An integrated schedule planning and revenue management model

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1 Introduction

The increase in air travel demand and the distance of travels in the last decades is an indicator of the increased mobility needs of individuals. Development of demand-responsive transportation systems is crucial to maintain the sustainability while satisfying the increased demand. In order to achieve this, actions need to be taken from both supply and demand sides. In our study we tackle the supply side by analyzing an innovative aircraft, called Clip-Air, which has flexibility in transportation capacity. On the demand side, we develop an appropriate demand model to better understand the underlying travel behavior. We integrate this demand model in a schedule planning model in order to make use of the endogenous interactions between supply and demand.

Clip-Air is a modular innovative aircraft, which is currently designed at the Ecole Polytechnique Fédérale de Lausanne (EPFL, [1]). It is based on two separate structures: a *flying wing* designed to carry the engines and the flight crew; and the *capsules*, designed to carry the passengers and/or freight. The wing can carry one, two or three capsules. The number of capsules can be changed with a clipping mechanism in order to adapt to changing demand patterns. This modularity of Clip-Air brings in various advantages in terms of transportation operations. A comparative analysis of Clip-Air and standard planes is presented in [2] with several scenarios. It is observed that there is a potential of Clip-Air in increasing the transportation capacity and profit of airlines.

The focus of this paper is the explicit representation of supply-demand interactions. With this purpose we introduce an integrated schedule planning and revenue management model. The schedule planning model is an integrated schedule design and fleet assignment model which is inspired by the model of [3]. However they treat the demand as being inelastic to the market conditions. They include supply-demand interactions with spill and recapture effects which are pre-processed based on Quality Service Index (QSI). However we explicitly model revenue management decisions through and itinerary choice model specific to each cabin class. The price of the itineraries can be updated according to the market conditions. Similarly spill and recapture effects are elastic to the attributes of the itineraries. Therefore supply-demand interactions are endogenously modeled. Moreover, the seat allocation for economy and business passengers are optimized according to their underlying demand behavior. [4] also works on an integrated schedule design, fleet assignment and pricing model where spill and recapture effects are ignored. [4] uses a demand model which defines the utilities with the price variable and does not differentiate between economy and business passengers. On the other hand, we develop a class specific demand model based on a real data including the variables of the travel time, number of stops and departure time of the day in addition to the price of the itineraries. Furthermore, we analyze the added value of the integrated model on a network of a major European airline.

2 Integrated model

We introduce an integrated schedule planning and revenue management model. The schedule planning model decides on the schedule design and fleet assignment. Schedule design decision is related to the set of optional flights which can be canceled if they are not profitable. The fleet assignment model uses a time-space network. It is an itinerary based fleet assignment model since the flow of passengers are considered through spill and recapture effects.

The revenue management decisions include the pricing and the seat allocation to each cabin class. The pricing decision is taken according to the demand model which is an itinerary choice model. It is formulated as a logit model and the parameters of price, travel time, number of stops, and departure time of the day are estimated with a maximum likelihood estimation. This logit model gives the market share for the alternative itineraries in the same market segment according to the relative values of their attributes. We have specific demand models for economy and business passengers and the seat allocation to each class is optimized in order to increase the profitability.

In order to quantify the advantages of our integrated approach we compare it with a sequential approach. This sequential approach is the common practice of airlines where the fleet assignment decision is given according to the demand forecast and subsequently the revenue is optimized over the fixed capacity. In Table 1 we provide results for this comparative analysis which is obtained by BONMIN solver. We list 12 experiments with different number of flights and different number of plane types in the fleet. The demand represents the average forecasted demand per flight. For the results of the sequential and integrated approach we present the profit, number of transported passengers, number of operated flights and allocated capacity (seats) respectively. It is seen that in half of the instances, the integrated approach is superior to the sequential approach with higher profit and more transported passengers. For those instances, the simultaneous decisions of the integrated approach change the schedule planning according to the knowledge on the demand. It either allocates more capacity or operates more flights when there is a potential.

3 Solution Methods

The integrated schedule planning and revenue management model is a mixed integer nonlinear problem which has a high complexity. The experiments presented in Table 1 show our limit such that the instances beyond those cannot be solved with a solver in 12 hours.

Table 1: Results of a comparative analysis between the sequential and integrated approach

				Sequential approach				Integrated model			
Experiments	Flights	Fleet	Demand	Profit	Pax.	Flights	Seats	Profit	Pax.	Flights	Seats
1	10	2	52	15,091	284	8	124	15,091	284	8	124
2	11	2	83.1	**35,372**	**400**	8	**150**	**37,335 (+5.5%)**	**534 (+33.5%)**	8	**217**
3	12	2	113.8	50,149	859	10	300	50,149	859	10	300
4	26	3	56.1	**69,901**	**931**	**22**	**274**	**70,904 (+1.4%)**	**1063 (+14.2%)**	**24**	**324**
5	19	3	96.7	82,311	1145	16	333	82,311	1145	16	333
6	12	3	193.4	**904,054**	1448	10	**1148**	**906,791 (+0.3%)**	1448	10	**1312**
7	15	5	58.1	27,076	448	10	207	27,076	448	10	207
8	14	5	87.6	**63,918**	**633**	**10**	284	**64,023 (+0.2%)**	**733 (+15.8%)**	**12**	284
9	13	5	100.1	51,160	793	8	402	51,160	793	8	402
10	39	4	64.5	**137,428**	**1517**	34	**391**	**138,575 (+0.8%)**	**1592 (+4.9%)**	34	**476**
11	23	4	86.1	**93,347**	**1144**	20	**387**	**96,486 (+3.4%)**	**1160 (+1.4%)**	20	**457**
12	19	4	101.4	83,251	1104	12	536	83,251	1104	12	536

Therefore it is crucial to develop solution methods in order to analyze the behavior of the integrated model for large networks. We propose a heuristic method based on Lagrangian relaxation and subgradient optimization which includes a local search procedure based on price sampling. The preliminary results show that for an instance of 26 flights and 5 fleet types, heuristic has a 1.5% deviation from the optimal solution in 10% of the time needed for the solver. For larger instances, where we do not have the optimal solution, the advantage of the heuristic becomes more evident. For a data instance of 42 flights and 7 plane types, the solver provides a feasible solution with a duality gap of 23% in 12 hours. However with the heuristic we find a feasible solution with a 5% duality gap in half an hour. This is an ongoing work and the performance of the heuristic will be tested for a comprehensive set of instances.

References

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