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Disruption management in the airline industry—Concepts, models and methods

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ABSTRACT

This paper provides a thorough review of the current state-of-the-art within airline disruption management of resources, including aircraft, crew, passenger and integrated recovery. An overview of model formulations of the aircraft and crew scheduling problems is presented in order to emphasize similarities between solution approaches applied to the planning and recovery problems. A brief overview of research within schedule robustness in airline scheduling is included in the review, since this proactive measure is a natural complement to disruption management.

1. Introduction

The airline industry is one of the most successful examples of applying operations research methods and tools for the planning and scheduling of resources. Optimization-based decision support systems have proven to be efficient and cost-saving for the scheduling of aircraft and crew, not to mention the short term re-scheduling problems, where modifications to the initial plans are required before the final schedules can be executed.

On the day of operation carefully planned crew and aircraft schedules can become infeasible due to external disruptions and internal failures. To date, no planning tools have been able to cope with the complexity of re-planning all airline operations at the same time during disruptions. Despite the increasing power of hardware and sophisticated solution methods, there is still a gap between the reality faced in airlines' operations control and the decision support offered by the commercial IT-systems targeting the recovery of aircraft, crew and passenger itineraries in one integrated system. However, substantial achievements have been made in developing solution methods that support the stand-alone recovery of aircraft and crew since the mid 1980s, and a few prototype systems for integrated airline recovery have been presented in the operations research literature. The majority of the mathematical models and solution methods for solving the airline recovery problems are similar to the methods applied for planning purposes. Tools for planning as well as for recovery are, in most research cases, based on a network representation that describes how flights can be sequenced either in a rotation or in a crew pairing. In the remainder of this section we present an overview of the most commonly used network models for airline optimization problems and a short description of the planning process used by major airlines today. Section 2 describes aircraft, crew, and integrated and passenger recovery as presented in the literature, while Section 3 briefly discusses robustness in relation to disruption management. Finally, Section 4 contains discussions of future prospects for disruption management systems in the airline industry.

1.1. Airline planning process

Prior to the departure of an aircraft, a sequential planning approach takes place. First, the flight schedule is determined, based on forecasts of passenger demand, available slots at the airports and other relevant information. Thereafter, specific types of aircraft are assigned to individual flights in the schedule, and sequences of flights are generated within each fleet—these processes are called fleet assignment and aircraft routing, respectively. Aircraft rotations must respect various types of constraints as e.g. maintenance and night curfews. In the subsequent crew scheduling phase, flight crew and cabin crew are assigned to all flights based on the already determined aircraft rotations. Individual flights are grouped to form anonymous crew pairings. Each pairing starts and ends at the same crew base and has a typical length of three–four days. Afterwards, pairings are grouped to form personnel rosters, which are lines of work typically for 14 days or one month, including rest periods, vacations and training. Finally, physical aircraft from a given fleet are assigned to flights in the tail assignment process. The complete planning process is illustrated in Fig. 1.

The planning process is very complex since numerous restrictions and rules have to be considered. For aircraft, rules on maintenance, differences between various aircraft types, etc. must be taken into

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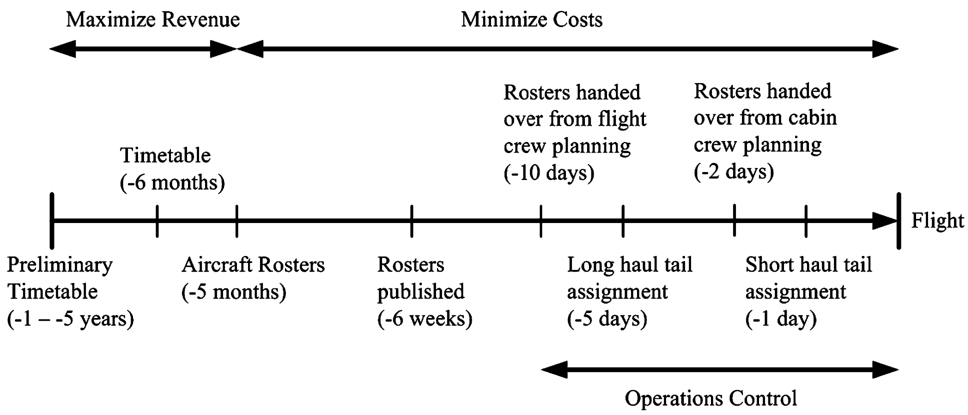

Fig. 1. The time line for the operation of a major European airline.

the planning. Also, characteristics of each individual airport have to be respected. For crew, there are regulations on flying time, off-time, etc., based on international and national rules, as well as regulations originating in agreements with unions, specific to each airline. Changes in plans due to e.g. crew sickness, aircraft breakdowns and changes in passenger forecasts take place in the tracking phase of the planning process. This phase normally resides with the planning department of the airline.

The plans for aircraft and crew assignments are handed over from the planning department to the operations control center (OCC) a few days ahead of the day of operation. It now becomes the responsibility of the OCC to maintain all resources so that the flight schedule is feasible as an integrated entity. Events like acute crew unavailabilities and delayed flights have to be handled. Not only the immediately affected flights, but also knock-on effects in other parts of the schedule can cause serious problems. Generally, a disrupted situation (often just denoted a disruption) is a state during the execution of the current operation, where the deviation from the plan is sufficiently large to impose a substantial change. This is not a very precise definition; however, it captures the important point that a disruption is not necessarily the result of one particular event.

The generation of recovery plans is a complex task, since many resources (crew, aircraft, passengers, slots, catering, cargo etc.) have to be re-planned. When a disruption occurs on the day of operation, large airlines usually react by solving the problem in a sequential fashion with respect to the problem components. First, infeasibilities in the aircraft schedule are resolved, then crewing problems are addressed. Afterwards, ground problems are tackled, and finally, the impact on passengers is evaluated. Sometimes, the process is iterated with all stakeholders until a feasible plan for recovery is found and can be implemented. As a rule, determining the quality of a recovery option is a difficult task. The objective function can be composed of several conflicting and sometimes non-quantifiable goals. Examples of objectives are minimizing the number of passenger delay minutes, returning to the plan as quickly as possible, minimizing passenger dissatisfaction, minimizing the cost of the recovery operation, etc. In most airlines, controllers performing the recovery have only limited IT-based decision support to help them construct recovery options or evaluate the quality of the recovery action they are about to implement. Often, controllers are content with only producing one viable recovery plan since there is no time to consider alternatives.

1.2. Models for airline optimization problems

The majority of airline recovery models are formulated and solved similar to the corresponding planning problems, using the same network representations to model the schedules. However, there are also some differences between the modelling approaches. In order to draw a parallel between recovery models and optimization problems occurring during the planning phase, we briefly present the aircraft routing and the crew scheduling problem formulations, as well as their substantial differences from the recovery models.

Table 1
A sample schedule for Sample Air with aircraft rotations.

Aircraft	Flight	Origin	Destination	Departure	Arrival	Flight time
AC1	11	OSL	CPH	14:10	15:20	1:10
	12	CPH	AAR	16:00	16:40	0:40
	13	AAR	CPH	17:30	18:10	0:40
	14	CPH	OSL	18:50	20:00	1:10
AC2	21	CPH	WAV	14:30	15:30	1:00
	22	WAV	CPH	15:50	16:50	1:00
	23	CPH	WAV	17:30	18:30	1:00
	24	WAV	CPH	18:50	19:50	1:00
AC3	31	AAR	OSL	15:00	16:20	1:20
	32	OSL	AAR	17:00	18:20	1:20

1.2.1. Network representations

The three most commonly used network representations for airline planning and recovery problems are time-line networks, connection networks and time-band networks. In order to illustrate the networks, consider a small flight schedule of an artificial airline Sample Air shown in Table 1, where flights connecting Copenhagen (CPH), Oslo (OSL), Aarhus (AAR), and Warsaw (WAV) are given. Assume that the turn-around-time for an aircraft is 40 min in CPH and OSL and 20 min in AAR and WAV.

A *connection network* is an activity-on-node network, where flight legs correspond to nodes in the network and connections between flight legs correspond to directed edges (arcs) between the nodes. A flight leg is given by its origin, destination, departure time and date and arrival time and date. A node i, representing the flight leg l_i, is connected by a directed edge (i,j) to a node j, which represents the flight leg l_j, if it is feasible to fly l_j immediately after l_i using the same aircraft with respect to turn-around-times and airport. In addition, there is a set of origin and destination nodes indicating possible positions of aircraft in a fleet at the beginning and at the end of the planning horizon, respectively. A path in the network from an origin to a destination node corresponds to a sequence of flights feasible as part of a rotation. Schedule information is not represented explicitly in the network, but is used when generating the nodes in the network. Maintenance restrictions can be easily incorporated through the concept of a maintenance feasible path,