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A hybrid meta-heuristic algorithm for optimization of crew scheduling

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ABSTRACT

Crew scheduling problem is the problem of assigning crew members to the flights so that total cost is minimized while regulatory and legal restrictions are satisfied. The crew scheduling is an NP-hard constrained combinatorial optimization problem and hence, it cannot be exactly solved in a reasonable computational time. This paper presents a particle swarm optimization (PSO) algorithm synchronized with a local search heuristic for solving the crew scheduling problem. Recent studies use genetic algorithm (GA) or ant colony optimization (ACO) to solve large scale crew scheduling problems. Furthermore, two other hybrid algorithms based on GA and ACO algorithms have been developed to solve the problem. Computational results show the effectiveness and superiority of the proposed hybrid PSO algorithm over other algorithms.

1. Introduction

Crew planning and scheduling problem is the determination of the number of crew with special skills and assignment of crew to meet demand. The objectives are minimizing costs, meeting customers' demands, and distributing work equally. The scheduling of crew members, which is the assignment of crew members to a flight for some period of time, is generally divided into crew scheduling and crew rostering [1]. These two problems have some differences in various airlines. Andersson et al. [2] have examined the major differences in terms of crew categories, fleet types, network structures, rules and regulations, regularity of the flight timetables, and cost structures. In fact, the objective of crew scheduling is to build a set of feasible pairings for minimizing the total crew costs and satisfying the given flight schedule, labor union and government regulations, the fleet routes, and the company's own policy. Whereas, in crew rostering problems, the objective is to find pairings assigned to crew members, satisfying crew member's skills, vacations, and other requirements.

Crew scheduling problem can be defined as assignment of a crew to a set of works. The crew scheduling problem can be formulated as a set covering problem (SCP) or set partitioning problem (SPP), which is the problem of covering some flights by crew members so that all the flights are covered, while the cost is minimized [1]. Crew scheduling is an NP-hard problem. Thus, it cannot be exactly solved in a reasonable computation time. It is more than three decades that the crew scheduling problem has taken numerous attentions in operations research community. The main challenge in this problem is that there is not any general method to work well with all kinds of nonlinear cost functions and constraints [3]. Meanwhile, this problem goes to a complicated problem when the number of inputs increases.

Most Researchers examined the crew scheduling problem as a SCP or SPP. For example, Rubin [4] modeled a large-scale crew scheduling problem as a SCP and suggested a solution algorithm based on decomposition and complete enumeration techniques. Gerbracht [5] formulated the crew scheduling problem as a SPP and proposed a solution method on the basis of Lagrangian relaxation and branch-and-bound (B&B) techniques. Lavoie et al. [6] modeled the crew scheduling problem as a SCP, where the column generation approach was used to solve this problem. Anbil et al. [7] modeled the crew scheduling as a SPP and developed a SPIRINT approach that would efficiently generate columns for the solution of large-scale problems. Chu et al. [8] formulated the crew pairing problem as a SPP and developed a graph-based branching heuristic for solving the restricted SPP representing a collection of the best pairings. Barnhart and Shenoi [9] presented an approximate model for the long-haul crew pairing problem. Stojkovic et al. [10] modeled a day-to-day operational airline crew scheduling problem as a SPP and to solve it, developed a column generation method embedded in a branch-and-bound search tree. Wang [11] considered the problem as a SCP and solved it by linear programming. Yan

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and Chang [12] modeled this problem as SPP and a column generation approach was suggested to solve the problem efficiently with a case study in Taiwan airline. Other methods applied in solving this problem are such as the multi-commodity network flow approach [13], the matching model [14], dynamic programming [15], and the network model [16].

Some researchers solved crew scheduling problem in large scale with meta-heuristics algorithms. For example, Ozdemir and Mohan [17] solved this problem using a genetic algorithm (GA) applied to a flight graph representation that represents several problem-specific constraints. Crawford et al. [3] formulated the problem as a SCP and solved it by ant colony optimization (ACO). They solved some test examples of Airline Flight Crew Scheduling by ACO algorithms and some hybridizations of ACO with constraint programming techniques like forward checking. Lo and Deng [18] modeled the problem as a traveling salesman problem (TSP) with flight graph representation and used the ACO algorithm to search near-optimal solutions for airline crew schedules.

PSO algorithm is a stochastic optimization technique developed by Eberhart and Kennedy in 1995 [19] and inspired by social behavior of bird flocking or fish schooling. In comparison to GA, PSO can be performed more easily and have fewer parameters to adjust. These advantages make PSO not only suitable for scientific research but also for engineering applications. The PSO has attracted broad attention in the fields of evolutionary computing and optimization. Although the PSO has been initially developed for continuous optimization problems, it has been successfully applied for solving discrete problems as well [20]. PSO has been used for solving TSP [20,21], vehicle routing problem (VRP) [22,23], cell formation problem [24], feature selection [25], and shortest path problem [26]. PSO has also been implemented for solving different scheduling problems such as single machine scheduling [27], parallel machine scheduling [28], flow shop scheduling [29–31], job shop scheduling [32,33], and open shop scheduling [34,35].

In this paper, a hybrid algorithm particle swarm optimization (PSO) algorithm is proposed for solving the crew scheduling problem. PSO is incorporated with a local optimization heuristic based on the problem-specific knowledge of the search space. Recent studies use GA or ACO to solve large scale crew scheduling problems. Furthermore, two other hybrid algorithms based on GA and ACO algorithms have been developed to solve the problem. Computational results show the effectiveness and superiority of the proposed hybrid PSO algorithm.

The organization of this paper is as follows. In Section 2, the problem of crew scheduling is described. In Section 3, different steps of the PSO algorithm is mentioned in detail. The proposed PSO algorithm is explained in Section 4. The results of the comparison of the proposed PSO algorithm with the well-known algorithms are discussed in Section 5. In Section 6, the conclusion of the paper is presented.

2. Problem description

The aim of crew scheduling is to assign a set of flights to a set of crew members with the objective of minimizing total crew assigning costs and satisfying various functional and legal restrictions including labor union and government regulations as well as the company's own policy [19]. The following regulatory restrictions and security rules have to be considered:

1. In a duty period, the city of arrival of a flight is the same city of departure of its immediately succeeding flight.
2. The sit time, i.e., the amount of time between two consecutive flights must be restricted within lower and upper bounds. If the sit time exceeds the maximum allowed time, the crew members must be sent to rest in hotel.
3. Number of flights in a pairing cannot exceed a prescribed maximum number of flights.
4. Total flying time in a pairing cannot exceed a maximum allowed flying time.
5. Duration of a pairing cannot exceed a prescribed amount of time.
6. Each pairing should start and end at the same base city, i.e., the city where the crew members are stationed. Otherwise, the crew members are taken to their respective bases as ordinary passengers at the end of the pairing by a deadhead flight.

The crew scheduling problem is solved as a daily problem in which it is assumed that every flight leg is operated every day. Although it is possible that some flight legs are not flown in specific days, it has been shown that the solution to the daily problem is a good approximation to the weekly and monthly problems [36].

The cost includes the basic payment for each pairing, the basic minimum payment for each flight, the bonus for overtime flying, the additional pay for the sit time, hotel expenses, and crew flying as passengers (deadheads).

3. Particle swarm optimization

PSO introduced by Kennedy and Eberhart [19] as a method for nonlinear optimization, has been inspired by the flight of birds in a flock or motion of particles. PSO is a population-based optimization algorithm in which each particle is an individual and the set of particles forms the swarm. In order to solve the optimization problem, any potential solution in search space is considered as a potential position for particles. Swarm of particles move through a multi-dimensional search space under a defined dynamics of flight and communicate about the historical solutions in order to find better ones. The position of ith particle in an n-dimensional search space is represented by an n-dimensional vector.

$$x_i = (x_{i1}, x_{i2}, \ldots, x_{in}) \quad (1)$$

Also, every particle possesses a velocity vector as follow:

$$v_i = (v_{i1}, v_{i2}, \ldots, v_{in}) \quad (2)$$

In any iteration, positions and velocities are updated by means of the following equations:

$$v_{ij}(t+1) = I_{ij} v_{ij}(t) + R_{1ij} c_1 (P_{ji} - x_{ij}(t)) + R_{2ij} c_2 (P_{gj} - x_{ij}(t)) \quad (3)$$

$$x_{ij}(t+1) = x_{ij}(t) + v_{ij}(t+1) \quad (4)$$

where P_{ji} and P_{gj} are, respectively, the jth coordinate of the best previous position of ith particle and the global best previous position, i.e., the best position found so far. R_{1ij} and R_{2ij} are two random variables in [0,1], c_1 and c_2 are acceleration constants, and I_{ij} is the parameter used to model the inertia effect of particle's previous velocity. I_{ij} is used to control exploitation vs. exploration. A lager I_{ij} yields to maintaining high velocities by particles and therefore, prevents particles from becoming trapped in local optima. On the other hand, if a smaller value is assigned to I_{ij}, the particles would possess smaller velocities and would be encouraged to exploit the same search space area. The process of PSO is shown in Fig. 1.

4. The proposed PSO algorithm

The proposed PSO algorithm for solving the crew scheduling problem is described in this section. The overall structure of the proposed algorithm is shown in Fig. 2.