Research on optimal allocation of resources for arrival flight

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ABSTRACT

In order to solve the problem of flight delays caused by limited flight schedule resources, an inbound flight schedule resource optimization model was established. Considering the interval constraints on arrival points during the control and command process, as well as constraints on airport capacity, flight transfer connections, wake interval, and other constraints, genetic algorithms are used to find the time schedule with the least total flight delays and the least amount of delayed flights. Taking the flight time resource allocation of double runway airport as an example, the proposed algorithm is simulated and verified by AirTop software. The optimization results show that the flight schedule optimized by the proposed algorithm can run smoothly and can completely absorb non-serious flight delays.

Keywords: Flight time, wake interval, genetic algorithm, AirTop simulation

1. INTRODUCTION

Airport capacity saturation and flight delay are one of the main problems restricting the high-quality development of civil aviation transportation services. In order to solve these problems, many scholars began to carry out a lot of research from the perspective of flight schedule optimization and flight demand management. Jacquillat et al. proposed a comprehensive strategy that can alleviate congestion at the tactical and strategic levels at the same time. By integrating the airport random queuing model and the dynamic control model of airport capacity utilization into the integer programming model of flight slot allocation, the cooperative optimization model of strategic flight slot allocation and tactical airport capacity utilization (icusm) is constructed[1]. Pyrgiotis and Odoni put forward a demand smoothing optimization model based on the existing flight schedule. The optimized flight schedule does not need to cancel any flights, follows the relevant airport restrictions, keeps the aircraft itinerary and passenger connectivity unchanged[2]. Domestic research on flight time resource optimization initially used the ground waiting strategy for reference to optimize flight time, in order to reduce the loss caused by delay by replacing air waiting with ground waiting. Hu et al. Proposed the flight schedule planning expert system to balance the traffic volume by smoothing the flight volume in peak hours[3]. In 2003, a multivariate constrained flight time resource optimization model was further proposed, and an improved heuristic algorithm was used to solve the model[4]. Yang et al., considering the airport capacity constraints and flight continuity and constraints, applied the improved squeaky wheel optimization algorithm to find the flight time allocation scheme with the minimum total amount of flight adjustment[5]. Zheng et al. Proposed a model for optimizing departure flight time based on control handover interval in view of the current situation of large flight flow and tight airspace resources in multi airport terminal areas, combined with track operation theory[6]. Aiming at solving the large-area delay caused by unreasonable flight plan, Wang established a hub airport flight time resource optimization model based on airline fairness on the basis of meeting the delay level, and designed a cuckoo search algorithm based on particle swarm optimization algorithm to solve the model[7]. According to the characteristics and operation status of airport flight time allocation, based on the existing flight time resource optimization model, considering the resource constraints such as airport capacity and corridor, the principle of fairness is introduced quantitatively, an airport flight time allocation optimization model considering efficiency and fairness is constructed, and an improved particle swarm optimization algorithm based on flight time allocation priority is developed[8]. Ren analyzed the execution of historical operation data, used JS divergence to mine the similarity of flight execution probability distribution in the same direction and time slice between different years, and constructed the flight execution deviation probability distribution function based on kernel density estimation. Then, a single airport flight time resource optimization model considering actual operation deviation is proposed. Within the adjustment range acceptable to airlines, it is constructed to minimize the total execution time deviation, improve flight normality and reduce actual operation delay[9]. Li and others, according to the air

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traffic control operation rules in the terminal area, aiming at minimizing the total flight delay time, considering the constraints of arrival point, flight time adjustment range, takeoff interval and runway occupation time, established the flight time resource optimization model, and solved the model by means of permutation coding and genetic algorithm. Comparing the best solution of the algorithm with the actual data derived from the radar trajectory, the results show that the proposed method can reduce the delay time by about 30%[10, 11]. Peng et al. Established a multi-objective flight time resource optimization ranking model with the least average runway delay time, the least total time slice adjustment and the least total delayed flight sorties, and used the non-dominated ranking multi-objective optimization algorithm to obtain the leading-edge solution set of the model[12].

The above research has done a lot of research in flight time resource optimization modeling and algorithm solution, which lays a foundation for the research of this paper, which makes us very inspired, but there is still room for improvement. We consider the arrival process of flights in the actual control process, analyze the causes of flight delay, establish the flight time resource optimization model with key factors as constraints, design the model by genetic algorithm, and use airtop for simulation verification, so as to obtain the practical and feasible flight time plan.

2. ARRIVAL FLIGHT TIME RESOURCE OPTIMIZATION MODEL

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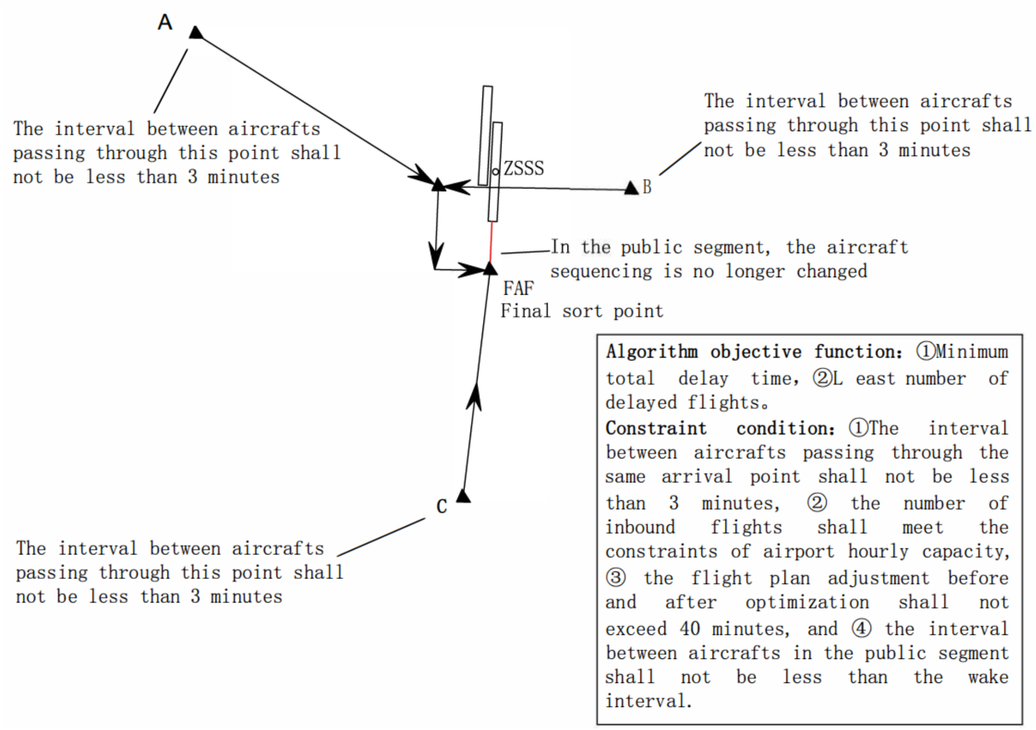
2.1. Model assumptions

The optimization range of arrival flight time resources designed in this paper is from the arrival point to the flight landing, and it is set that all flights have no delay before arriving at the arrival point. After passing the arrival point, the aircraft can land smoothly without special circumstances such as missed approach or abnormal flight. The implementation process of the algorithm is shown in Figure 1.



The interval between aircrafts passing through this point shall not be less than 3 minutes

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In the public segment, the aircraft sequencing is no longer changed

Algorithm objective function: ①Minimum total delay time, ②L east number of delayed flights。

Constraint condition: ①The interval between aircrafts passing through the same arrival point shall not be less than 3 minutes, ② the number of inbound flights shall meet the constraints of airport hourly capacity, ③ the flight plan adjustment before and after optimization shall not exceed 40 minutes, and ④ the interval between aircrafts in the public segment shall not be less than the wake interval.

The interval between aircrafts passing through this point shall not be less than 3 minutes

Figure 1. Arrival flight time resource optimization model.

2.2. Parameter setting and definition

i is the flight number to be optimized, and there are m flights to be optimized.

j indicates the entry point: 1 indicates the arrival from entry point A, 2 indicates the arrival from entry point C, and 3 indicates the arrival from entry point B.

$\mathrm{ATP}_{\mathrm{i,j}}$: The time when the optimized flight i passes the arrival point j.

$\mathrm{ATA}_{\mathrm{i}}$: indicates the landing time of flight i after optimization.

$\mathrm{ETA}_{\mathrm{i}}$: indicates the scheduled landing time of flight i.

$S_{i,i+1}$: represents the wake interval between two aircraft i and i + 1 with continuous departure.

Δt_j : indicates the average flight time from the arrival point j to landing.

We introduce a decision variable X_i, $X_i = 1$ indicates that flight I is delayed, and $X_i = 0$ indicates that flight I is not delayed.

$$X_i = \begin{cases} 0, & ATA_i - ETA_i \le 0 \\ 1, & ATA_i - ETA_i > 0 \end{cases} \tag{1}$$

2.3. Objective function

The purpose of flight time resource optimization is to reduce delay time and improve flight normality. Therefore, we establish the objective function with the least total flight delay time and the least number of delayed flights. As shown in equations (2) and (3), the objective function is: the least total delay time and the least number of delayed flights of all incoming aircraft in the airport terminal area, The aircraft delay here is defined as the difference between the actual arrival time of the aircraft passing the last sequencing point plus the flight time of the public approach segment (i.e. the actual landing time) and the planned landing time reported by FPL. If the optimized landing time of the flight is later than the planned landing time of the aircraft, it is counted as delay. If the optimized landing time is earlier than or equal to the planned landing time, it is not counted as delay.

$$Z_1 = \min \sum_{i=1}^{m} (ATA_i - ETA_i) \tag{2}$$

Equation (2) represents the least total flight delay. In equation (2), $ATA_i - ETA_i = 0$ means that the optimized landing time is earlier than or equal to the FPL plan time.

$$Z_2 = \min \sum_{i=1}^{m} X_i \tag{3}$$

Equation (3) indicates that the number of delayed flights is the least.

2.4. Constraints

In the process of time coordination, the published capacity of the airport is usually regarded as the only constraint, while the potential bottlenecks in other parts are ignored. Taking the corridor entrance as an example, as an important channel for inbound and outbound flights in the airport terminal area, traffic controllers often implement flow control to maintain flight order in daily operation. Generally, flights in the same direction enter and exit from the same corridor. It should be noted that flights entering and leaving from the same corridor may come from two or more airports in the region. In this case, time coordination is more complex. It is not only necessary to consider the capacity constraints of the corridor, but also need to coordinate the flight operation between multiple airports. Once the number of flights in some time intervals exceeds the control capacity of the controller, it will cause air traffic congestion and affect the subsequent flights passing through this point. Even if the airport operating conditions are normal, it will be delayed to take off or land.

In view of the above objective problems, in order to be close to reality to the greatest extent, we set the following constraints according to the flight operation rules in the airport terminal area:

Condition 1: entry point constraint. The time interval of aircraft passing through the same entry point is 3 minutes, which is expressed by equation (4).

$$ATP_{i,j} - ATP_{i+1,j} \geq 3 \tag{4}$$

The value of I in equation (4) is the sequence of aircraft in the same entry point J, and j is the entry point number. $ATP_{i,j}$ is obtained according to equation (5).

$$ATP_{i,j} = ATA_i - \Delta t_j \tag{5}$$

Condition 2: airport arrival capacity constraint (9:00-22:00, 36 sorties per hour), expressed as follows by equation (6).

$$ATA_{i+36} - ATA_i \geq 60 \tag{6}$$

Equation (6) shows that 36 flights landing continuously take more than 60 minutes, that is, 36 flights landing at most in any one hour.

Condition 3: adjust the range constraint, and the optimized flight landing time shall not exceed 40 minutes compared with the FPL planned landing time, which is expressed as follows by equation (7).

$$\left| ETA_i - ATA_i \right| \leq 40 \tag{7}$$

In equation (7), ETA_i represents the FPL planned landing time of the flight i, ATA_i represents the landing time after flight i optimization, and equation (7) represents that the landing time after flight optimization can only be adjusted within 40 minutes before and after FPL.

Condition 4: aircraft interval from FAF to runway continuous landing

$$ATA_i - ATA_{i+1} \geq S_{i,i+1} \tag{8}$$

3. EXAMPLE ANALYSIS

In this paper, a double runway airport is selected as the research object. The airport is used as a short-range runway. The single takeoff and single landing mode (from west to East) is the main operation mode. 36L takeoff / 36R landing is mainly used for North operation, and 18R takeoff/18L landing is mainly used for South operation. We select the flight operation data from 10:00 to 12:15 on October 28, 2018, use AirTop to simulate the FPL planned landing time to obtain the airtop simulated landing time, use the model algorithm proposed in this paper to optimize the FPL plan, and then conduct airtop simulation on the optimized timetable to verify whether the optimized result is feasible. The optimization steps are as follows:

Step 1. Determine the genetic strategy, including population number n, selection, crossover and variation methods. At the same time, the crossover probability, mutation probability and other genetic parameters are determined;

Step 2. Define the fitness function f (x);

Step 3. Randomly generate initialization population *p*;

Step 4. Calculate the objective function of the chromosome corresponding to the flight queue;

Step 5. Calculate the fitness value of individuals in the population;

Step 6. Find the optimal individual under the current conditions;

Step 7. Judge whether the evolutionary algebra reaches the maximum genetic algebra.

Step 8. Use roulette selection to cross chromosomes through single point cross mapping method;

Step 9. Perform Steps 4 to 6;

Step 10. Evaluate the effect of genetic algorithm;

Step 11. Output the optimal function value, and then obtain the optimal flight sequence.

Table 1 shows the flight schedule information before and after optimization by comparing the results of selected parts (11:00-12:00).

According to the comparison results in Table 1, the total delay before optimization is 11760.00 seconds, with an average of 7.84 minutes/flight; The optimized delay time is 0. It can be seen that the delay can be fully absorbed by using the algorithm proposed in this paper by adjusting the flight sequence within a certain range. Using airtop to simulate the optimized flight time, the deviation is within tens of seconds. The optimized flight time is simulated by airtop, and the deviation is within tens of seconds. A series of operations such as grasping the timing of releasing the brake and taxiing on the apron can be ignored. Therefore, the optimized flight time is considered to be feasible.

Table 1. Flight schedule information before and after optimization.

Flight number	**Type**	**Entry point**	**ETA**	**Simulation FPL landing time**	**Delay time before optimization**	**ATA**	**Optimized delay time**	**Simulation Optimized landing time**	**Airtop simulation time difference**
CES5801	M	C	11:00	10:39	0	10:42:59	0	10:43:35	0:00:36
CQH8910	M	C	11:00	11:11	660	10:34:38	0	10:35:12	0:00:34
CES5276	M	A	11:15	10:41	0	11:02:05	0	11:02:19	0:00:14
CES5104	H	A	11:15	10:35	0	11:12:40	0	11:11:46	0:00:00
CSN3951	H	A	11:15	11:13	0	10:45:01	0	10:44:43	0:00:00
CCA1838	H	C	11:20	10:54	0	10:51:55	0	10:52:29	0:00:34
CES2151	H	A	11:20	10:52	0	11:07:09	0	11:06:54	0:00:00
CSN3553	M	C	11:25	11:18	0	11:05:13	0	11:05:44	0:00:31
CSH9416	M	A	11:25	10:56	0	11:17:18	0	11:16:44	0:00:00
CSZ9503	M	C	11:30	11:20	0	11:00:01	0	11:00:58	0:00:57
CES5572	M	A	11:30	11:10	0	11:26:46	0	11:27:07	0:00:21
CCA1519	H	A	11:35	11:08	0	11:29:46	0	11:28:33	0:00:00
CQH8816	M	C	11:40	11:30	0	11:10:01	0	11:10:38	0:00:37
CES5324	M	C	11:40	11:22	0	11:19:57	0	11:20:33	0:00:36
CSH9246	M	C	11:40	11:48	480	11:33:36	0	11:34:12	0:00:36
JAL81	H	B	11:45	11:34	0	11:40:14	0	11:40:07	0:00:00
CES535R	M	C	11:45	11:38	0	11:15:03	0	11:15:32	0:00:29
CSH9074	M	A	11:45	11:28	0	11:36:26	0	11:35:52	0:00:00
CES2253	M	A	11:45	11:19	0	11:22:25	0	11:21:49	0:00:00
B8278	L	C	11:50	14:45	10500	11:25:17	0	11:25:49	0:00:32
CES5334	M	C	11:50	11:46	0	11:42:43	0	11:43:12	0:00:29
CES5314	M	C	11:50	11:52	120	11:47:34	0	11:48:07	0:00:33
CQH8958	M	C	11:50	11:41	0	11:38:23	0	11:39:00	0:00:37
DKH1124	M	C	11:55	11:36	0	11:54:24	0	11:54:58	0:00:34

CES2507	M	A	11:55	11:33	0	11:50:37	0	11:49:32	0:00:00

4. CONCLUSION

This paper combs the flight arrival process, considers the actual controller command scene, and establishes the arrival flight time resource optimization model with the constraints of airport capacity, control interval and flight connection. Airtop is used to verify the optimization algorithm. The results show that the optimized flight schedule proposed in this paper is feasible and can effectively alleviate flight delays.

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