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AIRLINE FLEET ASSIGNMENT : A STATE OF THE ART

Catherine Mancel and Felix Mora-Camino

ENAC, Air Transport department
7, avenue Edouard Belin 31055 Toulouse
(33)-5-62-17-40-00

Catherine.mancel@enac.fr felix.mora@enac.fr

ABSTRACT

With the hard competitive environment of the air transportation sector, airlines have to cope with more and more complex and large optimization problems at planning and operations levels, especially concerning the fleet management.

One of the major tasks consists in assigning profitable aircraft type to each flight, given the sets of flights and aircraft of an airline. The assignment has to meet a large variety of requirements and has to deal with the complementary objectives of maximizing revenue (by matching seat capacity to passenger demand) and minimizing costs (such as fuel, maintenance operations, airport gating …) over the operated network.

In this communication a state of the art relative to the fleet assignment models adopted in the Operations Research literature, is proposed. The different models are compared in terms of applicability to real life problems in a short term operational context. Side problems such as maintenance planning and crew assignment are also considered while performances such as robustness to common perturbations or to strong disruptions are of interest.

Keywords :

Airline Planning, Airline Operations, Fleet assignment, Operations Research

1- Problem Description

With the hard competitive environment of the Air Transportation sector, airlines have to cope with more and more complex and large optimization problems at planning and operations levels.

To face up this complexity the airline planning process is devided into several modules, each representing an optimization problem corresponding to a specific resource and time horizon.

The planning process might be devided according to different frameworks, but six relevant problems can be identified, as depicted in figure 1 :

- the Network Design problem, which should be solved on the long term (for example on a three years period) and consists in mainly deciding which airports should be served by the airline,
- the Fleet Design problem which consists in deciding the size and the composition of the fleet of the airline,
- the Flight Scheduling problem which consists in finding when and how often should each leg flight be operated (*ie* deciding departure and arrival times) in a planning period,
- the Fleet Assignment problem which consists in assigning a well suited aircraft type to each flight leg,
- the Aircraft Routing problem which consists in designing the sequence of flight legs each aircraft will have to operate on the short term,
- the Crew Management problem which consists in designing a work schedule for each crew member in order to be able to operate each flight leg.

These problems are directly or indirectly linked one to each other. The resolution of one problem depends on the solution of the previous one, and has to take account of the possible performances for the solutions of sub sequent problems. This means that for each problem, the airline has to forecast as precisely as possible the market behavior, and possibly (for example, if considerable changes occured in demand forecast) modify the previous problem statement to get updated solutions.

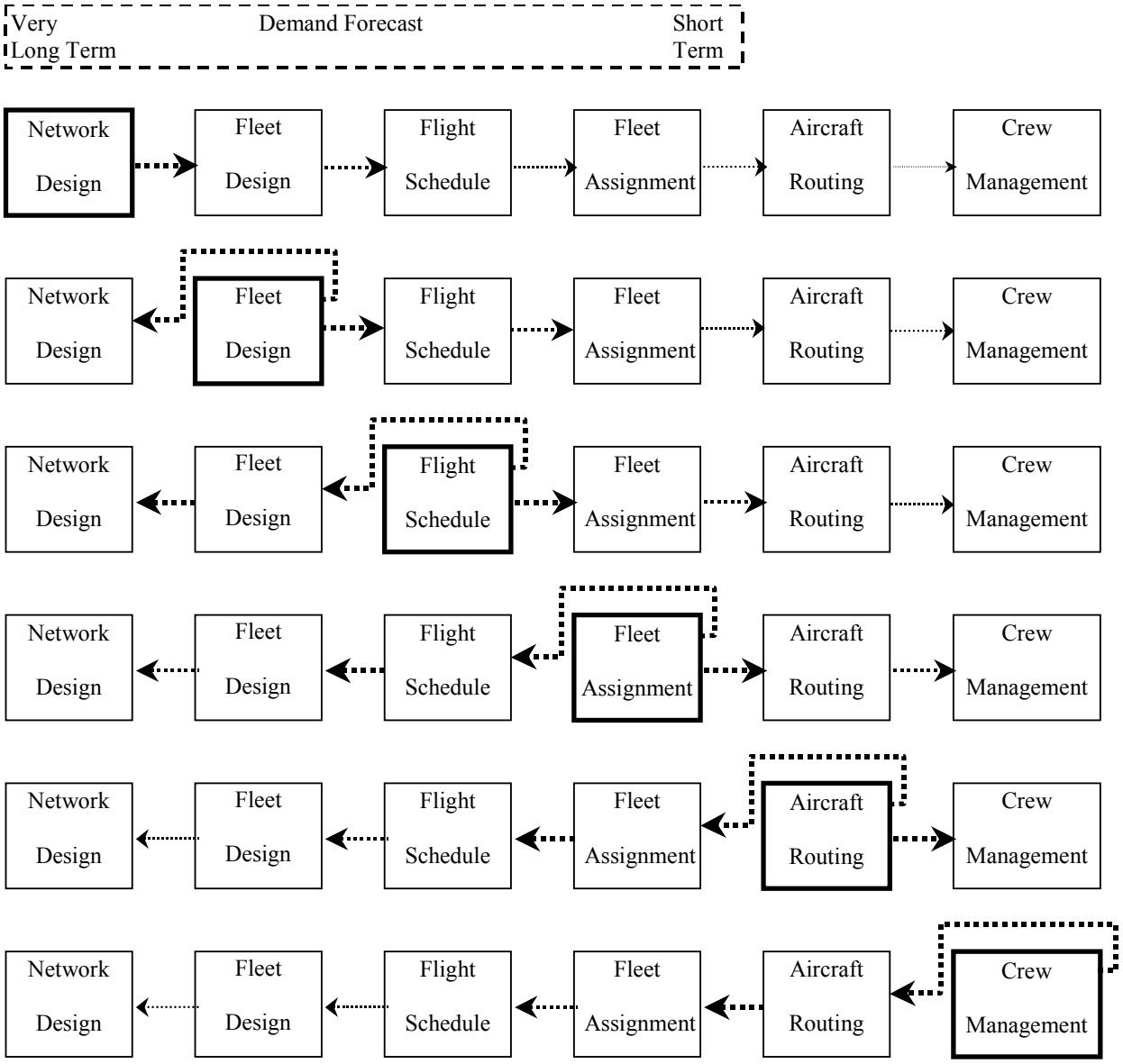


Figure 1 : A structural view of airlines' supply dynamic definition process

Because of their high acquisition and operations cost, the most critical resources an airline has to manage are the aircraft and the flight crew. Using the best aircraft type for each flight is thus crucial, to optimize the compromize between maximizing the offered capacity and minimizing the operations costs (fuel comsumption, crew wages, landing fees, ATC charges, etc.).

Thus, the Fleet Assignment problem is one of the most crucial problem an airline has to face up in its planning process. In the following this particular problem is considered.

The fleet assignment has to meet a large variety of requirements. The airline has to determine a fleet type for each leg capable to operate the leg (in term of aviability and technical performances) and to provide sufficient capacity. It has also to deal with the complementary objectives of maximizing revenue (by matching seat capacity to passenger demand) and minimizing costs (such as fuel, maintenance operations, airport gating, etc.).

The airline fleet assignment problem has been an important subject of industrial and academic studies for several decades. These planning tasks that have been at start manually operated, became quickly much more complicated. Thus the need of efficient decision aid tools early standed out. Operations Research methods, have been of particular interest to tackle this problem.

A first model has been proposed by Ferguson and Dantzig as early as 1955. This model combined fleet assignment and aircraft routing problems and maximized profit for a given flights schedule. In 1956 the authors enhanced this model by introducing stochastic levels of demand.

Simpson (1978) developped a model to assign aircraft to flights adopting as primary goals the satisfaction of demand and the minimization of operations costs.

These first academic studies were not really used by any airline.

After the deregulation of the US airline industry in the eighties, major airlines extended significantly their offer by developing hub-and-spoke networks and the assignment problem shown new features. With the increased competition in this sector, the problems of flights scheduling and of fleet assignment became even more critical. In the same time, improvements and diversification in Operations Reasearch methods (particularly in terms of heuristic methods), as well as increased computer hardware performances allowed to tackle the Fleet Assignment problem much more efficiently and in ways that better take into account the real needs of airlines.

2- Basic Fleet Assignment Model

Abara (1989) while working for American Airlines, introduced a basic framework for the Fleet Assignment problem. The proposed model resulted in a linear program that could either maximize profit or minimize operations cost. He introduced a time-space network to represent

the availability of the fleet at each airport in the course of time. The solution algoritm used Linear Programming and Branch-and-Bound methods. This work presented computational limitations to be efficiently applied to large-scale real problems.

Hane et al (1995) proposed an almost similar model to Abara's with significant computational improvments based on interior-point linear programming as well as network preprocessing techniques.

The problem considered can be described as follows :

"Given a flight schedule with fixed departure times and costs (fleet and flights specific operating costs and spill costs), find the minimum cost assignment of aircraft types to flights, such that : each flight is covered exactly once by an aircraft, flow balance of aircraft by type is conserved at each airport, and only the available number of aircraft of each type are used." (Lohatepanont (2002))

The following notations are adopted.

Sets

A : set of airports indexed by *a*.

L : set of flight legs in the flight schedule, indexed by *i*.

F : set of different fleet types, indexed by *f*.

T : set of all departure and arrival events, indexed by *t*.

CL(*f*) : set of flight legs that pass the count time when flown by fleet type k

I(*f,a,t*) : set of inbound flight legs to (*f,a,t*)

O(*f,a,t*) : set of outbound flight legs from (*f,a,t*)

Decision variables

$x_{i,f}$ = 1 if fleet $f \in$ F is assigned to flight leg $i \in$ L, 0 otherwise.

y_{f,a,t^+} = the number of aircraft of fleet type $f \in$ F on the ground at airport $a \in$A just after time *t*.

$y_{f,a,t-}$ = the number of aircraft of fleet type $f \in$ F on the ground at airport $a \in$A just before time *t*.

Parameters

N_f : the number of aircraft of type *f*

$C_{f,i}$: the operating cost of assigning fleet type $f \in$ F to flight leg $i \in$ L.

The following mathematical model, FAM, proposed by Hane et. al(1995), is referred to as the *basic fleet assignment model*.

(FAM)

Minimize $\sum_{i \in L} \sum_{f \in F} C_{f,i} . x_{f,i}$ (3.0)

Subject to :

$$\sum_{f \in F} x_{f,i} = 1 \quad \forall i \in L \tag{3.1}$$

$$y_{f,a,t^-} + \sum_{i \in I(f,a,t)} x_{f,i} - y_{f,a,t^+} - \sum_{i \in O(f,a,t)} x_{f,i} = 0 \quad \forall f,a,t \tag{3.2}$$

$$\sum_{a \in A} y_{f,a,0^-} + \sum_{i \notin CL(f)} x_{f,i} \leq N_f \quad \forall f \in F \tag{3.3}$$

$$x_{f,i} \in \{0,1\} \forall f \in F, \forall i \in L \tag{3.4}$$

$$y_{f,a,t} \geq 0, \forall f,a,t \tag{3.5}$$

FAM minimizes operations costs (3.0), which includes costs of flight crew, fuel consumption, airport gating, maintenance operations, etc. as well as spill costs which can be considered as a penalty associated to the fact that a passenger demand is not satisfyed.

Constraint (3.1) is the "cover constraint", which ensures that every flight leg is operated by one and only one aircraft type. Constraint (3.2), the "balance constraint", ensures for each airport and each aicraft type, the compatibility between the number of aircraft landing and the number of aircraft taking off, all along the planning period. Constraint (3.3) prevents for each aircraft type, from using more aircraft than are avaible. Then, constraints (3.4) and (3.5) lay the numerical domains of decision variables. The variables associated with the aircraft types

assignments are binary and the variables associated with ground flow are non-negative. Note that in any feasible solution, the ground flow is also integer.

Subramanian et al (1994) applied successfully a similar model to Delta Air Lines' Fleet Assignment problem. They published that a profit improvement of $100 million per year was achieved in that case, with their approach. Based on a same formulation of the Fleet Assignment problem other resolution approaches were tested. El Sakkout (1996) proposed an approach using the academic Constraint Logic Programming platform ECLiPSe. This solving method was tested on the British Airways shorthaul fleet assignment problem. The experiments showed the flexibility and practicality of the ECLiPSe platform. Götz et al (1999) proposed an approach by simulated annealing which is based on a local neighborhood search to improve a current solution and which can reduce computation time up to 75% compared to classical methods, over large problem sizes (up to 42 000 flight legs).

3- Problem extensions

In order to deal with the interactions between the fleet assignment problem and the other decision problems composing the whole airline planning process, different extensions of this problem have been studied.

Observing that solving the flights schedule problem and then the fleet assignment problem can leed to sub-optimal solutions, several works have been developped to integrate these two problems. Rexing et. al (2000) proposed a fleet assignment model with time windows, in which departure and arrival times vary around a preferred time, in a certain interval. The objective was to reduce the number and cost of aircraft required to operate a given flights schedule. Starting form a basic flights schedule, a heurisic algorithm is used to iteratively construct a feasible solution. This method was tested on a US major airline's schedule, the algorithm re-timed 8% of the flights an lead to a profit of $65000 per day.

Ioachim et. al (1999) considered the problem of fleet assignment and aircraft routing with time windows. This approach adds constraints to synchronize departure times of a same flight on several weekdays.

Belanger et. al (2003), on the basis of the Hane et. al (1995)'s model, took into account time windows and time-dependent revenues (i.e., revenue of a flight depends on its schedule) on

a daily problem. They proposed a branch-and-price algorithm which was tested on data provided by a medium north-American airline. Compared to a branch-and-bound method, this approach reduced the number of aircraft required and allowed to solve larger instances.

Kliewer (2000) combined also market modeling and fleet assignment problem. He proposed an iterative approach which connects a simulated annealing algorithm to assign fleet with a market model that calculates the passenger traffic flow in the network at each step of the iterative process. He proposed a second cooperation approach connecting the simulated annealing algorithm with an itinerary-based linear model for the passenger traffic flow. This second integration seems to increase by several percent the overall network profit.

Lohatepanont and Barnhart (2004) proposed an integrated model for flights scheduling and fleet assignment. They used a layer to control changes in an previous flights schedule. It is considered that the removal of flights changes the demand for the remaining flights. This approach showed good results for tests on data provided by a major US airline (costs ares reduced of several thousand dollars per day, while operating fewer flights).

An important point to consider is that passenger demand concerns most of the time not only one single flight but several consecutive flight legs (connecting at hub airports) to get from their origin to their destination. Thus, for each passenger demand, it might happen that several itineraries are possible and any modification on a flight leg can have effects on other flight legs of the network. The drawback of considering this "network effect" in fleet assignment problems, is that its makes the problem considerably more difficult to solve.

Farkas (1996) first tackled this problem with an itinerary-based fleet assignment model including also some Revenue Management aspects (in this communication, we do not focus on these particular problems, see Boyd and Bilegan (2003) for an overview of Revenue Management in the airline industry). He proposed two approaches : one using column generation where columns represent complete fleet assignment solutions and where the master problem evaluates the network traffic ; the second approach decomposes the flight schedule into sub-problems each corresponding to different sud-networks (a sub-network is a part of the whole network which has limited (or no) leg-interaction with the rest of the network). No computational results are yet published. Kniker and Barnhart (1998) worked on similar issues. They proposed an itinerary-based model combining a standard fleet assignment model with the "Passenger Mix Model" that

given a flights schedule and a passenger demand with known prices, determines optimal traffic and revenue. They used column generation with each column representing passengers spilled from one itinerary and recaptured on another. The demand is assumed to be deterministic. It seems that this approach still needs computational improvements.

Several works have been done in order to integrate fleet assignment with other planning processes. Barnhart et. al (1998) combined fleet assignment model with aircraft routing. They used sequences (called "strings") of maintenance feasible flight legs. Desaulnier et al (1997) proposed a similar approach. Rushmeier and Kontogiorgis (1997) replaced the standard time-space network formulation with an event-activity network that represents sequences of activities that can be operated by a particular aircraft. This model allows to tackle some aspects of aircraft routing problem within the fleet assignment problem. They relaxed some constraints and introduced non-linear penalties to reduce aircraft costs and in order to make solutions more robust to the operations level. This algorithm has been integrated into USAir's Schedule Development Environment with a reported benefit of $15 million per year.

Ahuja et al. (2004) formulated a multi-criteria optimization problem to tackle the integration of aircraft routing and crew scheduling in fleet assigment problem. They developed a large-scale neighborhood search which provides a robust and efficient approach to find good quality solutions for large-scale problems. This work, supported by United Airlines and the MIT, is still on process.

Clarke et al(1996) extended the standard fleet assignment model to integrate crew and maintenance considerations. This formulation is of great interest but each maintenance and crew modification increase drasticly the network size and complexity.

El moudani and Mora-Camino (2000) considered the joint problem of fleet assignment to flights and fleet maintenance operations scheduling for a medium charter airline. They proposed a dynamic approach which mixes a dynamic programming algorithm to assign the fleet and a heuristic technique to solve the embedded maintenance scheduling problem. On the data provided by the considered charter airline, this approach have appeared to significantly reduce the operations costs of the airline.

In general, the flights scheduling problem is solved for a 90 days period. During such a long period, several kinds of unexpected events can occur (aircraft delays, airport congestion, technical difficulties), and demand can change. Thus a schedule that is optimal under certain assumptions at a planning level can be sub-optimal (for example if demand is widely different from the airline's forecast) or even not feasible at the operational level. As a consequence, flights are rarely operated exactly as scheduled and it is obviously of great interest to take account into robustness aspects relative to uncertainty in operations and demand when solving the fleet assignment problem. Etschmaier and Mathaisel (1984) first suggested that delaying some fleet assignment decisions could improve airline's operations schedule by consisdering more accurate market forecasts. Berge and Hopperstad (1993) proposed the "Demand Driven Dispatch" method for "re-fleeting", which consists in iteratively re-sloving the fleet assignment problem with increasing accurate forescasts of demand as departure date approaches. This method has been adopted by several airlines. Winterer(2004) presented the "flight swapping with retiming problem", which consists in retiming and swapping flights between fleets close to the day of departure. The algorithm provides multiple solutions that allow to be more efficient that a mixed integer programming model on instances from two european airlines.

Rather than re-fleeting, some authors try to anticipate uncertainty when solving the problem. Rosenberger et al (2004) proposed a model that increase operational robustness by "reducing the hub connectivity". They introduced short sequences of flights starting at a hub and demonstrate that under certain conditions it is possible to cancel entire sequences with only few changes on other flights to keep an efficient schedule. Ageeva (2000) proposed an aircraft routing model that encourages overlapping routes in the solution to ensure to have swap opportunies in case of operation disruption. Kang (2003) described a method to decompose the schedule into independent sets (called "layer") of flights so that a disruption in one set does not affect flights of other sets. Simulation results show that these robust solutions allow to reduce significantly passenger delays and disruption compared to standard fleet assignment solutions. More recently, Smith (2004) tackled the problem of generating robust solutions to the fleet assignment problem by introducing "station purity", that is limiting the number of fleet types allowed to serve each airport. These additional constraints allow to limit the aircraft dispertion in the network and make solutions more robust relatively to crew planning, maintenance planning and operations. In a

second step, he incorporated revenue management issues in order to generate solutions more robust relatively to demand.

4- Conclusion

In this communication, we draw up an overview of the Operations Research literature concerning the airline fleet assignment problem. This problem is one part of a complex planning process. Thus, main work focus on intergrating the fleet assignment problem with other linked planning problems (flights schedule, aircraft routing, crew management, ...) in order to take account of the solution impact of one of these problems on the others. Airlines have to make some decisions far in advance of operations and adjust these decisions at the operation level. To make decisions, airlines rely on market forecasts (as precise as possible) and on a given operations environnement. Unfortunately, both of these parameters are liable to change between the moment when the solution is generated and the moment when the flights are really operated. Thus, a solution that is optimal under certain assumptions might be infeasible close to the departure date ; in order to prevent this drawback of planning long time in advance, several works have been recently published focusing on robustness aspects of fleet assignment solutions. It seems that it is a very promising way to improve the airlines planning process. Indeed, robutness is a topic of increasing interest in academic Operation Research community and these approachs are efficiently applied in several industrial areas.

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