Structuring the Process of Airline Scheduling

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Abstract

Constructing an airlines schedule is a complex task. Driving factors are economic and marketing considerations, safety regulations, and the availability of personnel, facilities and equipment. The overall schedule has to determine the plan of action for flight crews and planes as well as the timetable published for consumer needs. Different airlines subdivide the process of schedule construction into more manageable parts in different ways and organize them in different orders. In order to facilitate the comparison and the discussion of the different approaches we identify some basic building blocks commonly used along with their interdependencies. We show how different proposed strategies for schedule construction can be conceptualized using these building blocks. Several approaches will be outlined briefly.

1 Introduction

Planning the activities necessary to run an airline is a complex task. The process of schedule planning is certainly the heart of it. Wells (1994), p. 254, gives a description of the schedule planning problem:

> Defining what the *schedule planning* division does is simple: all that is necessary is to take the company's marketing goals for a particular period and turn them into a salable schedule that creates volume of new traffic; beats the competition; makes the most efficient use of personnel, facilities, and aircraft; serves the cities on the system; and earns ever-increasing profits. Scheduling may be the most difficult job in any airline.

Since much research has been published and many researchers have tackled parts of the planning problem, it seems worthwhile to review and organize their different approaches into an overall structure. There are many different ways used to partition the planning process and to identify and name the specific components of it. This leads to the open situation what the exact problem and the exact content of its solution is, when one talks about a certain part of the scheduling process. In order to facilitate a comparison and discussion of the approaches we present a framework of building blocks which allows the precise naming and explanation of approaches in a unique way.

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2 Airline Scheduling

Basically, there are only four types of questions to be answered by the scheduling department of an airline:

1. Which airports should be connected by a direct flight, i.e. which legs should be flown?
2. When and how often should one operate each chosen leg in a planning period, i.e. what are the departure and arrival times?
3. What aircraft should be selected to fly a certain leg at a certain time?
4. Which crew should operate the aircraft flying a certain leg at a certain time?

The planning process of an airline may be viewed from different angles. One angle is constant cycling through schedule construction and schedule evaluation until a satisfactory schedule is constructed or the available planning time is up. This view is described in Etschmaier & Mathaisel (1985). A second angle focuses on the time axis while approaching the point of implementation of the planned actions. Decision making along this time axis is commonly divided into strategical, tactical, and operational planning. Strategical planning deals with longterm aspects and determines a framework in which all subsequent decisions are placed. During tactical planning the airline develops a concrete plan of action for its operations, i.e. it selects a schedule to be implemented. Finally, the implementation of the schedule is guided by operational planning which adapts the schedule to variations and disturbances encountered.

3 Building Blocks

As an initial step each customer orientated airline will evaluate potential markets. This step is called *market evaluation problem* (MEP). As an result one often uses a *origin destination matrix* $D = (d_{od})$ giving the amount of demand d_{od} originating at airport o and destining to airport d.

In order to get a strategic direction, the airline is now in a position to select its primary target markets in combination with service and price policies. We deem this the *market selection problem* (MSeP).

The results of the market evaluation and selection may already indicate a probably sparse or even disconnected network of services to be offered. Based on the market evaluation on strategic decisions of partnership or on available ground assets the airline will now determine some intermediate airports to use, i.e. solve the *airport selection problem* (ASeP), and some connecting legs they would prefer to operate. The latter topic is called the *leg selection problem* (LSeP).

Generally, the next step is to determine the frequencies and capacities used in operating each leg. A frequency for a certain leg gives the number of times in a planning period—usually a week—the leg should be flown. One solves the leg *frequency assignment problem* (LFAP) in order to get each leg's frequency. A capacity for a leg specifies its total transport capacity for the planning period. To determine each leg's capacity one solves the *leg capacity assignment* problem (LCAP).

The question, which crew is to operate which leg, is answered by solutions of a two stage process of first construction of so called crew pairings followed by second the selection of a crew assignment based on these pairings. A *pairing* is a sequence of connected legs originating and ending at the same crew base giving duties for a single crew. The locations of the crew bases a predetermined in an earlier more strategic planning phase. There may be *off duty times* included in these pairing, i.e. so called lonely overnights at other airports. The *crew paring problem* (CPP) means to find a minimum cost set of pairings such that each leg offered is covered by at least one pairing. The

Table 1: Building Blocks

abbreviation	building block
MEP	market evaluation problem
MSeP	market selection problem
ASeP	airport selection problem
LSeP	leg selection problem
LFAP	leg frequency assignment problem
LCAP	leg capacity assignment problem
CPP	crew pairing problem
CAP	crew assignment problem
DSP	departure scheduling problem
ASP	arrival scheduling problem
ARP	aircraft rotation problem
FAP	fleet assignment problem

crew assignment problem (CAP) is to choose pairings for each individual crew such that each crew gets a plan of action for a whole month and again each leg has to be covered.

During the process of scheduling one has to select departure times as well as arrival times for each leg. The former are determined through a result of the *departure scheduling problem* (DSP), whereas the latter times are determined as a result of the *arrival scheduling problem* (ASP). These times have to give room for sufficient flying time and for enough time to switch planes according to the airlines hubbing policies (if any). The decisions for arrival and departure times are also influenced by customer preferences and airport restrictions such as *curfews* which are an intervals of time where an airport prohibits any takeoff or landing.

Aircrafts may be grouped according to their technical characteristics to form fleets of similar aircrafts. All aircrafts of a fleet are said to be of the same aircraft type. Two examples of aircraft fleets are all planes of the type Boeing 737 or all planes of the type Airbus A 320. Given the legs along with their capacities the *fleet assignment problem* (FAP) is to determine a fleet for each leg capable to operate the leg and to provide sufficient capacity. This *fleeting* enables one to decompose the schedule along the different fleets. Since the schedule of most airlines is to be repeated every week, one seeks to find connected sequences of legs for each aircraft such that the aircrafts cycle through the schedule starting each Monday. Such a sequence chosen for a certain aircraft is called a rotation. The *aircraft rotation problem* (ARP) is to determine a set of rotations for a part of the decomposed schedule in such a way that each leg is served by a rotation and the maintenance policy is followed for each aircraft. Since each aircraft is identified by its unique tail number, the result of the aircraft rotation problem is called a *tail number schedule*.

The table 1 summarizes the building blocks described above.

4 Combinations and Dependencies

Building blocks can be combined and therefore form more complex problems. The *network design problem* is a combination of the airport and leg selection problems along with the leg frequency and capacity assignment problems. The crew pairing and crew assignment problem together form the *crew scheduling problem*. Given solutions to the problems of leg frequency assignment, departure and arrival scheduling, one has solved the combination called *flight scheduling problem*. And finally the *aircraft routing problem* is defined by the problem group of leg capacity assignment, fleet assignment and aircraft rotation. These four groups are given quite natural since they are directly related to the four questions mentioned above. The network design problem gives answers to the question where to fly (1), the solution to a fight scheduling problem says when to fly (2), which equipment to use and how (3) is answered by solutions to the aircraft routing problem, and what crews are selected to operate the whole schedule (4) is determined by solutions to the crew scheduling problem.

Each building block is characterized by its inputs and outputs as depicted in figure 1. Some necessary inputs like crew bases, locations of airports, available planes and crews, etc. are assumed to be given. If one combines two ore more of the basic blocks to describe an integrated planning step their inputs combine as far as these inputs are not determined as output of a basic block of the combination. The output of this combination is the most detailed output of each of the basic blocks. I.e. the combination "Crew Scheduling" needs legs as input with optional fleeting, frequencies of legs, departure and arrival timetables. During the planning of this combination a crew assignment is determined being the more detailed output. Pairings may be extracted since the crew assignment specifies each individual crews duties.

5 Sequences

We are now in a position to analyze and explain different strategies for airline planning found in literature in terms of the building blocks defined above.

As an example, Etschmaier & Mathaisel (1985) explain a stepwise approach to schedule construction which may be stated as a sequence of the combination called *frequency planning* or *frequency optimization* followed by DSP and finally by ARP. Frequency optimization solves the combination of LSeP and LFAP. Since Etschmaier & Mathaisel focus solely on aircraft schedules they use the combination of CPP and CAP only to evaluate a given schedule.

Ghobrial et al. (1992) give a description of airline scheduling for small size airlines. They assume an airline operating only a single aircraft type. Further on they assume an O&D matrix and a set of candidate routes is given. Their first planning phase is called *frequency planning* and corresponds to the LFAP where candidate routes may yield a zero frequency, i.e. this phase also partially solves the LSeP. Next they determine departure time windows according to passenger arrival patterns at check-in counters for each leg using a *time-of-day model*. Finally, they solve an instance of their *aircraft routing model* which results in aircraft rotations neglecting maintenance needs.

Following the ideas presented by Suhl (1995) the process of airline scheduling may be viewed as a five step process. The first step is *capacity estimation* which combines the blocks MEP, MSeP, LSeP, LFAP, LCAP. Afterwards there is a choice offered between strategy 1 and strategy 2. Strategy 1 solves the *flight scheduling* problem, i.e. DSP and ASP, followed by a combination of *fleet assignment* and *aircraft routing*, which is solving FAP and ARP. On the other hand strategy 2 solves the fleet assignment as a first step followed by a combination of flight scheduling and aircraft routing as a second step. Here the sequence in terms of building blocks is FAP followed by a combination of DSP/ASP and ARP. The final step in each of the two strategies is the *crew scheduling* phase dealing with the solution of the combination of CPP and CAP.

Rushmeier & Kontogiorgis (1996) explain the planning process at USAir as a process of seven steps. Their first step is called *market planning* and corresponds with the combination MSeP, LSeP, and LFAP. The second step solves the DSP which is called *schedule design*. Afterwards they solve the *fleet assignment problem* followed by the ARP which they call *aircraft routing*. This gives an implicit solution of the ASP since knowing an aircraft type as well as a departure time for a leg allows the calculation of the arrival time in terms of the aircraft type's specific speed. Next is the combination CPP and CAP, the latter one being called the problem of finding *crew blocks*. Their last step is the *scheduling of ground staff* which we do not discuss in this article.

In order to construct better schedules Zils (1996) proposes the integration of the above stated two strategies of Suhl by the combined solution of DSP, ASP, FAP and ARP via genetic algorithms.

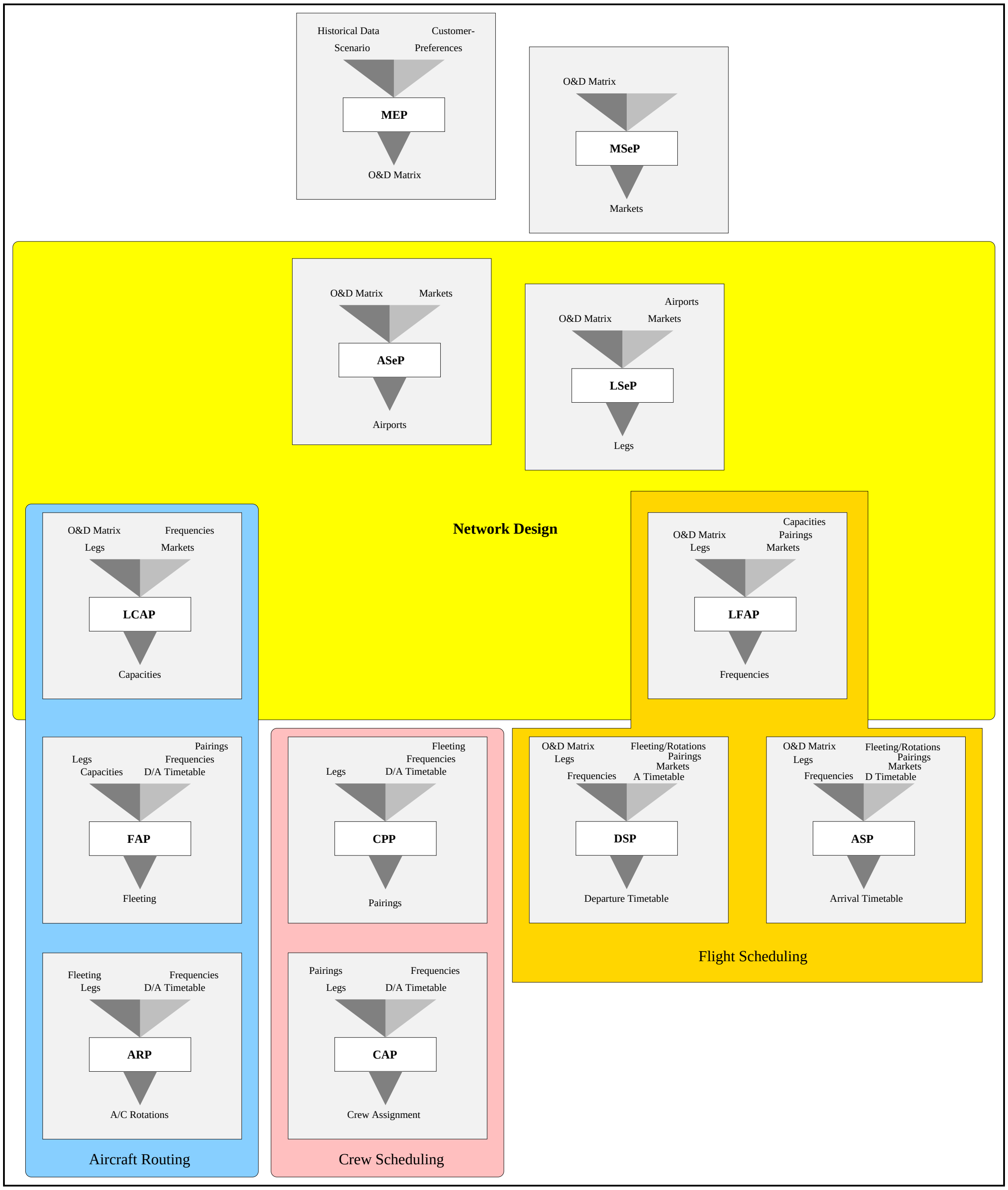

Figure 1: Dependencies and combinations of the building blocks.
The input of each building block is indicated above each block. The Text above the darker half of the triangle describes mandatory input whereas text above the lighter half of the triangle indicates optional input. This optional input has to be obeyed if present. Below each block is a triangle pointing to the name of the output of the block.

We denote a combination of the block A and B as A$\oplus$B. Sequential treatment of block A followed by B is denoted by A$\rightarrow$B. The operator $\oplus$ has a higher precedence than the operator $\rightarrow$. Using this compact notation the five different arrangements can be described as:

Stepwise Approach by Etschmaier & Mathaisel (1985):
LSeP $\oplus$ LFAP $\rightarrow$ DSP $\rightarrow$ ARP $\rightarrow$ CPP $\oplus$ CAP

Small Airlines by Ghobrial et al. (1992):
LSeP $\oplus$ LFAP $\rightarrow$ DSP $\rightarrow$ ARP

Strategy 1 by Suhl (1995):
MEP $\oplus$ MSeP $\oplus$ LSeP $\oplus$ LFAP $\oplus$ LCAP $\rightarrow$ DSP $\oplus$ ASP $\rightarrow$ FAP $\oplus$ ARP $\rightarrow$ CPP $\oplus$ CAP

Strategy 2 by Suhl (1995):
MEP $\oplus$ MSeP $\oplus$ LSeP $\oplus$ LFAP $\oplus$ LCAP $\rightarrow$ FAP $\rightarrow$ DSP $\oplus$ ASP $\oplus$ ARP $\rightarrow$ CPP $\oplus$ CAP

Integrated Approach by Zils (1996):
MEP $\oplus$ MSeP $\oplus$ LSeP $\oplus$ LFAP $\oplus$ LCAP $\rightarrow$ DSP $\oplus$ ASP $\oplus$ FAP $\oplus$ ARP $\rightarrow$ CPP $\oplus$ CAP

USAir Approach by Rushmeier & Kontogiorgis (1996):
MSeP $\oplus$ LSeP $\oplus$ LFAP $\rightarrow$ DSP $\rightarrow$ FAP $\oplus$ ARP($\oplus$ ASP) $\rightarrow$ CPP $\rightarrow$ CAP

6 Conclusion

The use and definition of building blocks for airline scheduling enables the classification and comparison of different approaches found in the literature. It facilitates the interpretation and discussion of strategies, problem descriptions, models, and algorithms, because it enables a precise characterization of the position and relevance within the whole planning process.

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