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An Intelligent Approach for Solving the Airlines Crew Rostering Problem

Walid El Moudani^{†*}, Carlos Alberto Nunes Cosenza[♦] and Félix Mora-Camino^{†*}

^{*} LAAS du CNRS, 7 Avenue du Colonel Roche, 31077 Toulouse, France.

{wmoudani, mora}@laas.fr

[†] Air Transportation Department, ENAC/DGAC, 7 Avenue Edouard Belin, 31055 Toulouse, France.

{walid.elmoudani, felix.mora}@enac.fr

[♦] APIT, COPPE/UFRJ Centro de tecnologia, Rio de Janeiro, Brazil.

Cosenza@pep.ufrj.br

Abstract

In this communication a bi-criterion approach for the nominal Airlines Crew Rostering Problem is developed. The nominal Crew Rostering Problem considers the assignment of the crew staff to a set of pairings covering all the scheduled flights so that operations costs are minimized while its solution must meet hard constraints resulting from the safety regulations of Civil Aviation as well as from the airlines internal agreements. Another goal is of the highest interest for airlines : since the overall satisfaction of the crew staff may have important consequences on the quality and on the economic return of the operations.

In this communication, a new mathematical formulation of the crew scheduling problem which takes into account the satisfaction of the crew members is proposed. A heuristic approach, combined with a genetic algorithms technique, is adopted to produce reduced cost solutions associated to acceptable satisfaction levels for the crew staff. The application of the proposed approach to a medium size Airline Crew Rostering Problem is evaluated.

1. Introduction

The Airlines Crew Scheduling Problem (ACSP) is a problem that has retained the attention of the Management and Operations Research community for more than three decades now. Crew costs in air transportation are extremely high, amounting 15-20% of total airlines operations costs. Therefore, airlines consider that the efficient management of their crew staff is a question of the highest economic relevance. Unfortunately, the exact numerical solution of the associated large scale combinatorial optimization problem is very difficult to obtain. Early rules of

thumb [13] have been quickly overrun by the size of the practical problems encountered (hundreds or thousands of crew members to be assigned to at least as many pairings) and by the complexity of the set of constraints to be satisfied, leading very often to poor performance solutions. More recently, with the enhancement of computer performances, optimization approaches have been proposed to solve this problem : mathematical programming methods (large scale linear programming and integer programming techniques) (see [3], [4], [9], [10]), artificial intelligence methods (logical programming, simulated annealing, neural networks, fuzzy logic and genetic algorithms) as well as heuristic approaches and their respective combinations [11], [12], [15], [20]. The nominal ACSP has been treated in many studies as a static decision problem, based on a monthly table of flights, and devoted exclusively to the minimization of airlines operations costs. This problem is in general split in two sub problems : a crew pairing problem where the set of pairings covering the programmed flights is defined and a crew rostering problem where the retained pairings are nominally assigned to the crew staff.

In this paper, after discussing the airlines crew scheduling problem, the nominal Airline Crew Rostering Problem (ACRP) is introduced as a bi-criterion decision problem where the main decision criterion is the crew operations cost of the airline and the secondary decision criterion is relative to the crew staff overall degree of satisfaction. The solution approach proposed here is composed of two steps : in the first one a heuristic approach is designed to get a first set of high satisfaction assignment solutions and in the second one, a specific optimization process, based on genetic algorithms (GA) is developed. The application of this solution approach to a medium size ACRP is displayed.

2. The airline crew scheduling problem

The Airline Crew Scheduling Problem (ACSP) is treated in general once the schedule of the flights has been established for the next month and once the available fleet has been assigned to the scheduled flights. Two classes of constraints are considered in order to produce the "line of work" for the crew staff over the planning period: *hard constraints* whose violation impair the security of the flight (crew qualifications, national regulations concerning duration of work and rest times, medical clearances, training and license renewal requirements) and *soft constraints* (internal company rules, agreements with unions regarding the crew's working and remuneration conditions, office duties, holidays and declared assignment preferences by the crew staff) which are relevant to build the crew schedule but whose relaxation may lead to lower cost solutions. While some of these soft constraints are common to most airlines, others are only relevant for some classes of airlines and some few are specific to a given airline. The primary objective sought by airlines at this level of decision making is to minimize the crew related operations costs, so in most research studies, the ACSP has been formulated as a mono-criterion minimization problem.

A sub optimal but widely accepted approach to tackle more efficiently the ACSP, which is of the NP-hard computational complexity class [8], consists in decomposing it in two sub-problems of lower difficulty.

The first sub-problem, the Airline Crew Pairing Problem (ACPP), involves the construction of an efficient set of pairings (a pairing is a sequence of flights which starts and ends at the same airline base while meeting all relevant legal regulations) which covers the whole programmed flights. The second sub-problem, the Airlines Crew Rostering Problem (ACRP), considers the nominal assignment of the airline crew to the generated set of pairings over the planned period so that an effective "line of work" is obtained for each staff member (Fig. 1).

To get in a simple way a solution to the ACRP, most North American airlines have adopted in a first place some heuristics such as bidding process where the crew is arranged by decreasing seniority and each one of them builds at his turn his own monthly "line of work" from the remaining pairings. This greedy heuristic approach generates too often uneven workloads and so induce repeated dissatisfaction among the crew staff. More recently, global approaches, based on Mathematical Programming techniques, have been proposed to tackle the ACRP [9].

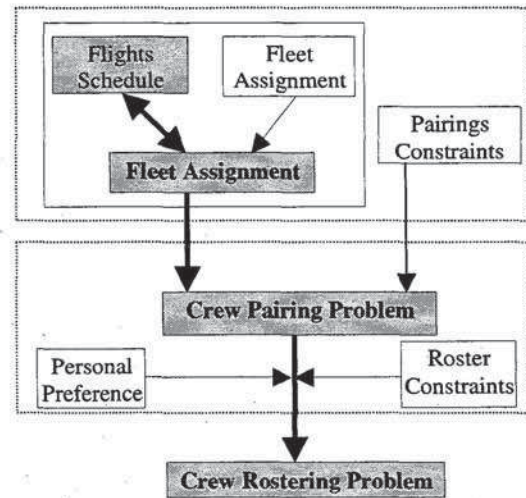


Figure 1. The Airline Crew Scheduling

3. A mathematical formulation of the nominal ACRP and analysis

In the specialized literature, the nominal Airline Crew Rostering Problem is most often formulated as a zero-one integer mathematical programming problem ([1], [13]) where the crew operations cost is the criterion to be minimized under a finite set of hard constraints:

$$\text{Minimize } \sum_{j \in J} \sum_{i \in A_j} c_{ij} x_{ij}$$

subject to

$$\sum_{i \in A_j} x_{ij} \geq 1, \quad \forall j \in J \quad (1)$$

$$(x_{ij_1} + x_{ij_2}) \leq 1 \quad \forall j_1 \in J, j_2 \in O_{j_1}, i \in I \quad (2)$$

$$\sum_{j=1}^m d_j x_{ij} \leq LH \quad \forall i \in I \quad (3)$$

$$\sum_{j=1}^m x_{ij} \leq R_{\max}^i \quad \forall i \in I \quad (4)$$

$$x_{ij} \in \{0, 1\} \quad \forall i \in I, \forall j \in J \quad (5)$$

where I is the set of the n pilots, J is the set of the "m" pairings to be covered during the planning period, c_{ij} is the cost resulting from the assignment of pairing "j" to pilot "i", A_j is the set of the pilots able to fly pairing "j", O_{j_1} is the set of the pairings

overlapping with pairing “ j_1 ”, d_j is the amount of flying hours associated to pairing “ j ”, x_{ij} are binary variables such that $x_{ij} = 1$ if pairing “ j ” is assigned to pilot “ i ”, $x_{ij} = 0$ otherwise.

Constraint (1) ensures that to each pairing is assigned a unique crew, the inequality sign allowing crew deadheading. Constraint (2) ensures that the same crew is not assigned to two overlapping pairings. Constraint (3) ensures that the number of hours flown by a pilot during the rostering period does not exceed an upper limit LH . In the fourth, R_{\max}^i is the maximum number of pairings that can be assigned to crew member “ i ” over a rostering period.

Some important comments can be retrieved from the above mathematical formulation :

- The cost associated to the assignment process is poorly defined since the whole workload of each crew member has not been established. Computing the crew payment is done in a complex way. It is based on parameters such as total amount of flown hours, standby duties and overtime.
- Effectively, in most airlines the crew staff can declare their preferences to carry out some pairings over the nominal rostering period, even if the final assignment decision is left to the airline operations management. Then, in addition to the minimum cost objective, it seems interesting to introduce a crew overall satisfaction objective either as a sub criterion or as a soft constraint.
- Exact solutions for the resulting large scale combinatorial optimization problems are not available in an acceptable computing time and in general, airlines have produced their crew schedules using simplistic heuristics. However during the last decade, a number of major airlines have developed optimization-based techniques to solve the ACRP : improved heuristics based on column generation techniques and exact solution approaches based on constraints logic programming [8], [20].

In addition to these constraints considered in the above mathematical formulation, qualified as hard constraints, a set of soft constraints can be added to this formulation. This will contribute by improving the quality of the assignment solution. Here, the soft constraints introduced are related to the satisfaction of the crew members which are detailed in a previous communication (see [22]).

4. A new solution approach for the nominal ACRP

It has been observed in section 3 that the cost structure of the ACRP is not separable with respect to pairings since to estimate accurately the operations cost associated with a given crew, his entire “line of work” for the next planning period must be known. Quite the same can be said about the crew individual and global satisfaction levels over a planning period. At this point, Genetic Algorithms techniques [16], [17], [18], [19] which manipulate complete solutions, appear interesting. [20] have used this property of AG to propose a new solution approach for the ACRP.

Here the ACRP is considered to present a main criterion, the airline operations cost, and a secondary criterion, the overall satisfaction degree of the staff.

So, in order to generate a representative set of near Pareto solutions, it is proposed to start from a population of solutions obtained from a heuristic whose aim is to maximize the overall degree of satisfaction regardless of the operations cost, then, genetic techniques are used to generate new solutions sets with reduced operations cost over a sequence of « generations ». During this process, the levels of the degrees of crew satisfaction of the solutions composing the current generation suffer some abatement. The three main stages of the proposed approach are showed in (Fig. 2).

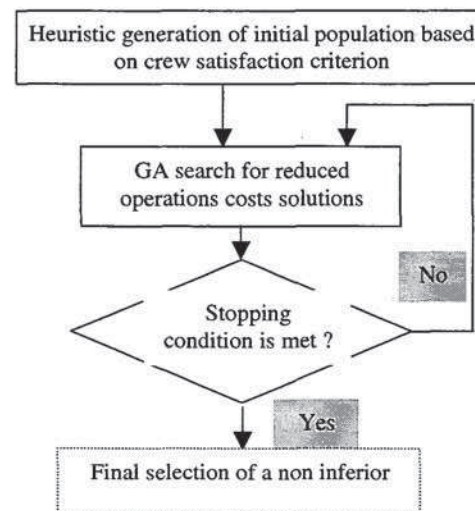


Figure 2. The proposed GA-based solution approach

4.1.A greedy heuristic approach to build the initial population

Once a representative index of the satisfaction of each crew member has been made available (see an internal rapport LAAS/CNRS] for an approach based on fuzzy set theory), the initial solutions set can be built from a unique greedy heuristic technique (the Crew Satisfaction Heuristic-CSH) applied to different arrangements of the set of crews. Note that the satisfaction of the crew builds up also from past assignments to different activities. It is supposed here that at the beginning of a new planning period each crew is characterized by a degree of satisfaction belonging to a qualitative scale such as $\{\text{VeryLow}, \text{Low}, \text{Medium}, \text{Fair}, \text{High}, \text{VeryHigh}\}$.

With the proposed greedy heuristic, the preferences of crew members of lowest satisfaction degree are considered first. This heuristic technique is divided in three stages. In the first stage, the crew staff of lowest satisfaction are assigned, when possible, to their requested pairings. In the second stage, the remaining rejected pairings are assigned to the crew staff who do not bother with them. However, if all remaining crew members wish to avoid some pairings, then the crew members with the highest satisfaction level will have to cope with them. Finally, the rest of the remaining pairings is assigned to the crew members in order to complete in a balanced way their "line of work".

To build the initial population this process must be repeated until the desired size of the population has been reached. Since in each satisfaction class 'i' of cardinal " n_i ", there are $n_i!$ different arrangements and since " n_i " can be high, the number of different arrangements can be an extremely high number $\left(\prod_{i=1}^5 n_i!\right)$. So, if sometimes, the heuristic assignment process produces identical assignment solutions, it is easy to find by random another arrangement in each satisfaction class, so that a new initial assignment solution is obtained.

4.2.A new GA solution strategy for the nominal ACRP using GA

Genetics Algorithms process sets of feasible solutions, called "populations" where each element of these populations is similar to a chromosome composed of genes, each gene corresponding to a particular parameter of the problem. The

chromosomes can be represented using either a binary or a non-binary codification.

For the problem tackled here, a non-binary codification has been adopted for the representation of the solutions composing a given population. The i^{th} component of a « chromosome » indicates which crew member is assigned to the i^{th} pairing (Fig. 3). The size of a population considered in the case studied here is equal to 30 chromosomes.

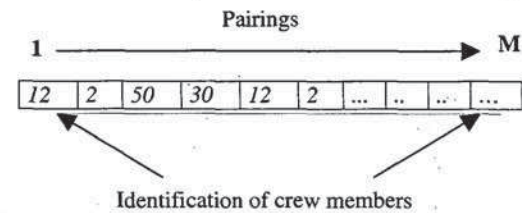


Figure 3. The adopted coding for an ACRP solution

This codification has been chosen in order to minimize the memory requirements to codify a whole population, however, it is straightforward to associate by inspection, to each of these chromosomes, a set of "n" independent paths.

A selection operator is used to select chromosomes to become parents according to their evaluation values. A roulette wheel method, which picks two chromosomes on which the classical GA operators like crossover, inversion and mutation has been applied. This is done with some chosen probability. Classical genetics operators (crossover, mutation and inversion) have been adapted to the context of the present assignment problem to produce in a progressive way improved new generations. Each elementary genetic operation processes indirectly the pairing assignments of two different pilots. When a noticeable improvement of the operations cost is obtained, the local modification is retained, but when local solution costs are equivalent, the respective degrees of satisfaction of the two pilots are taken into consideration to make the choice. The stopping rule adopted here is based on the allowed maximum number of non-improving successive generations.

5. Case study

This solution approach has been already applied to a medium size problem where 75 crew members must be assigned to 275 pairings corresponding to a total

amount of 4250 flight hours. Some learning can be obtained from this application with respect to the computer effectiveness of the proposed approach and with respect to the quality of the solutions obtained.

5.1. Computer effectiveness results

When applying the first step of the proposed approach, the satisfaction-based computation of the initial population through the CSH greedy heuristic is immediate and requires a relatively short computing effort.

To compare the efficiency of the different genetic operators combinations over the final cost effective solutions, some parameters have been introduced : the workload deviation index σ_{WL} and the proportion of non satisfied crews τ_{NS} . Here σ_{WL} is given by :

$$\sigma_{WL} = \sqrt{\sum_{i=1}^n (WL_i - \overline{WL})^2 / n} \quad (6)$$

where WL_i is the workload assigned to crew member "i", \overline{WL} is the average workload for the rostering period and "n" is again the size of the staff. The comparative results are displayed in Table 2.

Table 1. Effectiveness of CSH and genetic processes for the ACRP.

	Minimum Cost Solution	σ_{WL} WL Dispersion	Proportion of non satisfied crews (τ_{NS})
CSH Heuristic	4312:30	4:50	0.13
Crossover alone	4304:15	4:35	0.25
Mutation alone	4290:30	3:30	0.49
Inversion alone	4291:00	3:35	0.42
Crossover + Mutation + Inversion	4278:30	3:20	0.48

5.2. Analysis of the Assignment Solutions

In figures 5.a and 5.b, the total cost and the proportion of non satisfied crew distributions of the final population are displayed to provide an idea of the non inferior set of solutions to the considered

problem. In figures 6.a and 6.b, the individual workloads and satisfaction degrees corresponding to its extreme solutions are displayed: (WL_L, S_L) and (WL_H, S_H) . In figures 7 and 8, the individual workload distribution generated after using CSH and GA are displayed.

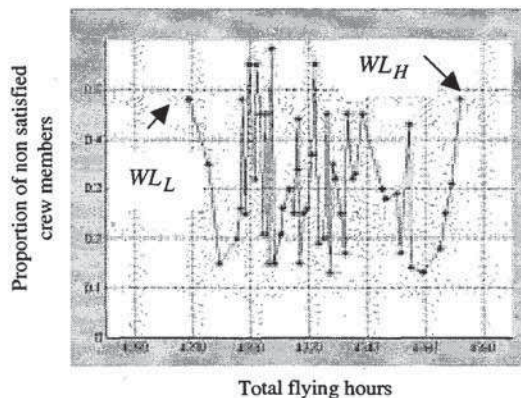


Figure 5.a : Final solution set by applying GA

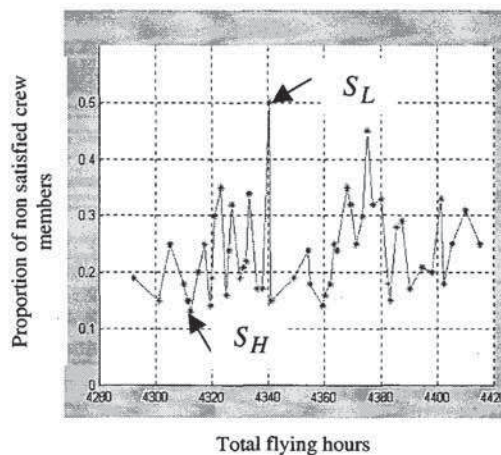


Figure 5.b : Final solution set by applying a greedy heuristic

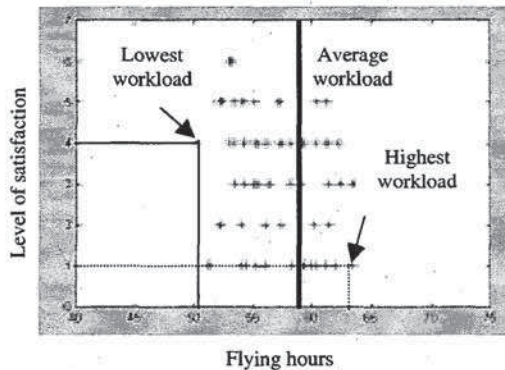


Figure 6.a. Solution corresponding to S_H

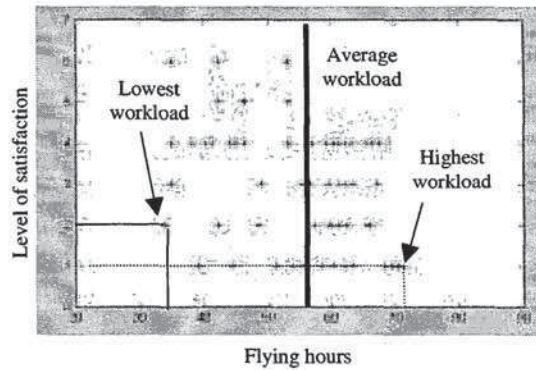


Figure 6.b. Solution corresponding to S_L

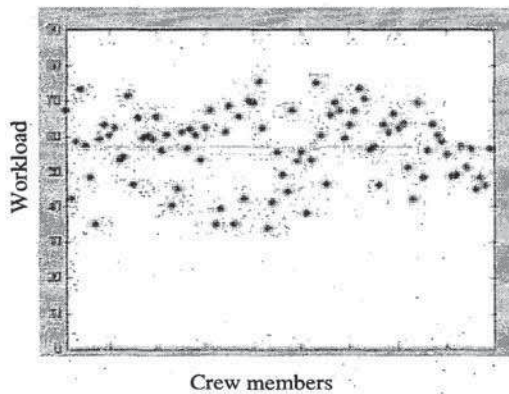


Figure 7. Example of workload distribution corresponding to the greedy heuristic

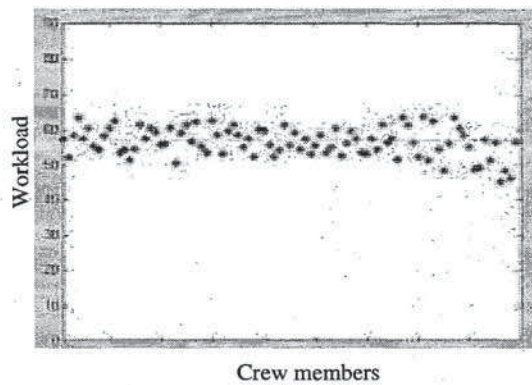


Figure 8. Example of final workload distribution with GA (S_L solution)

6. Conclusion

In this communication, one of the main operations decision problem faced by airlines has been dealt with using Mathematical Programming and Artificial Intelligence techniques. The proposed approach does not produce an exact solution in pure mathematical terms but appears to be quite adapted to give a real support to decision making, by providing, through a comprehensive process, an improved approximation of the set of non inferior solutions attached to this bi-criterion decision problem.

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