literature, the passenger recovery solution is implemented in the second stage followed by the flight rescheduling algorithm in the third stage. In our case, we interchange the second and third stages, and show that the resulting change in algorithmic sequence leads to a better (lower cost) recovery solutions;
(2) The multi-commodity network flow based formulations described in this work are shown to result in very compact model representations, leading to tight lower bounds being achieved at the root node. Our efficient use of greedy heuristic search techniques in conjunction with math programming-based exact algorithms enables the solution of these problems well within the prescribed computational time limits even for large-scale test instances;
(3) In the third stage, a math-heuristic implementation of the so-called 'destroy-and-create' algorithm is proposed to re-accommodate passengers. As the number of the disrupted passenger itineraries can be large in practice, the proposed destroy-and-create algorithm is implemented in an iterative manner, where at each iteration, only a select number of disrupted itineraries are included in the formulation, leading to manageable problem sizes; and
(4) A detailed sensitivity analysis of the characteristics of the algorithm also reveals that the proposed methodology achieves the best solutions when dealing with normal disruption scenarios (that are regularly encountered in practice), where resource shortages including aircraft availability and airport runway capacity are not completely debilitated, thereby, proving its applicability to real-world disruption scenarios.