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A Dynamic Fuzzy Approach for the Evaluation of Airlines’ Crew Satisfaction

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Abstract. The 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 fuzzy approach to evaluate the satisfaction of the crew members is developed. An application of the proposed approach to a medium size Airline Crew Rostering Problem, is evaluated.

Keywords: Crew Scheduling, Crew Pairing, Combinatorial Optimization, Fuzzy Logic, Air Transportation Operations.

1 Introduction

For more than three decades now the Airlines Crew Scheduling Problem (ACSP) has retained the attention of the Management and Operations Research community since crew costs in air transportation are extremely high [1, 2, 3], amounting to 15% of total airlines’ operation costs. Therefore, airlines consider that the efficient management of their crew staff is a question of the highest economic relevance. A significant factor associated to the assignment of crews to rotations, is the satisfaction degree which has a direct impact on the quality and the reliability of the service offered to the crews. This concept of “satisfaction” appears difficult to apprehend and a proposal evaluation approach, based on Fuzzy Logic, is developed here.

2 Description of the Airlines 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 impairs the security of the flight (crew qualifications, national regulations concerning duration of work/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, crew reserve, 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 a few of them are specific to a given airline. The primary objective sought by airlines at this level of decision making is to minimize the crew related operation costs. So in most research studies, the ACSP has been formulated as a mono-criterion minimization problem [4].

A sub optimal but widely accepted approach to tackle more efficiently the ACSP, which is of the NP-hard computational complexity class [1], 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 scheduled 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, also called “roster period”, so that an effective “line of work” is obtained for each staff member. In general, a “roster period” is considered as one month.

In addition to the hard constraints, the crew often has the possibility of expressing their preferences for a given flight or for taking a rest period. However, the full satisfaction of these preferences can have consequences which may result in a significant overcost. It is clear that this goes against the interests of the airlines whose decisions are founded primarily on the minimization of the related crew operations costs. In the mid or the long term, a strong dissatisfaction leads, for example, to increase the leaves and the health problems (figure 1). Thus, it is important for airlines to take this element into account and to find in the short term a compromise between the minimization of the cost resulting from the assignment of the crew members and the maximization of their satisfaction ([4]).

Unfortunately, the exact numerical solution of the associated large scale combinatorial optimization problem is very difficult to obtain. Early methods [5] have been quickly overrun by the size of the practical problems encountered (hundreds or thousands of crew members to assign to at least as many pairings) and by the complexity of the set of constraints to be satisfied, which has very often led to poor performance solutions. More recently, with the enhancement of computer performances, optimization approaches have been proposed to solve this problem: mathematical programming methods ([3, 6, 7]), artificial intelligence (logical programming constraints) [8], heuristics methods (simulated annealing, neural networks, fuzzy logic and genetic algorithms, etc.) [9, 10, 11]. Many studies refer to the nominal ACSP, which is a static decision problem, based on a monthly table of flights, and devoted exclusively to the minimization of airlines operation costs.

The present communication comes to supplement the work carried in [4]. It has been proposed to integrate the satisfaction of crew members in a bi-criterion approach. This paper is organized as follows: initially, the parameters retained which have impact on the evaluation of the crew satisfaction are identified and their various levels are modelized with the fuzzy subsets. Fuzzy inference rules for the evaluation of the levels of satisfaction are elaborated. The techniques of fuzzification and defuzzification associated with these fuzzy inference rules are also described. Finally, examples are presented and analyzed.

3 Mathematical formulation

3.1 Analysis and formulation of the nominal ACRP

The nominal Airline Crew Rostering Problem has been formulated as a zero-one integer mathematical programming problem, where the crew operations cost is the criterion to be minimized under a finite set of hard constraints [1, 2]:

![Fig. 1 Elements contributing in the planning roster process.](image-url)
Minimize \( \sum_{i \in I} \sum_{j \in A_i} c_{ij} x_{ij} \) \hspace{1cm} (1)

Subject to: \( \sum_{i \in A_j} x_{ij} \geq 1 \ \forall j \in J \) \hspace{1cm} (2)

\( (x_{ij} + x_{ij'}) \leq 1 \ \forall j \in J, j' \in O_j, i \in I \) \hspace{1cm} (3)

\[ \sum_{j=1}^{m} d_j x_{ij} \leq LH \quad \forall i \in I \] \hspace{1cm} (4)

\[ \sum_{j=1}^{R} x_{ij} \leq R_{\max} \quad \forall i \in I \] \hspace{1cm} (5)

\[ x_{ij} \in \{0,1\} \ \forall i \in I, \forall j \in J \] \hspace{1cm} (6)

where \( c_{ij} \) is the cost resulting from the assignment of pairing \( j \) to pilot \( i \), \( I \) is the set of the \( n \) pilots, \( J \) is the set of the \( m \) pairings to be covered during the planning period, \( A_i \) is the set of the pilots able to fly pairing \( j \), \( O_j \) is the set of the pairings overlapping with pairing \( j \), \( d_j \) is the amount of flying hours associated to pairing \( j \), \( x_{ij} \) are binary variables such that \( x_{ij} = 1 \) if pilot \( i \) is assigned to pairing \( j \), \( x_{ij} = 0 \) otherwise.

The first set of constraints ensures that to each pairing is assigned a unique crew, the inequality sign allowing crew deadheading (a transfer of crew members out of duty to another base in order to carry out a planned flight). The second set of constraints ensures that the same crew is not assigned to two overlapping pairings. The third set of constraints ensures that the number of hours flown by a pilot during the rostering period (a month in general) does not exceed an upper limit \( LH \) and in the fourth set of constraints, \( R_{\max} \) is the maximum number of pairings that can be assigned to crew member \( i \) over a rostering period.

The preferences of the crew staff can be added as soft constraints to the mathematical formulation of the nominal Airline Crew Rostering Problem. 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.

### 3.2 Mathematical formulation based on the crew satisfaction constraints

For an airline, it is not easy to adopt a global index representative of the overall crew satisfaction level, the latter being composed of a large number of individual evaluations over different elements such as total flown time, total standby time and satisfaction of pairing preferences over the current and the last planning periods. A standby duty occurs when a pilot has to remain ready for the possible replacement of other unavailable crew members. The number of standby duties assigned to a given crew member over a planning period should remain small since this situation is not attractive: its hourly rate is much lower than for the flights.

However, adopting a simplified approach, it is possible to represent the increment of satisfaction of crew member \( i \) when he is assigned his requested pairing \( j \) by a real number \( S_{ij} \) and by a real number \( \overline{S}_{ij} \) the increment of satisfaction of crew member \( i \) when he is not assigned pairing \( j \) which he wants to avoid [4]. Then the current degree of satisfaction of crew member \( i \) can be given by this separable expression:

\[ \text{DOS}_i = \sum_{j \in J} \left( S_{ij} x_{ij} + \overline{S}_{ij} (x_{ij} - 1) \right) \quad \forall i \in I \] \hspace{1cm} (7)

Then, it could be possible to introduce new restrictions to the nominal formulation of the ACRP, such as:

\[ \text{DOS}_i \left[ x_{ij}, j \in J \right] \geq \text{DOS}_i^{\min} \quad \forall i \in I \] \hspace{1cm} (8)

to ensure a minimum degree of satisfaction for each crew member, and such as:
\[ \pi_{ik} \cdot \text{DOS}_i[\chi_{ij}, \ j \in J] \geq \text{DOS}_k[\chi_{ij}, \ j \in J], \ \forall \ i, k \in I, \ i \neq k \]  

(9)

where \( \pi_{ik} \) is a relative seniority index, to ensure equity, tempered by seniority, between the different crew members.

Although straightforward, this approach increases notably the difficulty of the ACRP by introducing a large number of constraints in its formulation and requires the definition of many satisfaction-related parameters.

A first bi-criterion solution approach can adopt the following steps:

1. Solve by an approximate method the ACRP with restrictions (2) to (6), let \( c_{\text{min}} \) be the resulting minimum operation cost.
2. Choose a real number \( \lambda \), superior to unity.
3. Solve the following optimization problem:
   \[
   \text{Max} \sum_{i \in I} w_i \left( \sum_{j \in J} \left( S_{ij} x_{ij} + \overline{S}_{ij} (1 - x_{ij}) \right) \right) \]
   subject to constraints (2) to (6) and (11)
   \[
   \sum_{j \in J} \sum_{i \in I} C_{ij} x_{ij} \leq \lambda c_{\text{min}} \]
   (11)

   where the \( w_i \) are positive normalized seniority weights.

4. If this last constraint is active at solution, evaluates the degree of satisfaction of each crew member accurately and if too many crew members present a non adequate degree of satisfaction, parameter \( \lambda \) is increased and comes back to step 3, otherwise, it stops.

The main difficulties present in this bi-criterion approach are related with the quantification of the satisfaction degrees (values of the \( S_{ij} \) and \( \overline{S}_{ij} \), analytical expression for the \( \text{DOS}_i \)) and the choice of the seniority weights which can hardly be non suggestive.

Thus, to overcome these difficulties, an evaluation approach has been developed where fuzzy rules are defined to evaluate qualitatively the satisfaction of the crew staff. As it is difficult to satisfy all the crew members over a single roster period and as we can consider that the satisfaction degree of the crew is cumulative and suffers attenuation in time, a dynamic approach is proposed to consider the evolution of the satisfaction over a period of time composed of a succession of roster periods.

4 A new approach for the evaluation of the crew satisfaction degree

4.1 Satisfaction modeling

The evaluation of the crew satisfaction level is based on some basic hypotheses:

- The satisfaction degree built up over several roster periods.
- The satisfaction level depends on three main parameters:
  i. The number of preferences performed by crew member \( i \) over the roster period \( t \): \( SE_{t}^i \).
  ii. The number of preferences performed for crew member \( i \) over the roster period \( t \): \( SR_{t}^i \).
  iii. The number of standby activities assigned to crew member \( i \) over the roster period \( t \): \( R_{t}^i \).
The two first parameters, contribute to calculate the ratio of performed preferences for crew member \( i \) over the roster period \( t \). Let \( X^t_i \) be the variable, representing this notation, that can be expressed as follows: \( X^t_i = \frac{SR^t_i}{SE^t_i} \). Moreover, the third parameter \( (R^t_i) \) contributes to determine the standby activity degree for crew member \( i \) over the roster period \( t \).

### 4.1.1 Degree of performed preferences \( X^t_i \)

The degree of contentment declared preferences is characterized by a qualitative variable \( X^t_i \) which value belongs to \( \xi_p = \{ \text{Very Small}, \text{Small}, \text{Medium}, \text{High}, \text{Very High} \} \), which is composed of five qualitative subsets. To each value of \( X^t_i \), a quadruplet \( \psi_i = (V_i, \mu_i, V_2, \mu_2) \) is associated:

\[
V_i \in \xi_p, \quad \forall i \in \{1,2,3,4,5\} \text{ and } 0 \leq \mu_i \leq 1, \quad \forall i \in \{1,2,3,4,5\}
\]  

(12)

The membership function \( \mu_i \) is associated to the fuzzy set \( V_i \) of \( \xi_p \). The evaluation process of the satisfaction degree considers different situations such as:

If the value of the membership function \( \mu_i \) associated with the fuzzy subset \( V_i \) is higher than that of the membership function associated with the fuzzy subset \( V_j \), then the degree of performed preferences of the pilot belongs to the \( V_i \) fuzzy set (figure 2). In the opposite case, the degree of performed preferences belongs to \( V_j \) (figure 3).

\[
\begin{align*}
\text{If } \mu_i &> \mu_j \text{ then the degree of performed preferences is qualified as } V_i \\
\text{If } \mu_i &\leq \mu_j \text{ then the degree of performed preferences is qualified as } V_j
\end{align*}
\]

![Fig. 2 Example for evaluating the satisfaction degree in case of \( \mu_i > \mu_j \)](image)

![Fig. 3 Example for evaluating the satisfaction degree in case of \( \mu_i \leq \mu_j \)](image)
In the case where a crew member has no declared preferences over a roster period \( t \) (\( SE^t_i = 0 \)), then the quadruplet \( \psi_i \) associated with this crew \( i \) can be expressed as follows (figure 4):

\[
\psi_i = (\text{Medium}, 1, \text{High}, 0) \quad \text{or} \quad \psi_i = (\text{Small}, 0, \text{Medium}, 1)
\]

There is no priority among the crew members and the evaluation of the satisfaction degree is expressed as follows:

\[
\text{If } (\mu_{\text{Medium}} f \mu_{\text{Small}} = 0) \& (\mu_{\text{Medium}} f \mu_{\text{High}} = 0) \text{ then the degree of performed preferences is qualified as } \text{Medium}
\]

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Crew satisfaction fuzzy inference rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R^t_i )</td>
<td>Very small</td>
</tr>
<tr>
<td>Very Heavy</td>
<td>Very Low</td>
</tr>
<tr>
<td>Heavy</td>
<td>Very Low</td>
</tr>
<tr>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Light</td>
<td>Medium</td>
</tr>
<tr>
<td>Very Light</td>
<td>Fair</td>
</tr>
</tbody>
</table>

4.3 Dynamic fuzzy inference rules

Dynamic fuzzy rules [12] are used here to combine the satisfaction result from the former roster period with the current one. These dynamic fuzzy rules can be expressed as follows:

\[
\text{If } (S^t_i \text{ is } \varphi_s^i) \& (R^t_i \text{ is } \varphi_s^i) \& (X^t_i \text{ is } \varphi_s^i) \text{ then } S^{t+1}_i \text{ is } \varphi_s^{i+1}
\]
where $S^i$ and $S^{i+1}$ are two qualitative variables belonging to $\mathcal{S}$.

These inference rules are defined in order to reproduce experts’ opinions in estimating the crew satisfaction level. For example, in case we accept to perform 30% of the requests for a crew member over the next roster period and we assign him three standby activities of 8 hours each, while knowing that his last satisfaction is evaluated as “Fair”, then the new satisfaction degree is evaluated as “Low”. (see table 2)

5 Case study

This solution approach has been applied to a medium sized problem where 100 crew members must be assigned over a month to 500 pairings corresponding to a total amount of 9420 flight hours. The initial assignment solution is built from the maximization of the crew’s satisfaction degree. Some learning can be obtained from this first application with respect to the computer effectiveness of the proposed approach and with respect to the quality of the solution obtained. The satisfaction degree of the crew members is dynamically evaluated over a set of six roster periods (figure 5).

6 Conclusion and perspectives

The presented approach contributes to the operational evaluation of the satisfaction degree of each crew member in order to get effective crew rosters and during a reasonable computing time. In this paper, we have provided a mathematical formulation of the problem of crew rostering while introducing a set of constraints associated with the satisfaction of the crews. An assessment
method, using fuzzy logic is developed to evaluate the crew satisfaction. These techniques appear to be useful to provide, according to the airlines crew policy, global crew satisfaction levels.

Technically, the method used for assessing the degree of employee satisfaction by Fuzzy Logic and computation of global indices of satisfaction can be certainly improved and extended.

<table>
<thead>
<tr>
<th>Satisf. reached at period « t-1 »</th>
<th>Degree of performed pref. at period « t »</th>
<th>Number of standby duty performed at period « t »</th>
<th>New degree of satisfy. reached at period « t »</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fair</td>
<td>30%</td>
<td>3</td>
<td>Low</td>
</tr>
<tr>
<td>Fair</td>
<td>50%</td>
<td>3</td>
<td>Fair</td>
</tr>
<tr>
<td>Low</td>
<td>20%</td>
<td>1</td>
<td>Fair</td>
</tr>
<tr>
<td>Medium</td>
<td>10%</td>
<td>0</td>
<td>Fair</td>
</tr>
<tr>
<td>High</td>
<td>70%</td>
<td>0</td>
<td>Very High</td>
</tr>
<tr>
<td>Low</td>
<td>20%</td>
<td>2</td>
<td>Very Low</td>
</tr>
<tr>
<td>Fair</td>
<td>30%</td>
<td>3</td>
<td>Very Low</td>
</tr>
<tr>
<td>Medium</td>
<td>40%</td>
<td>3</td>
<td>Medium</td>
</tr>
<tr>
<td>Fair</td>
<td>50%</td>
<td>1</td>
<td>Medium</td>
</tr>
<tr>
<td>Medium</td>
<td>65%</td>
<td>1</td>
<td>High</td>
</tr>
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</table>

References