A dynamic approach for aircraft assignment and maintenance scheduling by airlines

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Abstract

The problems of assigning planes to flights and of fleet maintenance operations scheduling are considered in this paper. While recent approaches make use of artificial intelligence techniques running on main frame computers to solve combinatorial optimization problems for nominal operations, a dynamic approach is proposed here to face on-line operation conditions. The proposed solution mixes a Dynamic Programming approach (to cope with the fleet assignment problem) and a heuristic technique (to solve the embedded maintenance schedule problem). When applied to a medium charter airline, this approach shows acceptability characteristics for operational staffs, while providing efficient solutions. The proposed solution scheme can be considered as the basis for the development of an on-line decision support system for fleet operations management within airlines. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The high operational costs involved in air transportation as well as a fierce competitive environment, has led airlines to seek permanent improvements in their management practice at both the planning and operating levels. The deregulation policy adopted by many countries in recent years has stimulated this trend. In order to meet their daily commitments, airlines have to assign their aircraft to scheduled or unscheduled flights taking into account maintenance and other operational constraints. If this assignment was done in an ineffective way, airlines face substantial costs that can impair their financial.

The fleet assignment problem is then of considerable importance for airlines. That is why since the pioneering work of Simpson (1969), there has been considerable research on the subject (Abara, 1989; Feo and Bord, 1989; Balakrishnan et al., 1990; Subramanian et al., 1994; Rakshit et al., 1996; Larke et al., 1996). From the point of view of complexity theory, this problem is considered to be difficult since it presents a combinatorial choice within both time and space dimensions with complicating ingredients coming from operational constraints. Also, it appears that this problem is strongly related to the scheduling of preventive maintenance operations, and that a global solution for both problems may be considered. Here a solution approach based on efficient optimization method and heuristic procedures is proposed to solve simultaneously these related problems.

2. The fleet assignment problem

In this section, the general fleet assignment problem faced by airlines that are either passenger and/or freight carriers is introduced. The fleet assignment to flights is a combinatorial problem because it allocates discrete resources (aircraft) to discrete operations (flights). This is enough to qualify it as being complex but since the set of flights to which aircraft are assigned can change daily, and may be made only several hours before start time, its temporal and spatial dimensions make it even more complex.

In large airlines, the fleet assignment problem is solved using Integer Programming or Artificial Intelligence
packages running on dedicated main frame computers. The programs appear as black boxes to the operations managers. Once supplied with the adequate input data, a global solution is provided. Since minimizing computing times are important, little or no sensitivity and robustness analysis of the results are usually performed.

In general, maintenance constraints are considered by solving the independent maintenance scheduling problem. In small airlines, the assignment of the fleet is made manually, and is based on experience and practical knowledge. Whatever be the size of the airline, however, and the approach selected, in practice fleet assignment is achieved through two stages: a planning stage, where the assignment is performed periodically supposing nominal operations, and a regulation stage where amendments to the assignment plan are performed to cope with significant unexpected events. These perturbations consist mainly of cancelled or delayed flights that can be due to equipment breakdowns, corrective maintenance operations, adverse meteorological conditions, congestion effects at airports or delayed availability of crew members.

Assuming that the data about demand, costs and block times associated to the planned flights over a given period of time is available, a general mathematical formulation of the fleet assignment problem can be given by

$$MIN\left(\sum_{k \in K} \sum_{k \in I_k} c_{kk} x_{kk} + \sum_{k \in K} \sum_{k \in I_k} \sum_{x_{k}} d_{kk} x_{kk} x_{kk'}\right)$$

with

$$\sum_{x_{kk'}} = 1 \quad \forall k \in K,$$

$$A_{kk'} \leq 1, \quad \forall \ell \in F, \quad x_{kk'} = (x_{k_1}, \ldots, x_{m})'$$

where $K$ is the set of the $m$ planned flights ordered chronologically with respect to their scheduled departure time, $F$ is the set of the $n$ aircraft, $I_k$ is the set of aircraft able to operate flight $k$, $L_{kk'}$ is the set of flights that can be operated with aircraft $\ell$ after flight $k$ has been carried out with this aircraft.

The objective function (Eq. (1)) is composed of two parts. The first one is related to the costs of operations of effective commercial flights ($c_{kk}$ is the cost associated to flight $k$ when carried out with aircraft $\ell$). The second part is related to costs associated with non-commercial transfer flights ($d_{kk}$ is the cost of a non-commercial flight carried out by aircraft $\ell$ between the destination of commercial flight $k$ and the origin of commercial flight $k'$). Constraints (Eq. (2)) insure that every flight is covered by a unique aircraft with appropriate characteristics (range, capacity, etc.). The set of constraints (Eq. (3)), insure that no succession constraints (time or delay constraints) between flights, carried out by the same aircraft, are violated and that a particular aircraft is not assigned simultaneously to different flights.

The combinatorial nature of the problem appears clearly through constraints (Eqs. (3) and (4)). From the constraint (Eq. (4)), the number of binary decisions variables is $m \times n$ and theoretically, there are a priori $2^n \times m$ solutions to be considered (with a feasibility check and then an evaluation for comparison). This is more than unacceptable. In fact, according to computational-complexity theory (Gondran and Minoux, 1979; Minoux, 1983; Sakerovitch, 1984), this problem is NP-hard. Considering the formulation of constraints (Eq. (3)) and the definition of sets $I_k$ and $L_{kk'}$, it is clear that a lot of preprocessing must be performed before arriving at a traceable formulation of the problem. Note that every delay or reprogramming of a flight can imply a need to revise these constraints (because overlapping of flights can arise), and sets (a modification of the required minimum capacity can occur when the demand estimated for a flight is altered by a change in the time schedules).

The algebraic formulation is a static and does not directly allow for maintenance constraints that can be expressed more easily through temporal logic expressions. These maintenance constraints take a prominent part in air transportation operations, and can significantly affect the performance of the fleet assignment solutions. The mathematical formulation of the assignment problem allows us to introduce maintenance operations that are required. This involves introducing dummy flights to be operated within imposed time windows that are derived from the maintenance regulations mandated by national and international air transportation authorities, and whose positions depend on the past utilization of the aircraft (total number of rotations per aircraft and total flight hours since the last equivalent maintenance operation).

3. A solution strategy for the fleet assignment problem

It is assumed that the company tries to optimize its main maintenance operations (those inducing the longest immobilization of aircraft or necessitating their transference to remote maintenance bases). It seeks to establish a fleet maintenance plan with maintenance contractors who can commit themselves to be available at the right time. This is a common practice since it is of mutual interest for airlines and maintenance operators to know these constraints as accurately as possible. One way to do this is to fix them beforehand. It is then possible to accommodate in a second best way aircraft to flights and resources to maintenance operations. This can be done some months in advance through negotiation without wasting too much of the operational potential of the fleet. The fixed maintenance operations can thus be considered as dummy flights already assigned to particular aircraft.
The introduction of these constraints is, from a theoretical point of view, a source of sub optimality (tempered by the consideration of a longer planning period) for the original mathematical programming problem.

Once the fleet assignment problem has been solved, the second step, the handling of the maintenance scheduling problem, is to insert heuristically, aircraft by aircraft, into the other maintenance operations that need only short immobilizations or no transfer to a remote maintenance base, between two successive commercial flights assigned to the same aircraft. Here diverse greedy heuristics can be put to work those based on the latest processing times (Shangyao and Hwei-Fwa, 1996). If no complete solution can be found through this process, it is possible to design another heuristic procedure to detect which flights should be anticipated or delayed so as to open a feasible gap for a particular maintenance operation. In general, the search processes put at work by these heuristics are rather understandable by the operators manager.

The solution proposed is based on a Dynamic Programming technique in order to solve the fleet assignment problem relieved of its maintenance constraints. Several reasons have led to the adoption of this technique. The first, is that Dynamic Programming is recognized to be an efficient technique to treat combinatorial problems in a dynamic environment. The technique is appropriate here because the temporal succession of flights gives to the problem a dynamic nature, while the separability structure of the constraints insures its applicability. The second is that Dynamic Programming is well adapted to cope with perturbations because it can be implemented recursively, and can provide a feedback solution to deviations from nominal conditions.

In addition, the key point for using Dynamic Programming in this particular application is the identification of each planned flight \( k \) (real or dummy) with a stage of the search process to which is attached the set of states \( I_k \). This choice is judicious since it reduces drastically the number of states at each stage (its upper limit is equal to \( n \), the size of the fleet) and, because it is compatible with the on-line calculation of the sets \( I_k \) and \( I_{k+1} \), it avoids data storage and processing difficulties. These characteristics make the method compatible using micro-computers.

The proposed approach seems compatible with very different operational characteristics such as: the composition and size of the fleet, passengers and freight transportation, regular and non-regular operations, regional, domestic and international flights.

4. Application to the case of a charter airline

Since airlines can present very different operational characteristics, the general solution strategy needs to be customized. The proposed solution strategy has been adapted to a medium size charter airline operating on an irregular basis for different customers (travel agencies, customers associations, etc).

The charter airline examined (El Moudani, 1997), like many others, commits itself months ahead to provide transportation services using its own fleet or hired aircraft. To maximize its profits two goals are pursued: the maximization of revenue by selling the largest number of cost-effective flights and the minimization of operating costs through the efficient assignment of the fleet to the flights. When the available fleet is used near full capacity an interaction must take place between the marketing of services and operations management to handle the fleet assignment problem (maintenance constraints included). There is a need to know whether it is feasible and profitable for the airline to include additional flights in its planning.

The charter airline operates from a base located in South of France on medium range basis (Europe, North, parts of West Africa and near Middle East). Its main maintenance bases are at Toulouse-Montaudran, Marseille and Lyon airports. Since its permanent fleet is composed of 120–150 seats jets with approximately the same operating costs, the first part of the cost function in relation to Eq. (1) is taken as a constant for a given set of flights. However, since the maximum ranges and maximum take-off thrusts are different for each aircraft, some of them cannot carry out the longest flights and some cannot use shortened runaways at particular destinations. Since the airline sells flights and not seats, no payload is considered, and capacity problems are not acute. The definition of the sets \( I_k \) is straight forward: a set \( I_k \) is composed of the aircraft having a sufficient range to cover the distance of the flight \( k \), a sufficient maximum take-off thrust to use runways at its origin and destinations airports, and a sufficient capacity (different seat configurations are possible for each aircraft) to transport the planned group of passengers.

Fig. 1. CPU times to solve different fleet assignment problems.
Concerning the structure of the operated network (passengers airports and maintenance bases), the mean duration of the flights is about an hour and half. Since the effective planning horizon is about six months, the total number of flights ($m$) considered at a time in the corresponding assignment problem is about 3000. The solution method has been developed using the Visual FoxPro software on a PC computer equipped with a Pentium processor (El Moudani and Mora-Camino, 1999). Fig. 1 displays some CPU times for different sizes and composition of the fleet of the charter airline. This is a shorter computing time than the existing Artificial Intelligence or Mathematical Programming methods. This response time is compatible with on-line use in an operational management environment. A set of graphical displays has been developed to show in a clearer way the computed solutions to the operations staff (Figs. 2 and 3).

Different situations (flight plans and maintenance constraints) were considered and the solutions obtained from the proposed method appeared to be significantly superior to those obtained from lengthy manual procedures (gains up to 2.5% of total flight hours). Sensitivity analysis studies were also conducted through the use of the evaluation function of the fleet assignment software.

5. Conclusion

This paper looks at the joint problem of fleet allocation and maintenance scheduling. The approach proposed does not produce an exact mathematical solution but appears adaptable to the present operational context of airlines and provides, through a comprehensive process for the decision-makers, improved solutions. A case
study looking at a charter airline has been examined to validate a customization of the proposed approach. Finally, it is important to observe that the fleet assignment problem is strongly related not only to the maintenance scheduling problem, but also to many other decision problems involving airlines resources, including crew assignment, yield management, flight programming, ground logistics and catering.

References


