Multiobjective Optimization Genetic Algorithms for Domestic Airline Crew Pairing Problems

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Abstract

Airline crew pairing problems involve assigning the required crew members to each flight segment in a given time period, while complying with a variety of work regulations and collective agreements. Traditional researches formulate the pairing problems as integer programming problems, and use deterministic approaches to optimize the solutions. Such these approaches usually suffer from some critical issues such as time-consuming enumeration for possible pairings and difficulty to cover the whole search space. The goal of this paper is to develop a new multiobjective approach to solve the crew pairing problem by formulating it into multiobjective combination optimization equations and employing the inequality-based multiobjective genetic algorithm (MMGA) as the global optimization explorer. Besides, our experimental results for a real-world short-haul domestic airline show that the proposed approach can provide quite good pairing solutions.

Keywords: Multiobjective, Genetic algorithm, Airline pairing problems

1. Introduction

Airline crew pairing problems mainly assign the required crew members to each flight segment of a given time period. In general, the goal of the airline companies is to maximize the total profit under the lowest cost. One way of decreasing the total cost is to maximize the usage with limited number of aircrafts and crewmembers. Due to the safety and security reasons [1,2], the usage limitation related to personnel and mechanical health should be taken into consideration. Therefore, crew pairing is indeed a critical problem concerned to large cost in the airline industry. In these decades, many researches ever focused on the crew pairing problems. However, crew pairing is still extremely complicated in both stages of problem modeling and solving.

In the airline crew scheduling, all flights which are assigned to the aircrafts according to the routing schedule require the personnel, such as pilots and crew members. Due to the laws and regulations, the working hours of personnel are limited. Therefore, the flights assigned to one aircraft should be separated to several sets so they can be assigned to several groups of crew members. The crew pairing problem considered in this paper contains the following issues:

1. Minimizing number of groups
2. Minimizing layover number
3. Satisfying the laws and regulations

Most researches used the enumeration way to optimal solutions. The drawbacks of enumeration are the solution space will be limited and time consuming for planners. Hence, we use genetic algorithms (GA) to optimize them. We formulate the crew pairing problems into combination optimization equations and the optimal solutions would be globally searched by using a method of inequality-based multiobjective genetic algorithm (MMGA). A real-world case study would be presented in this paper to show the good pairing results of the proposed approach.

2. Related works

There are many evolutionary researches related to the Airline Crew Paring Problem. Chu et al. [3] applied a graph based branching heuristic to a restricted set
partitioning problem representing a collection of best pairings. Desauliniers et al. [4] modeled the aircrew pairing problem as an integer, nonlinear multi-commodity flow network model and used a Dantzig-Wolfe decomposition to solve this model. Pairing generation is performed by the approach of resource constrained shortest path subproblem. Stojković et al. [5] used the column generation method embedded in a branch and bound search tree to solve the aircrew pairing problem. Barnhart et al. [6] developed a heuristic methodology by using dual solutions determined in solving the linear programming relaxation of the crew pairing problem. Barnhart and Shenoi [7] used the approximation model of the airline crew pairing to be an advanced initial solution for conventional approaches. The method can identify deadheads quickly and improve the solution qualities. Goumopoulos and Housos [9] proposed an efficient trip generation approach with special pruning rules which are defined using a high-level language. The method is applied to a rule-based system in a real European airline company.

3. Mathematical models

In this section, we described the mathematical models and objective functions.

**Notations**

- $\alpha$: number of group of crew members
- $\beta$: maximal number of daily flights assigned to each group of crewmembers.
- $\gamma$: number of flights
- $f$: number of possible pairings suggested by planners
- $\mathit{f}$: identifier of the flight.

Also, various associated information of each $f$ are listed as follows:

- $\bar{p}$: origin of $f$
- $\bar{q}$: destination of $f$
- $\bar{t}$: departure time in $\bar{p}$
- $\bar{\bar{t}}$: arrival time in $\bar{p}$

First, we proposes an improved form of candidate solution to overcome the time-consumming problem is described follows as:

$$S = \{S_{ij} | S_{ij} \in F \cup \{-1\}\}.$$  

where $S$ is a two-dimensional matrix of $\alpha \times \beta$ elements, and each $S_{ij}$ represents a flight which means the $j^{th}$ flight assigned to the $i^{th}$ group of crew member. To keep the number of flights assigned to each group identical, we assign dummy flights with flight identifier -1. The main feature of proposed model is that the number of pairings becomes a controllable variable instead of unexpected value within the range $0 \leq \mu \leq 2^\beta - 1$. This is useful when performing practical pairing process since the number of pairing is related to the manpower in the airline company.

3.1 Objectives

The goal of aircrew pairing problem is to minimize the total cost. To minimize the total cost is equivalent to minimizing the following objective functions, such as ground transition time, number of deadheading crew, number of layover, flying time, and flight duty period, are described as follows.

Transition time objective ensures that each aircraft has sufficient ground turn-around time not less than the legal ground turn-around time, denoted as $T_g$, to be allowed for the subsequent flight. The objective is defined as:

$$\Phi_1(S) = \sum_{i=1}^{a} \sum_{j=1}^{\beta} x_{i,j}^{(1)}$$  

where $x_{i,j}^{(1)} = \begin{cases} 
0 & \text{if } (t_{i,j+1} - t_{i,j}) \geq T_g \\
1 & \text{otherwise}.
\end{cases}$

Deadheading crew objective ensures that the arrival airport of $S_{i,j}$ is the same with the departure airport of $S_{i,j+1}$ for each aircraft in $S$, for $1 \leq i \leq \alpha$, and $1 \leq j \leq \beta$. This object is reduce the extra cost of the nonprofit flight from $P_{i,j}$ to $P_{i,j+1}$. The objective is defined as:

$$\Phi_2(S) = \sum_{i=1}^{a} \sum_{j=1}^{\beta} x_{i,j}^{(2)}$$  

where $x_{i,j}^{(2)} = \begin{cases} 
0 & \text{if } P_{i,j} = P_{i,j+1} \\
1 & \text{otherwise}.
\end{cases}$

Layover objective ensures each group of crewmembers can start from and end to their home bases. However, we consider a different case of multiple home base consideration. In this condition, the start and end station is no need to be identical. Instead, the consideration of generating pairings is to let the start and end stations belong to the set of crew bases. Suppose the first and the last flights of the $i^{th}$ group in $S$ are $S_{i,1}$ and $S_{i,\text{last}}$, respectively. Also, let the set of crew bases be $P_B$. Then, the evaluation function can be defined as:

$$\Phi_3(S) = \sum_{i=1}^{a} k_i$$  

where $k_i = \begin{cases} 
0 & \text{if } (P_{i,1} \in P_B) \land (P_{i,\text{last}} \in P_B) \\
1 & \text{otherwise}.
\end{cases}$

According to the laws and regulations, the flight duty time, which is the total flight time except for the rest time, of each aircrew pair should not be more than a legal time $T_{\text{FDP}}$. Therefore, the fourth evaluation function $\Phi_4(S)$ can be defined as follows:

$$\Phi_4(S) = \sum_{i=1}^{a} \eta_i$$  

where $\eta_i = \begin{cases} 
0 & \text{if } t_{i,\text{last}} - t_{i,1} \leq T_{\text{FDP}} \\
1 & \text{otherwise}.
\end{cases}$

In other words, if the total flight duty time of one aircrew pair exceeds the legal time $T_{\text{FDP}}$, the evaluation function $\Phi_4(S)$ will be added the exceeding time, or the violation time.

3.2 Definition of Auxiliary Performance Index Vector

In the original formulations of multiobjective optimization, we haven’t consider the set of admissible bounds, and we decide the admissible bounds performance index for multiobjective optimization. The
original objective are transformed into the auxiliary performance index vector:

\[ \Lambda(S, \varepsilon) = \{ \lambda_1(S, \varepsilon), \lambda_2(S, \varepsilon), \lambda_3(S, \varepsilon), \lambda_4(S, \varepsilon) \} \]

where \( \lambda_i(S, \varepsilon) = \begin{cases} 0 & \text{if } \Phi_i(S) \leq \varepsilon_i \\ \Phi_i(S) - \varepsilon_i & \text{otherwise}. \end{cases} \)

The auxiliary performance index vector related to the inequalities is converted from the MOI problem to a multiobjective optimization problem. The multiobjective formulation using the auxiliary performance index vector is useful for MOI since the admissible bounds can be combined to all objectives. Therefore, each objective can be transformed to the form of inequalities.

3.3 Formulation of Airline Pairing Problems

Instead of combining these objectives into a single scalar, the air crew routing problem with multiple objectives can be formulated as follows.

\[ \text{Minimize } \lambda_i(S, \varepsilon), \quad 1 \leq i \leq 4 \]

Subject to \( S = [S_{i,j}]_{n \times p} \).

4. Solution by Using MMGA

We propose the MMGA to solve the airline crew pairing problem. MMGA employs the global search capability of genetic algorithms and the auxiliary vector performance index can always generate tunable parameters belong to a strictly Pareto ranking and optimized the multi-objective problems. A heuristic Pareto algorithm was also provided to lower the Pareto computation costs.

The flow chart of the algorithm can be summarized in Figure 1. Just like the general multi-objective genetic algorithm (MOGA), evolutionary population should be operated by iterations through initialization, fitness computation, multiobjective evaluation, crossover to generate offspring, mutation and selection for elimination.

4.1 Encoding Scheme

The encoding scheme of each individual is a two-dimensional matrix. To make the encoding more efficiency, we transform the chromosome to a string. To satisfy the objective of working hour, we use a modified approach to reduce the complexity on solving the working hour objective. In each individual, the flights that are earlier than time \( t \) are allocated in the left-hand side of the individual. On the other aspect, the flights that are later than time \( t \) are put in the right-hand-side of the individual.

4.2 Selection

Better parents are selected for a subsequent crossover operation, and a roulette wheel method, is utilized for the selection.

4.3 Crossover

In the crossover process, we use an order-based crossover. First, a 0-1 random mask string is generated to determine which flights are fixed on original positions, and which flights are selected to be changed. If the \( t^{th} \) element of the generated mask is 1, then the \( t^{th} \) gene of offspring1 is fixed on original position. Otherwise, it will be replaced. As shown in Fig. 2, the genes to be replaced on each offspring are in the following order:

- Children 1: A→B→C→D→E→F→G→H
- Children 2: D→A→F→H→C→E→G→B

After the process of crossover, the orders of the genes are exchanged according to the following order:

- Offspring1: D→A→F→H→C→E→G→B
- Offspring2: A→B→C→D→E→F→G→H

4.4 Mutation

The mutation operation as the Figure 3. The individual are temporarily transformed to the conceptual model of 2-dimensional matrix. When selecting the genes to be exchanged, only the segments with violations have more chances to be selected. This can prevent extra costs of inefficient search.
Figure 4. Gantt chart of MD90 schedule

Figure 5. Crew pairing with 11 groups
5. Experiment

In this subsection, we apply the MMGA to solving airline crew pairing case. All timetables are real data obtained from a local airline company.

The parameters used in MMGA, such as population size, number of generations, and crossover and mutation probabilities are 100, 10000, 0.95, and 0.03, respectively. Also, all experiments can stop earlier when the algorithm finds out the solutions without violations.

For the given number of groups of crewmembers, the proposed algorithm can find out feasible solutions, which can satisfy all objectives with no violations. The pairing results and convergences of test are shown in Figs. 4 to 5.

6. Conclusions

We have demonstrated an approach of using MMGA to solve the aircrew pairing problem both in the formulation and solution stages. In the formulation stage, we propose a novel permutation-based model that can save the overheads in traditional models, such as assigning cost values, and checking the number of coverage. In the solution stage, we apply the MOI-based MGA (MMGA) to solve the problems of aircraft routing and crew pairing.

According to the experimental results, the proposed method can find out the scheduling result of test case. Instead of using the heuristics of the twice number of aircrafts, the proposed method can further find out less group number of crewmembers when the number of flights is small. Hence, the proposed MMGA can not only find out solutions satisfying the given objectives, but also have more chances to find out optimal solutions especially the group number of crewmembers can be decreased so that the cost can be reduced.

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8. Reference


