Study on Large-scale Flight Delay Recovery

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Abstract

Under a large-scale flight delay, some flights could not be carried out according to schedule, the flight crew arrangement may be disrupted, and thus passengers and airlines suffer losses. In this paper, in view of the crew recovery under the large-scale flight delay, considering the cost of flight crew and introducing the constraint of the number of damage to the flight crew, the recovery model of the flight crew considering flight-crew pairing constraint under a large-scale flight delay was set up. The simulation annealing algorithm is used to simulate the case of airport delay, and the example analysis indicated that this model can largely reduce delay losses.

1 Introduction

In recent years, large-scale flight delays have become one of the major challenges and difficulties faced by the civil aviation industry. Due to bad weather, traffic flow controlling, military and other reasons, airport flight delays occur frequently. Under a large-scale of flight delay, flights can't be normally executed according to the schedule. In the meanwhile, the flight resources related to the operation of the aircraft cannot be used reasonably. When a flight are bound to be delayed or cancelled, the original flight crew arrangement is disrupted. Unused crew or crew insufficiency arises. Therefore, the study of flight crew recovery can largely restore flight to resume operation as soon as possible.

At present, research on flight delay recovery has made some achievements. In 2003, Rosenberger J M built an optimization model of flight route, crew and passengers aiming at the minimizing the cost of flight rerouting and cancellation [1];In the same year, Ma Zhengping built a terminal area flow distribution and flight dispatching model, which realized the optimal allocation of arrival and departure flows in the airport [2]; In 2006, Bratu S, etc. proposed a flight schedule recovery model and algorithm for the airline company for the interruption of the flight schedule caused by bad weather[3];In 2008, Weiqiang Liu designed a hybrid particle swarm optimization (HPSO) algorithm and obtained the optimized flight schedule with the minimum economic loss[4]. In 2008, Yuan Gao, etc. designed an improved particle swarm optimization (PSO) algorithm to generate the flight schedule to solve flight delay problem [5]. In 2010, Xiuli Zhao used ant colony algorithm to reschedule flight crew [6];In 2010, Tian Jun changed the flight delay established the dynamic optimization scheduling model of the arrival delayed flight with the aim of delay cost minimization and used simulated annealing algorithm to generate new arrival flight sequence[7]; in 2011, Liu Yanhong et al. bulilt a large-scale flight delay recovery model and constructed a genetic algorithm based on immune mechanism to solve the model which realized the minimum delay loss [8]; In 2014, Li Dancheng etc. proposed an improved genetic algorithm based on multi-objective scheduling method [9];In 2015, Stephen J.M built a flight integration recovery model which integrated the timetable, flight crew and the aircraft recovery [10] ;In 2015, Zhang Haifeng etc. built a flight recovery model aiming at minimizing the loss of flight delays, passenger spillovers and flight costs [11];In 2018,Yu Zhou etc.built a flight recovery model considering uncertain factors to minimize the cost of delays and ensure the fairness of flight[12].

2 Problem Description

The flight crew resources waste generally includes three parts: (1) idle crew, resulting in idle costs. When no suitable flight is paired with the crew it will be idle, or the flight delay causes the crew to be stranded. At this time, the airline still needs to pay for the crew members; (2) the required flight crews are not in the execution of the airport, producing the cost of adding flight crews. The cost of carrying the crews as passengers to the airport where the task will be carried out will have a certain cost. (3) There is no guarantee that all the resurgent flights will have the matched crews, resulting in the cost of calling the standby units. In order to ensure the normal operation of the flight, the airline generally a certain number of backup crews When the flight are rescheduled and not every flight has the matched flight crew, the standby crew is called to complete the flight task.

The flight crew recovery strategy includes: (1) exchange crew tasks (2) add units (3) call backup crews.

In the second chapter, the optimization model will be set up with the goal of the minimum flight crew recovery cost. Under the constraints of the operating conditions of the unit, and the constraint on the number of flight-crew pairing damage, the flight crews under the delay are restored.

3 Model Establishment

3.1 Parameter description

(1) Superscript and subscript

n, normal crew.

a, adding crew.

s, standby crew.

b, crew base.

(2)Set

N, normal crew set.

A, adding crew set.

S, standby crew set.

B, crew base set.

(3) Parameter

c_f^n， waiting cost for crew n to carry out flight f.

c_a， cost of adding a crew.

c_s， cost of calling a backup crew.

t_f^l， time of being all set for crew.

t_f^e， task end time of crew n.

t_f^d， departure time of flight f.

t_f^a， approach time of flight f.

o_f^s， flight f end all-day tasks in the base.

(4)Viarible

x_f^n equals 1 if crew n carry out flight f, otherwise 0.

x_f^a, equals 1 if crew a carry out flight f, otherwise 0.

x_f^s, equals 1 if crew s carry out flight f, otherwise 0.

3.2 Objective function

The objective function is established in the aim of minimizing crew recovery cost as follows:

$$\min\{\sum_{f\in F}\sum_{n\in N} c_f^n x_f^n + \sum_{f\in F}\sum_{a\in A} c_f^a x_f^a + \sum_{f\in F}\sum_{s\in S} c_f^s x_f^s\} \tag{1}$$

In the model, formula (1) is the objective function of minimizing the resource waste of the crew, the first is the waiting cost ,the second is the adding crew cost and the third is backup crew cost.

3.3 Constraints

$$\text{s.t.} \quad \sum_{f\in F}(\sum_{a\in A} x_f^a + \sum_{s\in S} x_f^s) < \sum_{f\in F}\sum_{l\in L} x_f^l \tag{2}$$

$$\sum_{n\in N} x_f^n + \sum_{a\in A} x_f^a + \sum_{s\in S} x_f^s = 1, \forall f \in F \tag{3}$$

$$\sum_{f\in F}\sum_{n\in N} o_f^s x_n^f + \sum_{a\in A} y_a + \sum_{s\in A} y_s = A_s, s \in S \tag{4}$$

$$\sum_{f\in F}\sum_{\substack{i\in I\\ n\in N}} x_n^f x_i^f = 1, \forall n \in N \cup A \cup S \tag{5}$$

$$x_n^f t_n^d \geq t_f^d, \forall f \in F, \forall n \in N \tag{6}$$

$$x_n^f t_n^e \leq t_f^a, \forall f \in F, \forall n \in N \tag{7}$$

$$x_n^f \in \{0,1\}, x_a^f \in \{0,1\}, x_s^f \in \{0,1\} \tag{8}$$

Formula(2)is the constraint on the number of flight-crew pairing damage; formula(3) is the flight coverage constraints, to ensure that a flight has either a normal, or an adding or a backup crew; Formula(4) is the constraints of crews being back to the base, all crews after the end of the mission to return to the crew base; Formula(5)is to ensure that the flight cannot be delayed because of crew reasons, the crew must be ready before the departure time of flight; Formula(6) is to ensure that the crew does not exceed the time limit; Formula(7) is the license constraints, ensuring that the type of crew license matches the flight; Formula(8) is a 0,1 integer constraint.

4 The simulated annealing algorithm

The simulated annealing algorithm is a kind of greedy algorithm. Greedy algorithm always makes the best choice in solving the problem, and it is the best solution in some sense. The greatest advantage of the simulated annealing algorithm is that it can accept a solution that is worse than the current solution by a certain probability, so it is possible to jump out of the local optimal solution and reach the global optimal solution.

The simulated annealing algorithm is derived from the principle of solid annealing. According to the Metropolis criterion, the probability that particles will tend to balance at temperature T is given as follows:

$$p = \exp(-\triangle E/(KT)) \tag{9}$$

E is the internal energy of temperature T, and K is the Boltzmann constant. Using solid annealing to simulate the combinatorial optimization problem, the internal energy E is simulated as the target function value f, and the temperature T evolves into the control parameter t. That is, the simulated annealing algorithm of the solution combinatorial optimization problem is obtained. The current solution at the termination of the algorithm is the approximate optimal solution.

The simulated annealing algorithm for flight crew recovery under flight delays is given as follows:

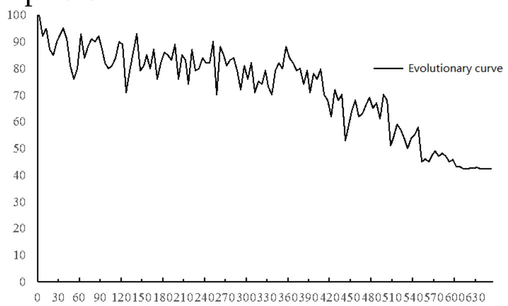
a. Get the scheduled arrival time for approaching flights and select delayed flights and cancel flights that need to be resumed;

b. List the information of delayed flights, cancelled flights and corresponding crews according to time sequence.
c. Initialization. The initial parameters of the annealing temperature T and the iteration coefficient L should be given.
d. Calculate the initial solution of the crew recovery cost according to postpone principle.
e. In the current temperature, recombine the flights and crews, the re pairing of the unit and flight to generate a neighborhood solution and then calculate the new recovery cost.
f. Compare the new solution with the previous one. Replace the previous one with the new solution if it is better. Or calculate the possibility according to Metropolis criterion and decide whether to accept the new solution.
g. Judge whether the new solution meet the internal cycle termination conditions. If not, jump to step e.
h. Judge whether the new solution meet the external cycle termination conditions. If not, lower the temperature and jump to step e. Or end iteration.

5 Example analysis

The flight delay data of a busy airport in China are selected for example analysis. Approaching flight delay arose at 11:30 on the same day, and a large-scale flight delay arose at 13:00.

The initial temperature $t_0=100$, annealing method is set as $t_{k+1}=0.95t_k$. The flight crew recovery cost using simulated annealing algorithm is shown in pic.1.



pic.1 Fitness evolution curve of simulated annealing algorithm

From the above picture, it can be seen that with the increase of iteration times, the cost of recovery gradually decreases, and finally a stable value which is the optimal solution are obtained. At this point, the recovery cost is 42.2% of the cost corresponding to the initial solution, which reduces the loss of 57.8%.

6 Conclusion

In this paper, the mathematical model of flight crew recovery under large-scale flight delay is established, and the simulated annealing algorithm is used to solve the model. Example analysis indicates that the optimal solution obtained by simulated annealing algorithm can reduce flight delay losses and restore crew schedule efficiently.

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