Integrated Airline Robust Scheduling and Fleet Assignment under Demand Uncertainty *

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Abstract
This paper looks at the airline-scheduling problem and develops an integrated approach that optimizes schedule design, fleet assignment and passenger use so as to reduce costs and create fewer incompatibilities between decisions. As passenger demand is characterized by uncertainty, we introduce stochastic variations caused by daily passenger demands in actual operations. To consider such stochastic disturbances we develop a stochastic-demand scheduling model where robust itineraries are introduced to ameliorate misconnected passengers. This integration leads to a huge model difficult to solve; an improved and accelerated Benders decomposition is proposed. The analytical work is supported with a case study involving the Spanish airline, IBERIA. Our approach shows that the number of misconnected passengers can be reduced when robust planning is applied.

Key words: Schedule design, Fleet assignment, Stochastic demand, Robustness.

1 Introduction
The airline schedule planning problem is defined as the sequence of decisions that need to be made to make a flight schedule operational. Given the high level of competition in the airline industry, effective decision making is crucial to the profitability of an airline. However, this decision making should not be only based on the available airline’s resources. Passenger demand fluctuations arising from stochastic market demands could affect the actual performance of the planned schedules. In practice, the performance of an optimal plan could be reduced when applied to actual operations where passenger demand fluctuations occur. In other words stochastic disturbances arising from variations in daily passenger demand could affect the optimality of the fleet assignments and timetables. Therefore, to set a good flight schedule, not only does the fleet and related supply have to be considered, but passenger demand fluctuations arising from stochastic market demands in actual operations also have to be taken into account. This is the motivation for this study in which we focus on the integration of the decision making process. Our goal is to achieve simultaneous rather than sequential solution, because a simultaneous solution will generate more economical solutions and create fewer incompatibilities between the decisions. Moreover, with the integration of the different planning

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process phases a greater robustness degree may be achieved, obtaining smoother solutions, which in case of incidents may be recovered in an easier way.

1.1 Contributions

In this paper, we present a mixed integer linear programming model for the schedule design and fleet assignment problem that accounts for demand uncertainty.

Our major contributions include:

1. We develop a robust, stochastic and integrated approach to solve the airline-scheduling problem, where schedule design, fleet assignment and passenger use are jointly solved.

2. Passengers’ flows are obtained through different itineraries in the network accounting for demand uncertainty.

3. We introduce robustness into the model accounting for expected misconnected passengers.

4. We use Benders decomposition. In order to speed up convergence we use a new set of cuts.

5. The model is tested using a simplification of IBERIA’s network.

2 Literature Review

The fleet assignment problem has been deeply studied. Hane et al. [5] present a multi-commodity flow model. They show various ways to reduce the problem size: variable aggregation, cost perturbations, dual simplex with steepest-edge pricing, and intelligent branch and bound strategies. Sherali et al. [11] present a tutorial on the basic and enhanced models and approaches that have been developed for the fleet assignment problem, including integration with other airline decision processes.

Lohatepanont and Barnhart [9], in their incremental optimization approach, select flight legs to include in the flight schedule and simultaneously optimize aircraft assignments to these flight legs. Kim and Barnhart [7] consider the problem of designing the flight schedule for a charter airline. Exploiting the network structure of the problem, they develop exact and approximate models and solutions, and compare their results using data provided by an airline. Lan et al. [8] consider passengers who miss their flight legs due to insufficient connection time. They develop a new approach to minimize passenger misconnections by re-timing the departure times of flight legs within a small time window. Jiang and Barnhart [6] maximize the number of potentially connecting itineraries weighted by their respective revenues allowing for limited changes in the schedule. Dumas et al. [4], using a passenger flow model devised in Dumas and Soumis [3], improve the fleet assignment model by taking stochastic demand prediction as inputs, and aim at computing expected numbers of passengers on each itinerary. Cadarso and Marín [2] look at the deterministic airline-scheduling problem and develop an integrated approach that optimizes schedule design, fleet assignment and passenger use so as to reduce costs and create fewer incompatibilities between decisions. The analytical work is supported with a case study involving the Spanish airline, IBERIA.

3 Problem Description

Frequencies and departure times must be determined for every itinerary for each market. Moreover, fleet types must be assigned to every flight leg. Two agents interact; the aircraft flow in the physical network
(supply), and passengers using the flight legs (passenger demand).

**Supply.** The network consists of airports and the feasible airways linking them. The airports are defined by the operations that can be performed within them and are characterized by available slots for landing and taking off. A flight leg is defined by an origin, destination and a departure time.

Each flight is assigned to a fleet type, with each fleet mainly characterized by its seating capacity and cruise speed and flight time depending on the assigned fleet type. In a tactical problem, used airplanes may vary due to uncertainty. It makes no sense, however, to plan to use a large number of aircraft if they have low utilization rates because of crew costs and issues of amortizing of the fleet. Consequently, minimum average block hour utilization is imposed for every fleet type.

A completely new schedule is not usually welcome in an airline because the carrier may have obligations in some markets especially if governments funding for 'essential services' is involved or there is a need to retain a market presence as a competitive force against rivals or to ensure retention of slots.

**Passenger Demand.** Unconstrained demand is characterized by the origin airport, destination airport, and the desired departure time. Demands for markets vary from day to day and we accordingly consider them as random variables. Their distributions are generally modeled as normal truncated at zero, or gamma, for small demands (Swan [12]).

Although the passengers have a desired departure time, it is not a fixed value, passengers will accept without any additional cost a departure time from a set of compatible times in each market.

For each market, passengers are considered in all possible itineraries. Each itinerary is defined by a set of flight legs that connect airports and a departure time and can be composed of one or more flight legs including intermediate stops at airports. If connecting time is not enough, passengers may misconnect and to minimize this, robust itineraries are introduced. A robust itinerary is one that minimizes misconnections resulting from a lack of time to change planes. Connecting time is thus a trade-off between an airline’s available resources and passengers’ perception regarding the inconvenience of waiting time.

Many markets face the problem that passengers will not have available ideal flight. Then, passengers will choose either a compatible, but different market or travel with another airline. We define compatible markets as those ones with identical origin and destination but alternative departure times. Therefore, some passengers will choose a compatible market, according to the relative recapture rate, and some will choose to travel with a different carrier; the recapture rate being a measure of the probability of accepting an alternative itinerary based on the time of day of departure, length of trip, and connections. It may also be that passengers willing to fly in a flight cannot find a seat, and thus the airline will try to offer them alternatives to fly. Depending on the available itineraries of other airlines the recapture rate can be calculated, and some of the disrupted passengers will take alternative itineraries offered.

Because competition effects are not considered, every flight leg will probably be crowded because demand in the market is unconstrained. This situation is not, however, realistic because demand will be shared between flight legs in real life. To represent this, the capacity offered for each flight leg is not 100% but that of the average load factor found in the airlines’ records. Additionally, competition within the same airline is avoided by imposing a separation time between flight legs operating from the same origin and to the same destination. Consequently, the model adjusts the unconstrained demand to the available capacity on the scheduled flight legs.
4 Integrated Robust Airline Scheduling and Fleet Assignment Model

We use an integrated, stochastic and robust model for timetable, fleet assignment and passenger use optimization to obtain a global optimum solution. The model is based on Cadarso and Marín’s [2] multi-commodity flow problem approach. The model in that paper was deterministic. However, due to the uncertainty in the passenger demand a two-stage optimization model is proposed: all supply related decisions are made in the first stage, while passenger demand realizations are in the second stage.

Solution Approach: Benders Decomposition. The problem has two decision levels: first, the system operator chooses flight legs and fleet assignment and second, passengers choose itineraries. To apply Benders decomposition, we divide the problem into a master problem defining a feasible network and a subproblem assigning the demand to this network. Benders decomposition iterates between the Master Model (MM) and the Sub-Model (SM) to find an optimal solution. In each iteration, the dual variables of the SM define Optimality Benders Cuts (OBC), which are added to the constraints of the master problem. The process continues until it converges under convex assumptions verified by the model.

Accelerating Benders Decomposition. The proposed Benders SM has a set partitioning structure, making it degenerate, that is, it has a non-unique dual solution. Thus, the chosen dual solution may correspond to a weak cut, increasing the number of iterations needed to reach convergence. Magnanti and Wong [10] solved this problem by choosing the strongest cut in the sense of the pareto-optimality. A cut is called pareto-optimal if no cut dominates it.

Benders [1] showed that after a finite number of steps his algorithm finds an optimal solution or proves that not exits. Finding a solution in a finite number of steps is in practice not good enough, and hence performance issues are improved using the previous pareto-optimal cuts.

Improved Accelerated Benders Algorithm. The necessity of solving repeatedly the Benders Master Problem is a bottleneck in the previous proposed algorithm. This is due to the fact that the problem is integer and the cuts added in each iteration complicate the problem.

Consequently, a new approach is proposed. First, the Benders Master Problem is relaxed. Then, the Accelerated Benders Algorithm is used to solve the problem until the convergence is reached. Every obtained OBC will be valid for the integer Master Problem, so they are automatically added when integrality constraints are reactivated. Then, again the Accelerated Benders Algorithm is used to solve the problem until convergence is reached.

Although the number of integer problems to solve has been reduced, the problem still remains because once the convergence for the relaxed problem has been reached, the first iteration with integrality constraints faces with a lot of OBCs, making it hard to solve to optimality by exact methods. However, subrogate constraints theory may be used to solve this problem. We also limit the solution space in order to get solutions in reasonable computational times.

5 Summary of Computational Experiments

All of our computational experiments is for the major airline in Spain, IBERIA. We present some results related to different realistic networks. Computational results show how robustness could be achieved, although at a price. The robust approach is compared with a non-robust one: misconnected passengers are reduced.
References


