MULTI-OBJECTIVE PROGRAMMING FOR AIRPORT GATE REASSIGNMENT

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Abstract: To improve the efficiency of gate reassignment and optimize the plan of gate reassignment, the concept of disruption management is introduced, and a multi-objective programming model for airport gate reassignment is proposed. Considering the interests of passengers and the airport, the model minimizes the total flight delay, the total passengers' walking distance and the number of flights reassigned to other gates different from the planned ones. According to the characteristics of the gate reassignment, the model is simplified. As the multi-objective programming model is hard to reach the optimal solutions simultaneously, a threshold of satisfactory solutions of the model is set. Then a simulated annealing algorithm is designed for the model. Case studies show that the model decreases the total flight delay to the satisfactory solutions, and minimizes the total passengers' walking distance. The least change of planned assignment is also reached. The results achieve the goals of disruption management. Therefore, the model is verified to be effective.

Key words: gate assignment; multi-objective programming; simulated annealing algorithm; disruption management

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INTRODUCTION

Airport gate assignment is the process of assigning right airport gates for flights in order to meet corresponding requirements, but the airport gate assignment must be under some constraints. Efficient gate assignment has an important significance on improving the utilization rate of airport gates, reducing flight delays, facilitating airline passengers, enhancing airport security ability, and so on. Proceeding from passengers' satisfaction maximization and walking distance minimization, domestic and overseas scholars have set up 0-1 programming[1] and integer programming model[2], worked out by branch and bound method and heuristic algorithm respectively. Xu and Bailey[3] took passengers' turnaround time minimization as objective to set up model. Yan and Huo[4] established multi-objective 0-1 programming model concerning the shortest passengers' walking distance and waiting time. As an NP problem, the gate assignment algorithm has been improved by some related research[5-7].

Planned assignment is the course of assigning gates according to certain information (flight schedule). In fact, there is certain randomness, including flight uncertainty (early arrived, delayed, cancellation, alternate, etc.), emergency cases (the long delay of departure flight which occupies a gate, the gate is unavailable because of equipment failure, etc.), and so on. When the above events occur, it is necessary to adjust the planned assignment to solve the problem of gate reassignment. In general, the assumption that

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the number and time distribution of flights remains in the scope of airport capacity and airport gates are sufficient to provide services for the same-day flights to match the actual situation[8]. Based on this assumption, Zhu Shiqun[9] considered flight uncertainty and took the shortest transferring distance of related people caused by gate changes as objective to set up a gate reassignment model, and good results were achieved. But he did not consider the arrival and transit passengers, and also did not take the emergency cases into account. In emergency cases, the assumption no longer holds, because in a certain period of time, the reduction of the total number of gates may lead to delays of arrival flights. For minimizing the total flight delays, Gu and Chung[10] established a gate reassignment model which was under perturbations of delayed flights and worked out by genetic algorithm. Yan and Tang[11] minimized the passengers′ waiting time and established a gate reassignment model concerning the random flight delays, meanwhile put forward a kind of heuristic algorithm. Refs. [10-11] respectively established single-objective optimization model. But they did not fully reflect either the passengers′ demands, or the characteristics of gate reassignment, and the solving process was too complex.

At present, there is less study on gate reassignment, especially in emergency cases; therefore, this aspect needs to be further researched[12-13]. Based on the above research and combining with the concept of disruption management represented in Ref. [8], this paper proposes a multi-objective programming model applied to emergency situation. This model minimizes the total time of flight delays, the total passengers′ walking distance and the number of flights reassigned to other gates different from the planned ones. Finally, an example is given.

1 AIRPORT GATE REASSIGNMENT MODEL

According to the concept of disruption management, Ref. [8] put forward three goals of gate reassignment.

(1) Maximum guarantee of carrying out smoothly ground support activities

It is no doubt that emergency situation will disrupt the normal order of the airport operation. The basic objective of gate reassignment is to make sure the airport ground activities are carried out smoothly. And this objective is the premise and foundation of other objectives.

(2) Making solutions of gate reassignment optimal as far as possible

The planned assignment is the optimal solution for the current working day, but the emergency situation will generally undermine its optimality. The airport services must regard passengers′ satisfaction as its purpose, so it is necessary to optimize the solutions of gate reassignment.

(3) Minimizing changes of original assignment as far as possible

If the number of flights reassigned to other gates different from the planned ones is too large, it will increase the load on the staff, and even make the operation of the airport chaos.

Based on the three above objectives, this paper proposes several objectives of gate reassignment when emergency cases occur. The primary objectives are to ensure that arrival flights reach the gate as soon as possible and to reduce flight delays caused by the shortage of gate resources. The secondary objectives are reducing passengers′ walking distance as far as possible, optimizing the solution of gate reassignment, improving airport service quality, and meanwhile, controlling the adjustment of planned assignment. Therefore, this paper takes the total time of flight delays minimization, the passengers′ walking distance minimization and the least change of planned assignment as objective function.

While solving the planned assignment problems that take the total time of flight delays minimization and the passengers′ walking distance minimization as objective function, each flight should be calculated for its objective function value and the solving process is complicated. According to the above discussion, in the planned assignment, there are no flight delays caused by capacity constraints, and passengers' walking distance is the optimal solution. The flights in the gate reassignment without making adjustments are absolutely optimal solution because gate reassignment is based on planned assignment, so the process of optimizing the gate reassignment scheme is to work out the optimal solution of flights which are adjusted and this process can be guaranteed to minimize changes of planned assignment at the same time [9]. In emergency cases, if a flight which occupies a gate is adjusted, it may affect other flights which are assigned to this same gate and even cause delays, but this will not affect other flights which are assigned to other gates. Thus, the total time minimization of flight delays can be simplified to the shortest total delay of flights which are assigned to the certain gates with flight adjustments. By the same token, passengers' walking distance minimization can be simplified to the shortest walking distance of passengers whose flights are adjusted.

Suppose that emergency cases occur in the period time of T and the airport needs to optimize the order of the arrival flights which arrive at the airport in the period time of T. The objective functions (1) and (2) are shown as follows

$$\min f_1 = \sum_{u=1}^{Q}\sum_{w=1}^{Q}\Big[\sum_{k=1}^{P}(T_k^{\mathrm{r}} - T_k^{\mathrm{a}})x_{ku}y_{ku} + \sum_{i=1}^{P}(T_i^{\mathrm{r}} - T_i^{\mathrm{a}})x_{iu}y_{iw}\Big) \tag{1}$$

$$\min f_2 = \sum_{i=1}^{P}\sum_{u=1}^{Q}\sum_{w=1}^{Q}\Big(D_u^{\mathrm{a}}N_i^{\mathrm{a}} + \sum_{j=1}^{P}\sum_{v=1}^{Q}D_{uv}^{\mathrm{t}}N_{ij}^{\mathrm{t}}x_{jv} + D_{wu}^{\mathrm{d}}N_i^{\mathrm{d}}\Big)x_{iu}y_{iw} \tag{2}$$

where

$$x_{iu} = \begin{cases} 1 & \text{Flight } i \text{ is assigned to gate } u \text{ after gate reassignment} \\ 0 & \text{Others} \end{cases}$$

$$y_{iw} = \begin{cases} 1 & \text{Flight } i \text{ is assigned to gate } w \text{ in planned assignment} \\ 0 & \text{Others} \end{cases}$$

and P, Q respectively represent the total number of flights and the total number of available gates both in the period time of T, N_i^{a}, N_i^{d} the number of arrival passengers and departure passengers of flight i, N_{ij}^{t} represents the number of passengers transferring from flight i to flight j, D_u^{a} the distance of arrival passengers moving from gate u to the baggage claim area, D_{wu}^{d} the distance of departure passengers transferring from gate w to gate u, D_{uv}^{t} the distance of transit passengers transferring from gate u to gate v, T_i^{r} the actual time of flight i reaching the gate, T_i^{a} the expected time of flight i reaching the gate.

To simplify the model and improve its versatility, this study does not consider such constraints as the matching between gate and aircraft type, the special gate and the flight priority. In other words, all the gates can be assigned to any flights. This paper considers basic constraints as follows.

(1) Each flight can only be assigned to one gate, that is

$$\sum_{u=1}^{Q} x_{iu} = 1 \quad \forall i \in P$$

(2) Each gate can only be assigned to one flight, that is

$$\sum_{i=1}^{P} x_{iu} \leqslant 1 \quad \forall u \in Q$$

(3) Capacity constraint: The actual time of the flight reaching the gate is not earlier than its expected time, that is

$$T_i^{\mathrm{a}} \leqslant T_i^{\mathrm{r}} \quad \forall i \in P$$

2 ALGORITHMS

Such methods as evaluation function method, objective programming method and interactive programming method are generally used to solve the problems of multi-objective programming. As the objectives of a multi-objective programming model are hard to reach the optimal solutions simultaneously, finding satisfactory solution that depends on the application background is an effective way to solve problems of multi-objective programming.

As mentioned above, reducing flight delays is primary task when emergency occurs, followed by the consideration of the shortest passengers' walking distance. Therefore, in the above multi-objective programming model proposed, the importance of f_1 is greater than that of f_2. This study deems that it can decrease the solution space of f_2 and the complexity of solving process by setting f_1 a satisfactory solution threshold according to airport requirements or empirical value, and then working out a satisfactory solution set using simulated annealing algorithm. The next step is to find the optimal solution of f_2 in the satisfactory solution set and that is the definitely optimal solution of the model. The algorithm is shown as followes.

(1)Initialization

Set that satisfactory solution threshold is f_s, satisfactory solution set is F, the initial value is t_0, and the iteration index $c=0, t_c=t_0$. The selection of initial solution and the setting of initial value are conducted by the following steps.

① Generate free time quantum of all the available gates. $[B_{ul}, S_{ul}]$ $(l=1,2,3,\cdots)$ is the first free time quantum of the gate $u(u\in Q)$.

② Considering each flight in M (M is a collection of all flights which are assigned to unavailable gates in planned assignment), calculate the value of $\min\{|T_i^a - B_{ul}|\}, i\in M, u\in Q$.

③ According to the result of step ②, generate the initial scheme of gate reassignment. Then, calculate the value of objective function f_1, take the result as initial solution, and note it as s_0.

④ Considering each flight in M, calculate the value of $\max=\{|T_i^a - B_{ul}|\}, i\in M, u\in Q$.

⑤ According to the result of step ④, generate the scheme of gate reassignment. Then, calculate the value of objective function f_1 and note it as s^*.

⑥ Obtain the initial value $t_0 = |s^* - s_0|$.

(2)Generation of new solution

While using natural number to code, one solution represents one assignment scheme. For example, [5, 10, 10, ⋯] represents that flight 1 stops at gate 5, flight 2 stops at gate 10 and flight 3 stops at gate 10. Any position exchange of two numbers can generate a new solution. Randomly generate a neighborhood solution $n\in N(m)$ ($N(m)$ represents the neighborhood of m). If the value of objective function f_1 is smaller than f_s, store the neighborhood solution into F and then calculate the increment of the objective function value $\Delta f_1 = f_1(n) - f_1(m)$.

(3)Judgment and treatment of new solution

If $\Delta f_1 < 0$, set $m=n$, and jump to step (4); otherwise generate $\xi=U(0,1)$. If $\exp\left(-\frac{\Delta f_1}{t_c}\right) > \xi$, set $m=n$.

(4) Judgment of inner loop termination criterion

If the thermal equilibrium is reached, namely, the times of inner loops is bigger than $g(t_c) = P(c+1)$ (P is the total number of all flights), jump to step (5); otherwise jump to step (2).

(5) Judgment of outer loop termination criterion

If lower t_c, the cooling function is $t_{c+1} = \frac{t_c}{1+\alpha t_c}$ $(\alpha = 0.98)$, $c=c+1$. If the optimal solution remains the same after 100 consecutive iterations, jump to step (6); otherwise jump to step (2).

(6) Seeking optimal solution of objective function f_2

After a search of the above steps, the initial solution space of the model is greatly reduced, meanwhile, the satisfactory solution set F is obtained. And F is the feasible solution space of the objective function f_2. In the process of seeking the optimal solution of objective function f_2, the each value of f_2 should be calculated firstly, followed by using exhaust algorithm to sort order and look for the result.

3 NUMERICAL EXAMPLE

This study takes the operation of a domestic airport in 11:00—14:00 as an example. Flight 13 delays for some reason and it will not take off until 14:00. Gate 11 is unavailable caused by malfunction before flight 31 arrives. There are 54 arrival flights in 11:00—14:00 in total. And eight flights that arrive before 11:00 will no longer be adjusted. Airport requires that the average delay of arrival flights is no more than 2 min. It means that the satisfactory solution threshold f_s is 108 min. This study applies the proposed model to optimize gate reassignment for arrival flights. After the calculation of steps (1)—(5), the satisfactory solution set F consisting of 68 groups of satisfactory solution is obtained. And then, importing the relevant airport gate distance and the number of related airline passengers, the optimal solutions can be calculated by step(6) and the results are shown in Table 1. Because of the huge amount of data, this paper only lists the calculation results, and the operating time in Table 1 includes the flight safety time interval.

Table 1 Results of gate reassignment

Flight number	Gate number in planned assignment	Expected time of reaching gate	Operating time/min	Expected time of leaving gate	Actual time of reaching gate	Gate number in gate reassignment	Delay/min
1	1	1110	65	1215	1110	1	0
2	1	1230	30	1300	1230	1	0
3	1	1307	113	1500	1307	1	0
4	2	1021	44	1105	1021	2	0
5	2	1122	68	1230	1122	2	0
6	2	1302	63	1405	1302	2	0
7	3	1113	87	1240	1113	3	0
8	3	1257	30	1327	1257	3	0
9	4	1038	42	1120	1038	4	0
10	4	1150	60	1250	1150	4	0
11	4	1304	45	1349	1304	4	0
12	4	1355	65	1500	1355	4	0
13	5	1102	30	1132	1102	5	0
14	5	1140	50	1230	1146	13	6
15	5	1245	30	1315	1306	17	21
16	5	1330	60	1430	1330	7	0
17	6	1002	60	1102	1002	6	0
18	6	1133	72	1245	1133	6	0
19	6	1308	50	1358	1308	6	0
20	7	1110	45	1155	1110	7	0
21	7	1202	60	1302	1202	7	0
22	8	1128	52	1220	1128	8	0
23	8	1229	60	1329	1229	8	0
24	8	1340	60	1440	1340	8	0
25	9	1112	68	1220	1112	9	0
26	9	1237	54	1331	1237	9	0
27	9	1336	65	1441	1336	9	0
28	10	1119	41	1200	1119	10	0
29	10	1208	66	1314	1208	10	0
30	10	1334	55	1429	1334	10	0
31	11	1112	58	1210	1112	12	0
32	11	1233	60	1333	1236	13	3
33	11	1350	30	1420	1350	3	0
34	12	1011	57	1108	1011	12	0
35	12	1133	67	1240	1210	12	37
36	12	1310	33	1343	1317	12	7
37	12	1355	60	1455	1355	12	0
38	13	1106	90	1236	1106	13	0

(Continuation)

Flight number	Gate number in planned assignment	Expected time of reaching gate	Operating time/min	Expected time of leaving gate	Actual time of reaching gate	Gate number in gate reassignment	Delay/min
39	13	1310	53	1403	1336	13	26
40	14	1126	42	1208	1126	14	0
41	14	1215	60	1315	1215	14	0
42	14	1325	60	1425	1325	14	0
43	15	1120	70	1230	1120	15	0
44	15	1237	73	1350	1237	15	0
45	15	1358	80	1518	1358	15	0
46	16	1118	44	1202	1118	16	0
47	16	1210	60	1310	1210	16	0
48	16	1312	35	1347	1312	16	0
49	16	1352	54	1446	1352	16	0
50	17	0900	191	1211	0900	17	0
51	17	1227	39	1306	1227	17	0
52	17	1347	60	1447	1347	17	0
53	18	0932	90	1102	0932	18	0
54	18	1121	63	1224	1121	18	0
55	18	1251	45	1336	1251	18	0
56	18	1359	80	1519	1359	18	0
57	19	1041	110	1231	1041	19	0
58	19	1237	120	1437	1237	19	0
59	20	1035	101	1216	1035	20	0
60	20	1221	40	1301	1221	20	0
61	20	1308	40	1348	1308	20	0
62	20	1352	110	1542	1352	20	0

The total flight delay is 100 min and the total passengers' walking distance is 49 265 m. This study reassigns gates to six flights whose original gates in planned assignment are unavailable now, while not adjusting gates of other flights. The results show that the change of planned assignment is least by using this model. At the same time, this model fully demonstrates the characteristics of gate reassignment. And it is simple and can be easily solved, in line with the requirements of disruption management.

4 CONCLUSION

In this paper, the problems of gate reassignment in emergency cases are studied, and a multi-objective programming model is established and solved by using simulated annealing algorithm. Considering the interests of passengers and the airport, the model minimizes the total flight delays, the total passengers' walking distance and the number of flights reassigned to other gates different from the planned ones. While using simulated annealing algorithm to solve the model, the initial solution and the initial value are selected according to the characteristics of model, and satisfactory solution threshold is set as well. All of these reduce computational complexity and improve efficiency. Simulation results prove the validity of the model, and the gate assignment solutions obtained meet the requirements of disruption management.

The model proposed in this paper does not consider the impact of cargo and does not fully reflect the randomness of flights. Such aspects as modeling process and algorithm design can be improved. Flight randomness is where the difficulty of gate reassignment lies, and it mainly displays in two aspects: It is difficult to draw its probability distribution; it is difficult to carry out effective prediction. Hence, the research on the randomness law of flights is of great significance for gate assignment problems. Under the circumstances of unclear flight randomness, the process of planning how to improve the robustness of planned assignment scheme and reduce the difficulty of real-time assignment caused by flight randomness needs to be studied in depth. How to adopt recovery strategy as well as set up reasonable real-time assignment model under the circumstances of perturbations of delayed flights is also the direction of further research.

References:

[1] Babić O, Teodorović D, Tošić V, et al. Aircraft stand assignment to minimize walking [J]. Journal of Transportation Engineering, 1984, 110(1): 55-66.

[2] Mangoubi D F X, Mathaisel R S. Optimizing gate assignments at airport terminals[J]. Transportation Science, 1985, 19(2): 173-188.

[3] Xu J, Bailey G. The airport gate assignment problem: Mathematical model and a tabu search algorithm[C]//Proceedings of the 34th Hawaii International Conference on System Sciences. Hawaii, USA: [s. n.], 2001: 102-111.

[4] Yan Shang-yao, Huo Cheun-ming. Optimization of multiple objective gate assignments[J]. Transportation Research Part A, 2001, 35(5): 413-432.

[5] Lim A, Rodrigues B, Zhu Y. Airport gate scheduling with time windows [J]. Artificial Intelligence Review, 2005, 24(2): 5-24.

[6] Liu Qing. Wu Tongshui, Song Xianbo. Optimization of airport taxing planning during congested hours based on inmune clonal selectin algorithm[J]. Transactions of Nanjing Universsity of Aeronautics & Astronautics, 2012, 29(3): 296-301.

[7] Luo Rongwu, Xie Ruhe, Zhang Dezhi. Vertex coloring model and algorithm of gate assignment [J]. Systems Engineering—Theory & Practice, 2007, 27 (11): 148-152.

[8] Chang Gang. Research on aircraft stands assignment and optimization in civil airport[D]. Xi'an: Northwestern Polytechnical University, 2006. (in Chinese)

[9] Zhu Shiqun. Research on gate reassignment problems in large airports[D]. Nanjing: Nanjing University of Aeronautics and Astronautics, 2007. (in Chinese)

[10] Gu Y, Chung A. Genetic algorithm approach to aircraft gate reassignment problem [J]. Journal of Transportation Engineering, 1999, 125 (1): 384-390.

[11] Yan Shang-yao, Tang Chung-hui. A heuristic approach for airport gate assignments for stochastic flight delays [J]. European Journal of Operational Research, 2007, 180(3): 547-567.

[12] Chang Gang, Wei Shengmin. Research on optimization of aircraft stands assignment problem[J]. Journal of Civil Aviation University of China, 2006, 24 (2): 25-29. (in Chinese)

[13] Ulrich D, Andreas D, Yury N, et al. Flight gate scheduling: State-of-art and recent developments[J]. The International Journal of Management Science, 2007, 35(3): 326-334.

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