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A robust mathematical model and heuristic algorithms for integrated aircraft routing and scheduling, with consideration of fleet assignment problem

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One of the most important airline's products is to determine the aircraft routing and scheduling and fleet assignment. The key input data of this problem is the traffic forecasting and allocation that forecasts traffic on each flight leg. The complexity of this problem is to define the connecting flights when passengers should change the aircraft to reach the final destination. Moreover, as there exists various types of uncertainties during the flights, finding a solution which is able to absorb these uncertainties is invaluable. In this paper, a new robust mixed integer mathematical model for the integrated aircraft routing and scheduling, with consideration of fleet assignment problem is proposed. Then to find good solutions for large-scale problems in a rational amount of time, a heuristic algorithm based on the Simulated Annealing (SA) is introduced. In addition, some examples are randomly generated and the proposed heuristic algorithm is validated by comparing the results with the optimum solutions. The effects of robust vs non-robust solutions are examined, and finally, a hybrid algorithm is generated which results in more effective solution in comparison with SA, and Particle Swarm Optimization (PSO).

1. Introduction

Airlines exploit operations research methods to tackle the complex planning and operational problems. Due to the size of their operations not all planning decisions can be made simultaneously. Airline schedule planning includes all the planning decisions that have to be made for a schedule to be considered operational. The airline schedule generation problem takes the airline passenger demand, airport and aircraft characteristics, maintenance and personal requirements as inputs. The output is a selection of flight legs and the associated timetables that maximizes airline profit subject to resource constraints such as aircraft and airport capacity, maximal working hour, and minimal ground time. Generally, this large scale problem is divided into five more manageable and sequentially computed sub-problems as shown in Fig. 1.

These sub-problems are defined as follows:

- Route Development

In this problem, planners intend to define the sets of origin destination pairs they want to offer.

- Aircraft Routing and Scheduling

The purpose is to determine itineraries for the aircrafts, and develop the timetable such that the costs are minimized. Timetables can be created for one day and repeated every day. The fleet assignment can be found exogenously or endogenously.

In this paper, we focus on the route selection, as well as scheduling the aircrafts in one day operation, and therefore, this problem is formulated as follows; given a heterogeneous aircraft fleet, each having a different capacity, a collection of flight legs that might be selected to be flown in a one-day period, so that a fleet schedule is generated that maximizes the airline's profits. Moreover, the fleet assignment problem which deals with assigning aircraft types, are also considered.

- Fleet Assignment

Considering the aircraft timetable as the input, each flight must be assigned to a fleet type so as to minimize assignment cost of

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0969-6997/

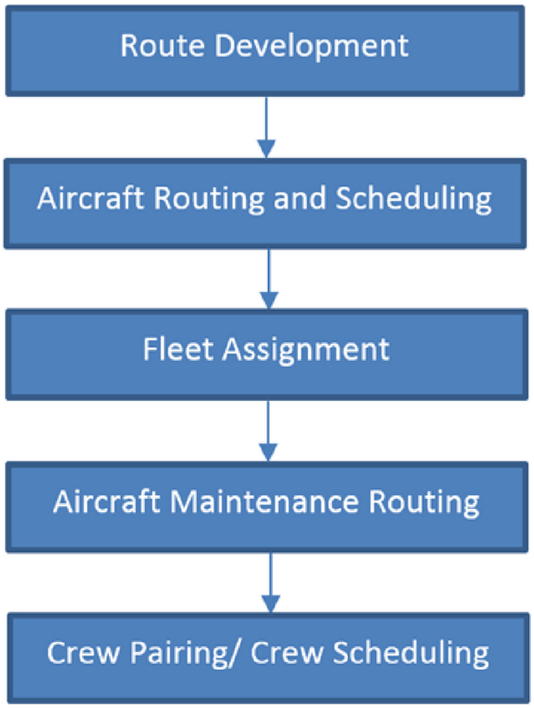

Fig. 1. Five steps of Airline Schedule Design.

flight legs to aircraft types.

- Aircraft Maintenance Routing

In this problem, decision makers determine feasible aircraft routes, sequences of flight legs flown by aircrafts, under maintenance requirements.

- Crew Paring or Crew Scheduling

In the crew scheduling problem, both cabin and cockpit crew must be assigned to a flight leg. The objective is to minimize the crew's costs. An airline crew can only be assigned to an aircraft it is qualified to run. The period that flight crews are away from their home station, base, must be satisfied. Moreover, the airline crews are not allowed to stay on duty longer than a maximum flying time requirement.

The fleet assignment problem (FAP) deals with assigning aircraft types, each having a different capacity, to the scheduled flights, based on equipment capabilities and availabilities, operational costs, and potential revenues.

1.1. Literature review

Clarke et al. (1997) presented a mathematical model which addresses aircraft rotation problem and applied a lagrangian relaxation approach that adds sub tour-elimination and maintenance constraints when violated. In this paper, the aircrafts' routes are determined given a set of assigned airports. Bartholomew-Biggs et al. (2003) studied and applied three algorithms for the aircraft routing problem to find an optimal flight path between a given origin and destination pair. In this paper, the aircrafts' origins and destinations are fixed, and the optimum paths are achieved considering the obstacles, i.e. no-fly zones such as geographical features. Desaulniers et al. (1997) addressed daily aircraft routing and scheduling problem which consists of determining daily schedules which maximize the anticipated profits derived from the aircraft of a heterogeneous fleet and used branch-and-price schemes with departure time-windows imposed within the sub problems. In this paper, two mathematical model are proposed. The first one is based on set partitioning problem, and the second one is a time constrained multi-commodity network flow formulation. Similarly, Barnhart et al. (1998) presented a single model and solution approach to solve simultaneously the fleet assignment and aircraft routing problems, which can capture costs associated with aircraft connections and considering some complicating constraints such as maintenance requirements. They proposed a string model to assign the fleets and determine the sequence of flights, under the condition that the schedules defining the departure and arrival times for each flight leg, are determined a priori. Yan et al. (2006) combined airport selection, fleet routing and timetable setting to develop an integrated scheduling model. The model, given the fleet-flow and the cargo-flow time space networks is formulated as a mixed integer program. The objective of this model is to “flow” all aircraft and cargos simultaneously, in all networks at a minimum cost. The model is formulated as a nonlinear mixed-integer program and solved using some heuristics. Sandhu and Klabjan (2007) proposed a model that integrates the fleeting and crew-pairing problems introducing two solution methodologies based on Lagrangian relaxation and column generation, as well as Benders decomposition approach. Gopalan and Talluri (1998) conducted a survey on mathematical models in airline schedule planning problems. Ruther (2010) proposed a multi-commodity flow formulation for the integrated aircraft routing, crew pairing, and fleet assignment problems. Cordeau et al. (2001) developed a model that integrates aircraft routing and crew pairing. Papadakos (2009) presented a model that is based on Cordeau et al. (2001) but integrates fleet assignment, aircraft routing, and crew pairing all together. Mercier et al. (2005) developed the Cordeau et al. (2001) approach by considering solution robustness by penalizing connections that are likely to cause delays if they are not performed by the same aircraft and crew. Sandhu and Klabjan (2007) integrated fleet assignment and crew pairing and developed a model which ensures that a pairing is assigned to a single fleet type only, thus permitting different sizes and qualifications of crews. Karaoglana et al. (2011) presented the implementation of aircraft routing and scheduling for cargo transportation. In this paper, three set of constraints are considered: (1) covering all flight legs exactly once, (2) Considering the maximum number of aircrafts, and (3) flow conservation at each airport for each aircraft type. Hu et al. (2015) proposed an integrated integer programming model based on an approximate reduced time-band network and a passenger transiting relationship, for the joint problems of aircraft and passenger recovery after a schedule disruption. Further to aircraft routing and scheduling problem, the aircraft routing in ground and terminals are also studied (Guépet et al., 2016; Samà et al., 2014). Dožić, and Kalić (2015) proposed robust model for airlines' fleet planning that deals with both fleet size and fleet composition problems based on fuzzy logic, heuristic and analytic approaches, and multi-criteria decision making methods. Dong et al. (2016) proposed two mathematical models and a heuristic algorithm for the problem of integrated flight scheduling and fleet assignment problem. Shao et al. (2015) proposed a mathematical model and decomposition approach for the integrated airline fleet assignment, aircraft routing, and crew pairing problem.

Based on the above survey, and according to the author's knowledge, there is no researches with the subject of integrated aircraft routing and scheduling, with consideration of fleet assignment problem where no airports, and flights are previously selected, and the attraction for passengers for direct and indirect flights are considered. Moreover, the unwilling uncertainties during