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Crew Scheduling Optimization with Artificial Bee Colony Algorithm

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Abstract

Crew scheduling is one of the most important optimization problems for airline companies. It is the scheduling of weekly or monthly work schedule under certain constraints, such as working hours and weekly permits. There are many studies using analytical and heuristic approaches in the literature in order to solve this problem. In studies using heuristic approaches, genetic algorithms are used frequently. In this study, an artificial bee colony algorithm, which is a heuristic method, is used instead of the approaches applied to the current problem. Weekly work schedules are optimized according to daily working hours and days off for crew scheduling under a number of different personnel. From the simulation results, it is clearly seen that the artificial bee colony algorithm produces successful results within reasonable time.

Keywords: Artificial bee colony, crew scheduling, optimization.

1. INTRODUCTION

Crew scheduling is the organization of weekly or monthly work schedule under certain constraints, such as working hours and weekly or monthly permits. If the scheduling is not prepared properly, it'll reveal more cost for the companies than it should be. In addition, there are some legal obligations that airline companies have to comply. Airline companies have to make a planning according to legally recognized rights of the crew personnel.

Given the constraints, the crew scheduling problem can also be considered as an optimization problem. There are several approaches in order to solve crew scheduling problem in the literature. For example; the study carried by Levine tries to solve the airline crew scheduling problem with hybrid genetic algorithm [1]. Ozdemir and Mohan implemented the genetic algorithm to a flight graph representation which demonstrates several problem-specific constraints [2]. Zeren and Özkol developed a new solution to the crew pairing problem using the genetic algorithm. They proposed a new genetic operator which is called perturbation operator [3]. The study carried by Agustin, Gruler, Armas and Juan presented a meta-heuristic approach based on biased randomization to find a solution to the crew pairing problem [4]. In the study carried by Aoun, Sarhani and El Afia based on the estimation of the most probable situation and using the Markov model they tried to find the most optimal configuration for the algorithm. They intended to find the best parameter values of the particle swarm optimization algorithm for the crew scheduling problem [5]. Lagerholm, Peterson, and Söderberg presented a Potts feedback neural network approach and applied it to the airline crew scheduling problem in their study [6]. Sasaki and Nishi proposed a combinatorial auction algorithm for the crew scheduling problem in their study. A new combinatorial auction algorithm with price-adjustment mechanism is proposed [7]. The study carried by Lo and Deng, scheduling problem is formulated

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as traveling salesman problems with flight graph presentation. Then, the ant colony optimization is applied to search near-optimal solutions for crew schedules [8].

In recent years, there are several heuristic approaches using to solve complex optimization problems, such as genetic algorithm (GA), ant colony optimization (ACO), particle swarm optimization (PSO) and artificial bee colony (ABC) algorithm. These algorithms do not always guarantee to obtain the optimal solution, but they can give near-optimal solutions for large-scale optimization problems in acceptable time. As given above, there are many studies using the GA for crew scheduling problem. In this study, the ABC algorithm, which has been widely used recently, is proposed in order to solve the crew scheduling problem.

The rest of the paper organized as follows; section 2 describes ABC algorithm, the crew scheduling problem and solving the problem with ABC algorithm. In section 3, experimental results obtained are presented. Finally, conclusions are given in section 4.

2. MATERIALS AND METHODS

2.1. Artificial Bee Colony Algorithm

The ABC algorithm developed by Karaboğa is an optimization algorithm simulates the intelligent foraging behavior of honey bee swarms [9]. It has been widely used in many fields including image processing, neural networks, wireless sensor networks, vehicle routing problem and data mining [10].

In the ABC algorithm, the bees are grouped into three categories; the employed, the onlooker and the scout bees. Half of the colony consists of employed bees, and the other half includes onlooker bees [11]. Employed bees exploit the food source and share the information with onlooker bees which are waiting in the dance area for information. Then, onlooker bees select a food source probabilistically and try to improve the source. After a food source is exploited, employed bee which works on that source becomes a scout and starts to search for new food source. In the ABC algorithm, the position of a food source represents a candidate solution to the problem and the nectar amount of a food source corresponds to the quality, known as fitness, of the related solution [12].

At the first step of the algorithm, an initial population of *SN* food sources is generated randomly by the following Eq. (1):

$$x_{ij} = x_j^{\min} + rand(0,1)\left(x_j^{\max} - x_j^{\min}\right) \tag{1}$$

where $i \in \{1,2,\ldots,SN\}$, $j \in \{1,2,\ldots,D\}$ and rand(0,1) generates a random number in the range of (0,1). x_i which is a D-dimensional vector represents i^{th} candidate solution. x_j^{max} and x_j^{min} denote the lower and upper bounds of the j^{th} variable, respectively.

After the fitness value of each solution x_i represented by fit_i is calculated according to the Eq. (2):

$$fit_i = \frac{1}{(1 + f_i)} \tag{2}$$

where f_i represents the objective function value of the solution x_i.

The employed bee searches for a new food source, v_{ij}, around the adjacent source according to the Eq. (3):

$$v_{ij} = x_{ij} + \varphi_{ij}\left(x_{ij} - x_{kj}\right) \tag{3}$$

where $k \in \{1,2,\ldots,SN\}$. k is a randomly determined solution, but it has to be different from i, and φ_i is a random real number in the range of $[-1,1]$. After v_{ij} is evaluated, its quality is compared with the old source to memorize better one in terms of fitness value.

The onlooker bee chooses a food source depending on the probability value, p_i, associated with its nectar amount, calculated by the following Eq. (4):

$$p_i = \frac{fit_i}{\sum_{j=1}^{SN} fit_j} \tag{4}$$

where fit_i is the fitness value of the i^{th} solution, by using Eq. (2).

A random number is generated for each food source in the range of [0,1] after the probability values calculated. If p_i value is greater than a random number generated, then onlooker bee produces a new solution by using Eq. (3) and calculates the quality of it. The new solution is compared with the existing solution and greedy selection is applied.

A parameter has been defined in the ABC algorithm to indicate that the food source cannot be updated anymore after a predetermined number of cycles, which is called "*limit*" for abandonment. If the food source has reached the "*limit*" value, this food source is abandoned, and then the scout bee discovers a new food source using Eq. (1). These steps in the algorithm are repeated until a predetermined maximum number of cycles (*MCN*).

Detailed pseudo-code of the ABC algorithm is given below [10], [12]:

- Initialize the population of solutions x_i, $i=1,2,\ldots,SN$
- Evaluate the population, f_i
- cycle = 1
- Repeat
  - Generate new solution v_i that is neighbor to the x_i by using Eq. (3) and evaluate it
  - Apply the greedy selection process between x_i and v_i
  - Calculate the probability values p_i for the solution x_i by using Eq. (4)
  - Select a solution x_i depending on p_i
  - Generate new solution v_i and evaluate f_i for the onlooker bees from the solutions
  - Apply the greedy selection process for the onlooker bees
  - Determine the abandoned solution for the scout, if exists, and replace it with new produced solution by using Eq. (1)
  - Memorize the best solution obtained so far
  - cycle = cycle + 1
- Until cycle = *MCN*

2.2. Crew Scheduling Problem

2.2.1. Description of the Problem

The objective of the crew scheduling problem is to optimize the weekly or monthly working hours and days off for the crew under given constraints. The constraints, such as the days off, flight times and instructions on applying principles of crew personnel are defined by Directorate General of Civil Aviation [13]. Weekly, monthly, quarterly and annual days off for personnel are given in Table I. In this study, it is aimed to schedule weekly working hours and days off for each personnel.

Table I. Days off of flight crew [13].

	Weekly	Monthly	Quarterly	Annual
Period	1 Day	7 Day (2+2+1+1+1)	21 Day	96 Day

There are some constraints to be considered for the crew scheduling. While some of these constraints are taken from [13], the rest of them are assumed for this study. Constraints of the scheduling problem are given below:

- Personnel should work minimum 6 hours and maximum 12 hours.
- Personnel should have one or two days off in a week.
- Personnel should work maximum 6 days repeatedly.
- Personnel should work maximum 56 hours in a week.
- Personnel should work minimum 45 hours in a week.
- It is not allowed that more than 1/4 of the personnel has days off on the same day.

2.2.2. Solving the Crew Scheduling Problem

The sample food source structure which is a D-dimensional vector represents a candidate solution used in the study for the crew scheduling is shown in Fig. 1.

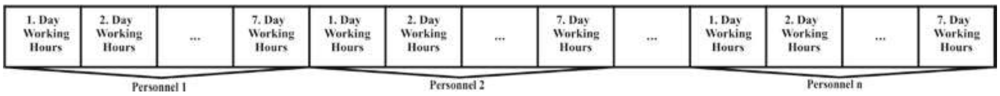

Fig. 1. Food source structure for crew scheduling

Integer numbers for candidate solutions that represent weekly working hours and days off are generated randomly either 0 (represents days off) or between 6 and 12.

In order to calculate the objective function, D-dimensional vector is divided by the number of personnel, *np*, and the weekly working hours for each of them is summed, k_j. Then, standard deviation of these sums are calculated. Standard deviation is calculated by the following Eq. (5):

$$Std = \sqrt{\frac{1}{np-1}\sum_{j=1}^{np}\left(k_j - \bar{k}\right)^2} \quad (5)$$

where *Std* is standard deviation and $\bar{k}$ represents arithmetic average of k_j values. The food source whose standard deviation is closest to 0 is taken as the best source. The penalty points are added to the objective function value for infeasible solutions. The aim here is to eliminate the infeasible solutions and keep the feasible ones. Three penalty values (Pen_1, Pen_2 and Pen_3) are used for the above-mentioned constraints in the problem. Pen_1 is used for checking the weekly working hours, k_j, by using Eq. (6), Pen_2 is used for checking the days off for each personnel, do_j, by using Eq. (7), and Pen_3 is used for checking the number of personnel who has days off on the same day, wdo_j, by using Eq. (8). The penalty value of 5 is added to objective function value for all constraints.

$$Pen_1 = \begin{cases} 0, & k_j \geq 45 \,||\, k_j \leq 56 \\ 5, & k_j < 45 \,||\, k_j > 56 \end{cases} \quad (6)$$

$$Pen_2 = \begin{cases} 0, & do_j > 0 \,||\, do_j \leq 2 \\ 5, & do_j \leq 0 \,||\, do_j > 2 \end{cases} \quad (7)$$

$$Pen_3 = \begin{cases} 0, & wdo_j \leq np \times 1/4 \\ 5, & wdo_j > np \times 1/4 \end{cases} \quad (8)$$

The objective function value of the crew scheduling problem, f_i, is calculated according to Eq. (9).

$$f_i = Std\left(\sum_{j=1}^{np} k_j\right) + \sum_{n=1}^{3} Pen_n \quad (9)$$

where *np* is the number of personnel and k_j is the sum of weekly working hours for each personnel.

3. RESULTS AND DISCUSSIONS

In order to test the efficiency of the algorithm, experimental studies were carried out for 10, 30, 50 and 100 crew schedules separately. The algorithm usually produces between 48 and 55 working hours per week for the crew. In addition, each crew has one or two days off in a week according to simulation results. The parameters and values of the ABC algorithm for the experimental studies are shown in Table II.

Table II. The parameters of the ABC algorithm

Number of Crew	SN	D Size	Limit	MCN
10	60	70	100	100
30	60	210	100	400
50	60	350	100	600
100	60	700	100	1500

The convergence characteristic of the ABC for experimental studies is shown in Fig. 2. The algorithm was executed 10 times for each case and the average objective function values were taken for convergence graphics.

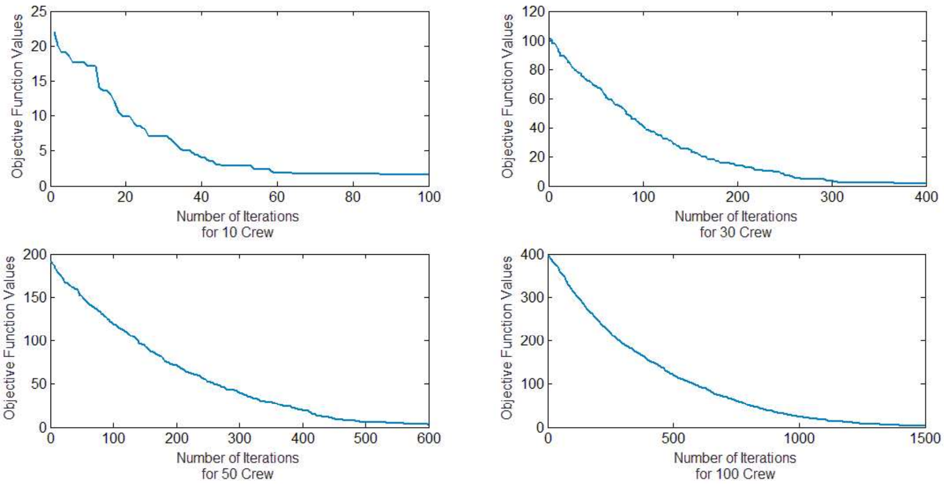

Fig. 2. Convergence of the ABC algorithm

4. CONCLUSION

In this study, it is aimed to optimize the weekly working hours and days off of the crew under given constraints. The crew scheduling problem was solved using the ABC algorithm. Experiments were done for a different number of crew. Simulation results show that the ABC algorithm can find optimized solutions in a reasonable time. It is understood that the ABC algorithm can be efficiently used for solving the crew scheduling problem.

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