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Research article

Research on airport multi-objective optimization of stand allocation based on simulated annealing algorithm

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Abstract: In this study, a multi-objective optimized mathematical model of stand pre-allocation is constructed with the shortest travel distance for passengers, the lowest cost for airlines and the efficiency of stand usage as the overall objectives. The actual data of 12 flights at Lanzhou Zhongchuan Airport are analyzed by application and solved by simulated annealing algorithm. The results of the study show that the total objective function of the constructed model allocation scheme is reduced by 40.67% compared with the actual allocation scheme of the airport, and the distance traveled by passengers is reduced by a total of 4512 steps, while one stand is saved and the efficiency of stand use is increased by 31%, in addition to the reduction of airline cost by 300 RMB. In summary, the model constructed in the study has a high practical application value and is expected to be used for airport stand pre-allocation decision in the future.

Key words: Stand; pre-allocation; airline cost; multi-objective optimization; simulated annealing

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1. Introduction

The stand is an important resource of the airport. It is a place for the aircraft to park when receiving a series of ground services (including loading and unloading passengers, loading and unloading cargo, refueling, and water filling, etc.) during the airport's transit. With the rapid growth of the number of flights, the fixed and limited airport stand and gate resources have been overloaded. At present, there are generally two ways to solve the shortage of airport stand resources: One is to directly increase hardware facilities and equipment resources such as Expansion of the airport and apron, etc. On the one hand, the various hardware facilities of the airport cannot be expanded indefinitely; on the other hand, the expansion of the airport and the investment of hardware equipment require a lot of capital, time, manpower, land, etc., which are restricted by many factors. The second is to optimize the allocation of airport stand resources. Through the optimized allocation of airport stand resources, it can improve the utilization efficiency of airport hardware resources and reduce airport operating costs. At present, the allocation of stand in domestic large and medium-sized airports is mainly based on manual allocation based on manual experience, supplemented by computer system allocation. Especially in large hub airports, the take-off and landing process of flights has the characteristics of short time and high density. This makes the stand scheduling work under the condition of limited aircraft space resources not only high in intensity, high operating cost and low efficiency, the quality of aircraft space allocation depends on the experience of the staff, and it is difficult to ensure the optimal allocation of airport stand. According to statistics, more than 70% of all flight delays caused by the airport are caused by improper airport resource scheduling; 15.45% of all flight delays are ground operations delays and cause flight departure delays [1,2]. It can be seen that the airport resource scheduling has an important impact on the various operations of the flight at the airport. In addition, the stand allocation plan is related to the operational safety of the airport. Improper scheduling may cause economic losses or casualties due to aviation accidents. In short, the airport stand is the core resource of the airport operation organization. The aircraft's various ground service operations (including passengers on and off flights, baggage loading and unloading, cabin cleaning, water filling, refueling, etc.) and the dispatching plan of the personnel required to complete the above operations are all developed on the basis of the machine seat allocation plan. Therefore, the establishment of a reasonable airport stand optimization allocation plan is of great significance for reducing airport operating costs and improving airport operating efficiency and service levels.

Stand provides a place for aircraft to park. When the stand assigned to an aircraft changes, the parking location of the aircraft changes accordingly, and the trailer scheduling scheme may change as well, which will result in changes in operational efficiency, operational costs and service quality for airports and airlines. In order to optimize the stand allocation plan, scholars at home and abroad have conducted comprehensive research. S. H. Kim [1] and other scholars construct an aircraft stand allocation model with the equilibrium of the three perspectives of the shortest travel distance for passengers, the smallest taxiing time for aircraft and the shortest conflict time for aircraft stand as the optimization objectives. C. Yu [2] and other scholars optimized flight towing cost, passenger transit walking distance and robustness of aircraft position allocation, constructed a multi-objective optimization of aircraft stand allocation model. S. Liu [3] and other scholars used the minimum idle time period and the minimum number of far aircraft stand as optimization objectives, constructed aircraft stand allocation model, and designed a genetic algorithm. W. Deng [4] and other scholars used the distance traveled by passengers; the variance of the idle time of the aircraft, the number of aircraft parked in the far aircraft and the utilization rate of the aircraft as the optimization objectives of the stand allocation, and solved them by adaptive particle swarm algorithm. S. Yang [5] used the minimum number of flights which location are in far stand, the minimum perturbation of the stand and the minimum passenger approach time as the optimization objectives of the stand allocation, and solved them by using the artificial raindrop algorithm. W. Deng [6] and other scholars designed an improved ant colony optimization algorithm to solve the optimization objectives of the stand allocation with the equalization of the stand idle time, the shortest travel distance of passengers and the minimum number of the far position. M. Bagamanova and M. M. Mota Proposed an innovative method of parking space allocation, combined with the advantages of Bayesian model and heuristic algorithm, and formulated a solution to the disturbance of airport flight schedule [7]. J. Lin, X. Ding, H. Li and J. Zhou constructed a multi-objective optimization model with the objective function as the highest utilization rate of the airport boarding gate, the smallest passenger transfer failure rate, and the least average passenger transfer time. The example data also verifies that the constructed model optimizes the boarding gate. Distribution, reducing the variance of relaxation time [8]. U. Benlic, E. K. Burke and J. R. Woodward used airport/airline service convenience and passenger comfort as the boarding gate assignment goal, and solved the objective function based on the heuristic algorithm of Breakout Local Search (BLS) [9]. S. Srinivas and S. Ramachandiran scholars proposed an online customer review (OCR) method to improve airline passenger satisfaction and airline competitiveness, using unsupervised text analysis methods to obtain airlines and their competitors from OCR The cost-effective and time-effective performance summary, and provide implications for post-pandemic preparedness in the airline industry considering the unprecedented impact of coronavirus disease 2019 (COVID-19) and predictions on similar pandemics in the future [10]. S. Rajendran, S. Srinivas and T. Grimshaw scholars use machine learning algorithms (MLA) to pass several factors related to the ride (such as the month of the year, the day of the week, and the time of day) and weather-related variables (such as temperature, weather conditions, and visibility) are used as predictors for four popular MLAs, namely logistic regression, artificial neural network, random forest, and gradient boosting to predict different times of the day in different geographic areas of New York city demand for air taxi urban air transportation (UAM) services. At the same time, the forecast results also provide reference for airlines to formulate efficient flight plans [11]. However, no scholars have considered passenger travel distance, stand utilization efficiency and airline cost at the same time. In this paper, we construct a multi-objective optimization model for the allocation of parking position in terms of the minimum travel distance of passengers, the maximum efficiency of parking position utilization and the minimum cost of airlines, and then solve it by using a simulation degradation algorithm. Finally, a domestic airport is used as an example to analyze and calculate the differences between the multi-objective optimized parking position allocation and the actual parking position allocation scheme of the airport.

2. Construction of airport stand pre-allocation model

According to the results of airport research, the airport operation command center (operation control center) is responsible for the allocation of parking position. In general, the airport operations command center arranges the positions before the arrival of the flight and adjusts the results of the positions allocation according to the operational situation during the operation. For example, the day before a flight is scheduled to arrive; the airport operations command center arranges for the next day's flight and then makes adjustments at any time according to the actual operating conditions. Therefore, there are two cases to be considered for the allocation of aircraft position. The first case is the overall allocation of aircraft positions, and the second case is the adjustment of aircraft positions during the operation. In this paper, the first case is called the pre-departure position allocation (before the early departure, it is necessary to arrange the position allocation for the whole day in advance), i.e., the pre-departure position allocation. The second case is called the post-early departure position allocation (after the early departure, the flight operation may operate according to the flight plan, or there may be delays and other situations that require the adjustment of the position). This paper focuses on the first case (airport parking position pre-allocation) and uses it to reflect the optimization objectives into the operational efficiency, operational cost, operational safety and service quality of airlines, airports and passengers.

In the process, note ar_f represents the arrival time of flight f, and de_f represents the departure time of aircraft$f$. A 0–1 decision variable $x_{f,a}$ is introduced. If flight f stops at parking position a,

$x_{f,a} = 1$, otherwise $x_{f,a} = 0$. The time of stay at the flight position is described with Eq (1):

$$t_{f,a} = x_{f,a}(ar_f - de_f) \tag{1}$$

In actual operation, each parking position serves multiple flights in sequence. When an aircraft occupying a position is pushed out of the position, other aircraft can occupy the position. Therefore, for a certain position, its position occupancy time t_a is described with Eq (2):

$$t_a = \sum_f x_{f,a}(ar_f - de_f) \tag{2}$$

Airports have a limited number of parking position, so a proper arrangement of parking position can improve the operational efficiency of the airport. In a certain time period, flights should be arranged in the least number of parking position as much as possible. For example, small aircraft should not occupy wide body aircraft position as much as possible, and aircraft with long parking time should not occupy near position as much as possible. The utilization rate of the near-airport corridor is also an important index of the operational efficiency of an airport. For the parking position utilization, where T is the total time, then the objective function considering the parking position utilization can be expressed as Eq (3):

$$Z_1 = \max\left(\sum\nolimits_f x_{f,a} \quad (ar_f - de_f) \;/T\right) \tag{3}$$

Passengers can be roughly divided into arriving passengers and departing passengers. For arriving passengers, the distance from the security position to the aircraft is considered. For near-airport passengers, the walking distance is the distance from the security position to the boarding position plus the distance from the boarding position to the aircraft. For near-arrival passengers, the distance from the position to the aircraft can be considered as the length of the bridge since passengers get on and off the aircraft through the bridge. For the far-airport passengers, the distance traveled by passengers is the distance from the security position to the boarding position plus the distance from the boarding position to the airplane, because for far-airport passengers, they get on and off the airplane through the ferry and the passenger lift car, so the distance from the boarding position to the airplane for the far seat passengers can be considered as the distance traveled by the shuttle bus. The meanings of variables are as follows:

$l_{f,de}$ is the distance traveled by passengers arriving at the port;

$l_{k,g}$ is the distance from the security position k to the boarding position g;

l_{lb} is the length of the bridge;

$l_{g,a}$ is the distance from the boarding position g to the parking position a;

$n_{f,de}$ is the number of departing passengers;

$x_{f,g}$ is decision variable, if boarding positions g are arranged for flight f,$x_{f,g} = 1$ otherwise $x_{f,g} = 0$;

$x_{g,a}$ is decision variable the boarding position g corresponds to the position a, then, $x_{g,a} = 1$, otherwise, $x_{g,a} = 0$.

The distance traveled by departing passengers on flight f is described with Eq (4):

$$l_{f,de} = n_{f,de}[\sum_{g} x_{f,g} l_{k,g} + \sum_{a} \sum_{g} x_{g,a} x_{f,a} (g_a l_{lb} + u g_a l_{g,a})] \tag{4}$$

For arriving passengers, the distance traveled by passengers is the distance from the aircraft to the terminal plus the distance from the terminal to the exit. If the aircraft is parked near the aircraft, then the distance from the aircraft to the terminal can be considered as the length of the corridor. If the aircraft is parked in a far position, then the distance from the aircraft to the terminal can be considered as the distance travelled by the shuttle bus. The meanings of variables are as follows:

$l_{f,ar}$ is the distance traveled by passengers arriving at the port;

l_a is the distance from the position a to the terminal building;

l_e is the distance from the terminal building to the exit;

$l_{g,e}$ is the distance from the bridge entrance (boarding position, divided into upper and lower floors, the departure passenger walks on the upper floor, the arriving passenger Go downstairs) to the exit;

$n_{f,ar}$, is the number of passengers arriving on the flight f;

The travel distance of arriving passengers is described with Eq (5):

$$l_{f,ar} = n_{f,ar}[n g_a (\sum_{a} (x_{f,a} l_a) + l_e) + g_a (l_{br} + \sum_{a} x_{f,a} x_{g,a} l_{g,e})] \tag{5}$$

Then, the objective function of the smallest travel distance of passengers can be expressed as Eq (6):

$$Z_2' = min \sum_f (l_{f,de} + l_{f,ar}) \tag{6}$$

Since a passenger on a flight may go through security from any of the security checkpoints, it can be assumed that a passenger randomly chooses a security checkpoint to go through security, then the probability of a passenger passing through each security checkpoint is the same. Without considering which security checkpoint the passenger passes through and without considering the way the passenger gets on the plane, the distance from the security checkpoint to the position a is L_a^{de}. Similarly, without considering the way passengers get off the plane to reach the exit, the distance from the aircraft position a to the exit is recorded L_a^{ar}, then the objective function of the smallest travel distance of the passenger can be simplified as Eq (7):

$$Z_2 = \sum_f \left(n_{f,de} \sum_a x_{f,a} L_a^{de} + n_{f,ar} \sum_a x_{f,a} L_a^{ar} \right) \tag{7}$$

When arranging parking position, there will be some “special requirements” aircraft that will be parked at one or a certain type of designated parking position. For example, some aircraft need to be parked in the hangar attachment, some aircraft need to be parked on the cargo apron, and some aircraft may need to wait by bridge. Introduce a 0–1 decision variable y_f, $y_f = 1$ means that the aircraft f has a designated seat requirement, the designated position is a_f, otherwise$y_f = 0$; introduce a 0–1 decision scalar y_{f,a_f}, the flight is arranged on the position a_f, $y_{f,a_f} = 1$, otherwise $y_{f,a_f} = 0$. Then the objective function can be expressed as Eq (8) :

$$Z_3 = max \sum_f y_f y_{f,a_f} \tag{8}$$

In actual operation, in addition to the efficiency of the use of stand, parking requirements and passenger walking distance also need to consider the cost of airline position use. Close to the aircraft can save the cost of passenger elevators and shuttle buses. The flight can leave the airport as soon as possible after the flight is ready, which can reduce the parking fee. The cost of parking for a wide-body aircraft is twice as high as that for a narrow-body aircraft. Here set the airline cost required for flight f to be arranged on the position a_f as h_{f,a_f}. According to the cost of the position occupied by the flight, set the minimum total cost of the airline required to park the flight as the objective function and the objective function can be expressed as Eq (9):

$$Z_4 = min \sum_f h_{f,a_f} \tag{9}$$

Then the total objective function can be expressed as Eq (10):

$$Z' = Z_1 + Z_2 + Z_3 + Z_4 = \beta_1 \min \left(-\sum_f x_{f,a} \ \ (ar_f - de_f) \ /T\right) + \beta_2 min \sum_f \big(n_{f,de} \sum_a x_{f,a} L_a^{de} + n_{f,ar} \sum_a x_{f,a} L_a^{de}\big) + \beta_3 \min \left(-\sum_f y_f y_{f,a_f}\right) + \beta_4 min \sum_f h_{f,a_f} \tag{10}$$

For every flight arriving at the port, a position must be allocated. Once the aircraft is assigned to a position, it will no longer be able to be placed in other positions. Therefore, for an aircraft, its position is unique. Therefore there are constraints as Eq (11):

$$\sum_a x_{f,a} = 1 \, , \quad \forall f \in F \tag{11}$$

Aircraft can be arranged in the same stand in sequential order when certain conditions are met. For multiple aircraft arranged in the same position in sequential order, they form a queue and enter and exit in chronological order. Introduce decision variables $Z_{i,j,a}$, $i,j \in F$which represents aircraft and a represents the position. If the flight i and flight j are assigned to the stand k, and when flight i is the first flight before flight j, or flight j is the first flight after flight i (the next flight), $Z_{i,j,a} = 1$, otherwise $Z_{i,j,a} = 0$. For a flight, there is at most one flight immediately following it (flight immediately following), and at most one flight immediately preceding it (flight immediately preceding). The constraint conditions can be expressed as Eqs (13) and (13):

$$x_{i,a} \geq \sum_{j,j \neq i} z_{i,j,a} \tag{12}$$

$$x_{j,a} \geq \sum_{i,i \neq j} z_{i,j,a} \tag{13}$$

If two aircraft are placed in the same position one after another, then these two aircraft are called immediate neighbors. There should be enough time intervals between the immediately following aircraft so as to ensure that the free time can be left after the previous aircraft comes out from the position. On the one hand, it can leave time for the aircraft immediately after it to enter the position smoothly, on the other hand, this free time can avoid adjusting the position in case of slight delay of the flight and play a buffer role. Set the time interval between two aircraft as λ, the constraint condition can be expressed as Eq (14):

$$x_{j,a}ar_j - x_{i,a}de_i \geq \lambda z_{i,j,a} \tag{14}$$

Potential conflicts should be avoided when arranging stand. During operation, if the following three situations occur: 1) Aircraft at adjacent stand are pushed out of at the same time, 2) Aircraft at adjacent stand are pushed out of at the same time, 3) If the aircraft in adjacent stand is pushed out and pushed in, it may cause conflicts, thereby increasing the risk of collisions between aircraft. Recorded γ_1 as the arrival and departure time interval between two aircraft on two adjacent aircraft positions, γ_2 is the departure time interval between two aircraft on two adjacent aircraft positions, and γ_3 is the arrival and departure time interval between two aircraft Port time interval. Constraints can be expressed as Eq (15):

$$\begin{gathered}\left|x_{f,a}ar_f - x_{f',a+1}de_{f'}\right| \geq \gamma_1 x_{f,a}x_{f',a+1} \\ \left|x_{f,a}de_f - x_{f',a+1}de_{f'}\right| \geq \gamma_2 x_{f,a}x_{f',a+1} \\ \left|x_{f,a}ar_f - x_{f',a+1}ar_{f'}\right| \geq \gamma_3 x_{f,a}x_{f',a+1}\end{gathered} \tag{15}$$

Then, the parking position pre-allocation model can be sorted into Objective function: $Z = Z'$

Then the parking position pre-allocation model can be expressed as Eq (16):

$$Z = \beta_1 \min\left(-\left(\sum_f x_{f,a}\left(ar_f - de_f\right)/\mathrm{T}\right)\right) + \beta_2 min \sum_f \left(n_{f,de}\sum_a x_{f,a}L_a^{de} + n_{f,ar}\sum_a x_{f,a}L_a^{de}\right) + \beta_3 max \sum_f y_f y_{f,a_f} + \beta_4 min \sum_f h_{f,a_f} \tag{16}$$

Restrictions can be expressed as Eq (17):

$$\begin{cases}\sum_a x_{f,a} = 1, \forall f \in F \\ x_{i,a} \geq \sum_{j,j\neq i} z_{i,j,a} \\ x_{j,a} \geq \sum_{i,i\neq j} z_{i,j,a} \\ \left|x_{f,a}ar_f - x_{f',a+1}de_{f'}\right| \geq \gamma_1 x_{f,a}x_{f',a+1} \\ \left|x_{f,a}de_f - x_{f',a+1}de_{f'}\right| \geq \gamma_2 x_{f,a}x_{f',a+1} \\ \left|x_{f,a}ar_f - x_{f',a+1}ar_{f'}\right| \geq \gamma_3 x_{f,a}x_{f',a+1}\end{cases} \tag{17}$$

3. Solve by simulated annealing algorithm

The following Figure 1 shows the solution process of the simulated annealing algorithm:

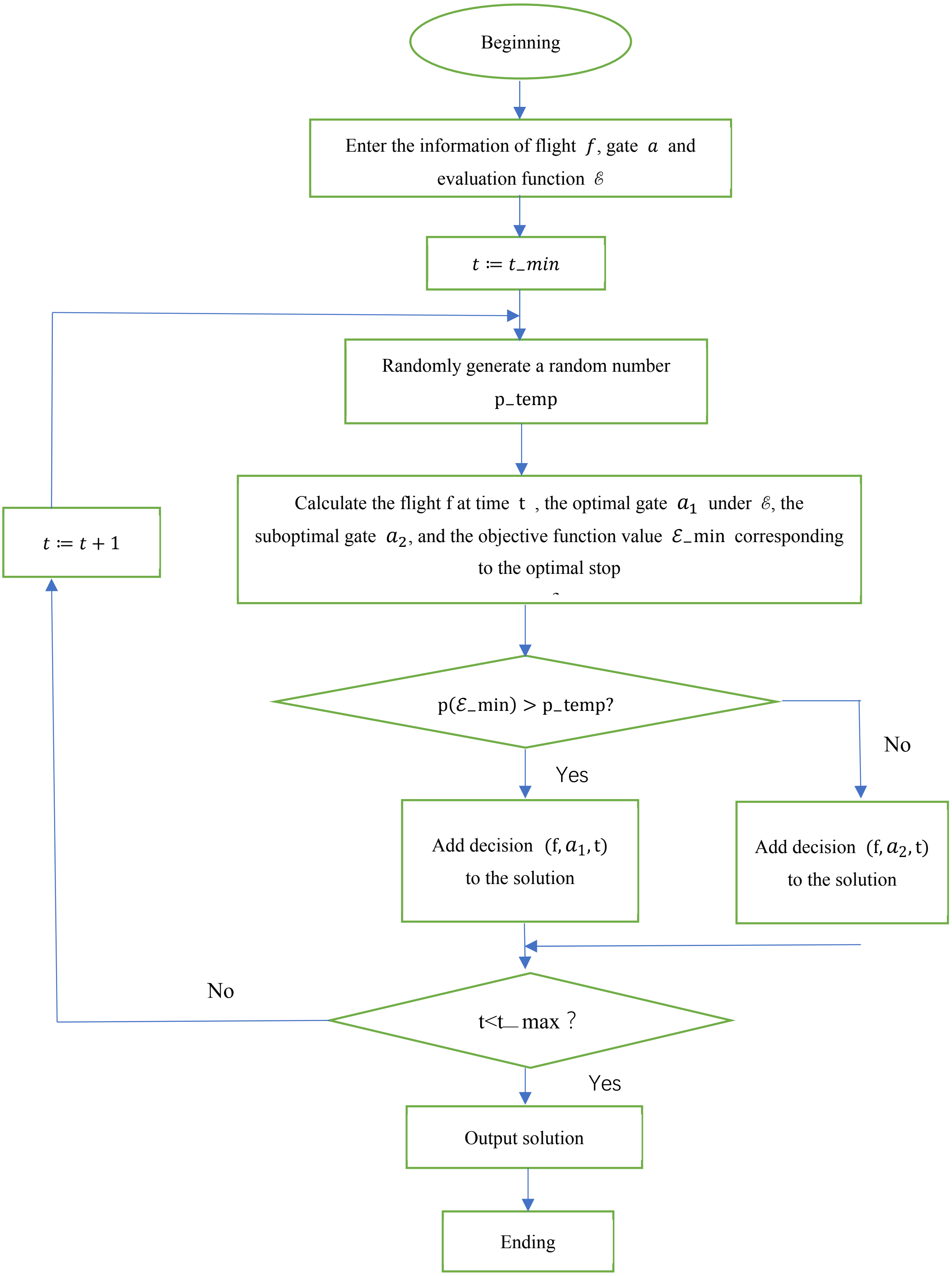

Figure 1. Flow chart of position allocation algorithm based on simulated annealing algorithm program calculation steps.

In order to solve the pre-allocation model of airport positions, a simulated annealing algorithm with faster convergence speed is used here [12]. The simulated annealing algorithm (simulated annealing, SA) was successfully introduced into the field of combinatorial optimization by scholars such as S. Kirkpatrick as early as 1983 [13]. The principle of simulated annealing algorithm is derived from the annealing process of solid matter in physics. It is first heated to make the particles move freely, and then the particle system is reduced in temperature at a slow enough speed. At this time, the speed is slow enough, and the system is approximately in thermodynamic equilibrium at last, the particle system will reach its own lowest energy state, the ground state, which is equivalent to the global minimum point of the energy function [14,15]. The objective function of the optimization problem is equivalent to energy, and the optimal solution is equivalent to the lowest energy state. The simulated annealing algorithm searches for random changes from one state to another at a given temperature, and uses a random acceptance criterion for judgment. When the temperature drops slowly to a very low level, it stays on the optimal solution with probability 1 [16]. For a specific position allocation problem, first, establish a function $\mathcal{E}(f_i, a_j, t_{i,j})$ from flight f_i, position a_j and parking time $t_{i,j}$ to the target value. The return value of this function is evaluation of flight f_i at time Stopping$t_{i,j}$ at the position a_j is the key to decision-making. The next step is to use the simulated annealing algorithm to advance in accordance with the time, making selections at each step, until the entire program is finally reached.

Step1: Enter the landing and take-off time of the flight, the function $\mathcal{E}(f_i, a_j, t_{i,j})$ of the aircraft model and target value adapted to each position, where f_i represents the flight, a_j represents the stand and $t_{i,j}$ represents the stand time.

Step2: Select the time of the first landing flight as t_min, and set $t = t\_min$.

Step3: Generate a pseudo-random number p_temp through a 0–1 uniformly distributed pseudo-random number generating function.

Step4: For the flight f landing at time t, filter out the optimal stand a_1 and its target value $\mathcal{E}$ and the second best stand a_2.

Step5: Calculate $\mathrm{P} = e^{-\frac{\varepsilon}{T(t)}}$, where T(t) is a decreasing function with respect to time. If $P > p\_temp$, add $(\mathrm{f}, a_1, \mathrm{t})$ to the solution, otherwise, add $(\mathrm{f}, a_2, \mathrm{t})$.

Step6: If $t < t\_max$, set $t = t + 1$, return to Step3, otherwise, output the solution. Here t_max is the departure time of the last flight.

From the above calculation steps, we know that as an adjustable parameter, in addition to the initial value of the annealing temperature, there are three weight coefficients in front of the standardized objective function. The initial annealing temperature determines the possibility of selecting the optimal solution in the initial stage, and the weight coefficient determines the importance of the corresponding objective function value. For the annealing temperature, we can draw the following curve between the normalized total objective function value and the initial annealing temperature. In view of the strong randomness of the SA algorithm, the logarithmic scale we use is from 1.0 to 10^{50}. Each time the difference is $10^{0.5}$ times, calculate 100 times at each initial temperature point and take the average value to get the average total objective function value. In Figure (2), we fixed the three weighting coefficients to be 1.0.

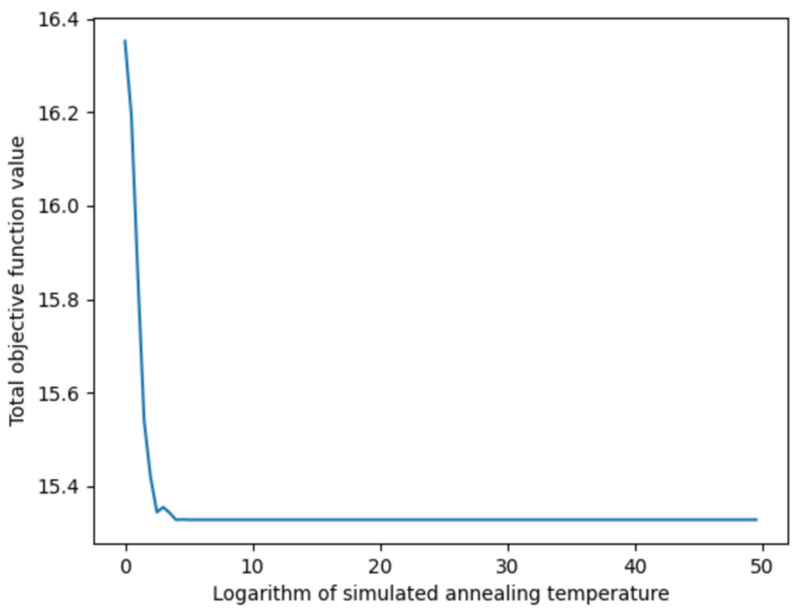

Figure 2. The relationship between the initial annealing temperature and the value of the standardized total objective function when the weight coefficients of the sub-objective function are all 1.

In Figure 3, we consider the three weighting coefficients to be 1.0, 2.0 and 0.0 respectively, and then draw the curve.

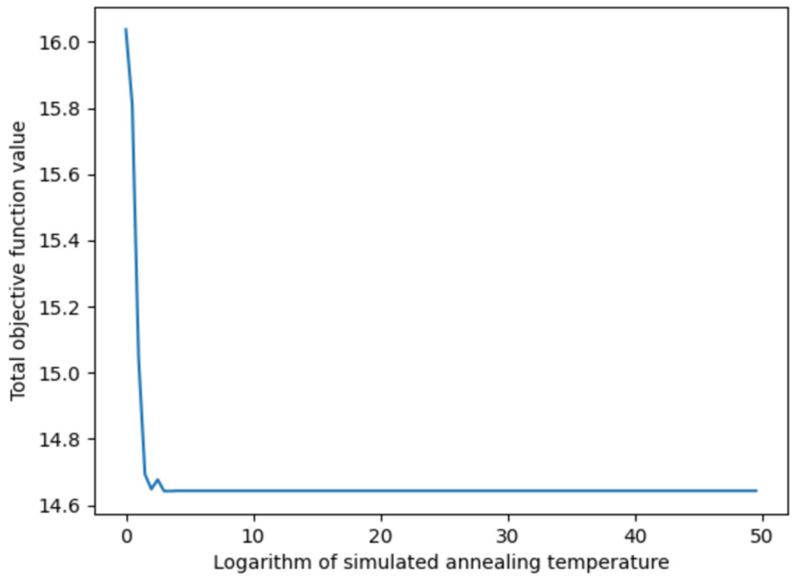

Figure 3. When the sub-objective function weights are 1, 2 and 0, the initial annealing temperature and the standardized total objective function value.

Combining Figures 2 and 3, here we choose the annealing temperature to be 100.0, at this time there is a greater probability of obtaining a better solution. As for the larger case, the impact of the sub-optimal solution on the result becomes small, losing the meaning of simulated annealing, and more like a greedy algorithm. The choice of the three weighting factors, because the problem to be considered in the research is to take into account the three factors, and none of the factors can be discarded. The final result is to set the three weights to equal 1.0.

4. Application analysis

Here we choose Lanzhou Zhongchuan International Airport as an example to perform model simulation verification calculations. The airport has 59 stands, 16 near stands (with bridges), 43 far stands, and numbers 101–116 are near stands, Numbered 201, 203, 205, 207, 209, 211, 213, 215, 227, 229, 231, 233, 235, 237, 301–308 are far stands. The floor plan of the airport apron layout is shown in Figure 4:

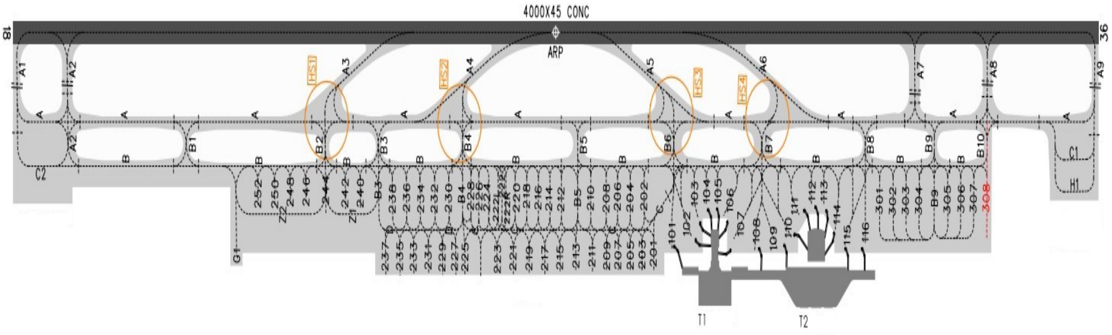

Figure 4. The floor plan of the airport apron.

Restrictions on the use of stands at Lanzhou Zhongchuan international airport:

1) Parking restrictions near the aircraft in T1 terminal

101, 102, 106, 107 can park wide-body machines; 103, 104, 105 can only park narrow-body aircrafts

2) Parking restrictions near the aircraft in T2 terminal

108, 109, 111, 114, 115, 116 can park wide-body aircrafts, 110, 112, 113 can only park narrow-body aircrafts

3) Restrictions on parking at far stands

208, 210, 211, 215, 308 can park wide-body aircrafts, 201–207, 209, 212–220, 222, 224, 226–238, 301–307 can only park narrow-body aircrafts.

According to the "civil airport charge reform implementation plan" promulgated by the civil aviation administration of China in 2007, the airport stand charge stipulates that a single bridge is charged 100 yuan for parking fees within 1 hour; 50 yuan per half hour for more than 1 hour; half hour for less than half an hour toll. The passenger elevator fee is 45 yuan per hour, and the shuttle bus is 55 yuan per hour. Aircraft parking at the parking lot also need to charge parking fees. According to the "Civil Airport Charge Reform Implementation Plan", the parking fees are related to the take-off weight of the aircraft and the category of the airport. In this article, the parking time is less than 2 hours. Parking fees are waived. For flights with a parking time of more than 2 hours and less than 24 hours, the parking fee will be calculated according to 24 hours. The situation where the airport is parked for more than 24 hours is not considered here; cf values 1, 2 and 3 respectively represent the aircraft's small size, Medium and large, the flight's landing fee is 1000cf, and the parking fee is calculated at 10% of the landing fee.

The allocation of airport stand mainly considers the matching degree of the aircraft type. The wide-body passenger aircraft carries more than 300 passengers, has an outer diameter of 5–6 meters, and has two channels. One row can accommodate 7–10 seats, and the narrow body Passenger planes can carry between 100–200 passengers, the diameter of the fuselage of the plane is 3–4 meters, and a row of cabins generally has 2 to 6 seats and an aisle. The classification of passenger planes commonly used in civil aviation of china [11]:

1) Representative models of wide-body passenger aircraft include: B747, B777, A300, A340, etc.;

2) Representative models of narrow-body passenger aircraft include: B737, Canadian CRJ series (CRJ200, etc.), Brazil ERJ series (ERJ135, etc.), B737, A320 series (including A319, A320, A321, etc.)

Taking into account the comparison with the actual data of the airport, here we choose the stand commonly used in the airport for allocation. Therefore, we choose the nearest seats of the T1 and T2 terminals of Lanzhou Zhongchuan International Airport near the bridge for allocation. At present, the airport has 16 nearby seats. Here, suppose that 4 planes have been parked at stands 103, 106, 108, and 115 respectively, and the other 12 flights are about to arrive. Allocate 12 flights to the remaining 12 near positions, simulation time 01 December 2019 11:00 to 17:00, Among them, $\beta_1 = \beta_2 = \beta_3 = \beta_4 = 1$, the 12 flight schedule data is shown in Table 1.

Table 1. The 12 flight information table of the selected airport.

	flight	type	ETA	Stop time	Departure airport	Destination airport
F_1	SC8741	B737	11:15	1.5 h	Qingdao	Lanzhou
F_2	TV6011	A320	11:45	2 h	Yantai	Lanzhou
F_3	UQ2520	B737	12:00	3 h	Changsha	Lanzhou
F_4	CA1221	A319	12:15	2 h	Beijing	Lanzhou
F_5	CZ3919	A321	12:35	4 h	Shenzhen	Lanzhou
F_6	FU6568	B737	11:15	2 h	Haihou	Lanzhou
F_7	SC8732	B737	13:05	2.5 h	Chongqing	Lanzhou
F_8	FM9213	B737	13:25	3.5 h	Hongqiao	Lanzhou
F_9	JD5824	A320	13:36	1.5 h	Kunming	Lanzhou
F_{10}	ZH9240	B737	12:47	1 h	Urumqi	Lanzhou
F_{11}	GS6651	B777	13:43	2 h	Hohhot	Lanzhou
$F1_2$	GS7877	A320	13:50	1.5 h	Tianjin	Lanzhou

The calculation will use the passenger flow information of the connecting flight, as shown in Table 2 and the distance between the boarding positions near the boarding position, as shown in Table 3:

Table 2. The passenger flow matrix for different positions.

	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116
F1	7	6	12	8	5	0	2	0	5	10	3	1	0	0	15	4
F2	13	0	5	7	10	12	0	4	1	16	2	5	1	13	2	4
F3	3	5	7	6	4	0	0	2	23	12	3	4	6	14	3	7
F4	5	6	2	1	0	0	13	4	5	18	17	16	15	4	2	3
F5	3	15	6	2	12	0	0	5	13	0	2	6	4	3	2	4
F6	0	3	1	2	0	4	3	14	0	4	0	8	6	2	0	2
F7	12	3	5	7	8	2	5	4	0	2	0	0	5	4	3	4
F8	3	7	6	1	4	6	5	0	12	1	2	4	5	3	7	12
F9	0	9	15	0	0	6	14	7	9	2	5	2	1	0	15	14
F10	2	6	0	14	5	2	2	2	5	0	12	5	0	14	4	2
F11	3	5	0	3	3	0	3	3	2	1	5	2	2	2	1	2
F12	4	0	6	0	1	5	7	8	0	5	0	4	1	3	8	0

Table 3. The distance matrix from walking to different parking positions.

	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116
101	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
102	10	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140
104	30	20	10	0	10	20	30	40	50	60	70	80	90	100	110	120
105	40	30	20	10	0	10	20	30	40	50	60	70	80	90	100	110
107	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80	90
109	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70
110	90	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60
111	100	90	80	70	60	50	40	30	20	10	0	10	20	30	40	50
112	110	100	90	80	70	60	50	40	30	20	10	0	10	20	30	40
113	120	110	100	90	80	70	60	50	40	30	20	10	0	10	20	30
114	130	120	110	100	90	80	70	60	50	40	30	20	10	0	10	20
116	150	140	130	120	110	100	90	80	70	60	50	40	30	20	10	0

The optimal allocation plan of the model using the simulated annealing algorithm and the actual pre-allocation plan of the airport are shown in Table 4:

Table 4. Positions allocation for 12 flights-comparison between model calculation results and actual airport allocation results.

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}	F_{12}
Model calculation results	105	104	112	111	113	110	107	110	109	105	102	105
Airport actual distribution plan	114	107	112	111	105	110	104	110	109	113	102	113

In order to facilitate the comparison between the model allocation plan after the multi-objective optimization and the actual airport allocation plan, the total objective function value of the multi-objective optimization is standardized here. The standardization method is as follows:
Standardized result = (actual value-minimum)/(maximum-minimum)

Table 5. Standardized total objective function value and pre-standardized target value of the model allocation plan and the actual airport allocation plan.

	Total objective function value after normalization	Total distance traveled by passengers before standardization	Total positions utilization efficiency before standardization	Total airline cost before standardization
Model allocation plan	15.3285	35908 step	9.0937	6550 Yuan
Airport actual distribution plan	25.7926	40420 step	8.7812	6850 Yuan

The model calculation results with the actual airport allocation data, as well as the calculated data for the total objective function values after normalization and the sub-objective function values before normalization are shown in Table5.

The calculation results show that the model constructed after numerical normalization calculates a stand allocation scheme that is 40.67% lower than the total objective function value of the actual airport allocation scheme. In which, the passenger walking distance is reduced by 4512 steps, the model allocates one less parking position, the stand usage efficiency is increased by 31%, and the airline cost is reduced by $300.

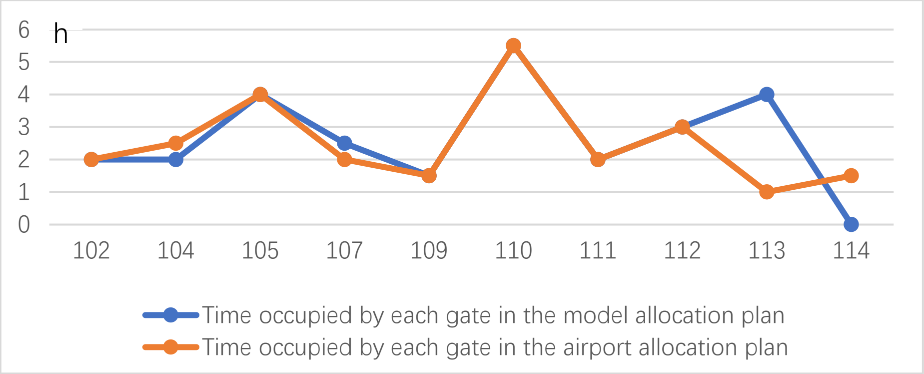

Figure 5. Comparison of positions occupancy time allocated for 12 flights of the two plan.

From Figure 5, it can be seen that the model allocation scheme does not occupy the parking position 114 compared with the actual airport allocation scheme, thus saving the airport stand resources. At the same time, the model allocation scenario has higher occupancy time for stand107 andstand 113 than the actual airport allocation scenario. In particular, the occupancy time of 113 is higher than that of the actual airport allocation scheme by 3 hours.

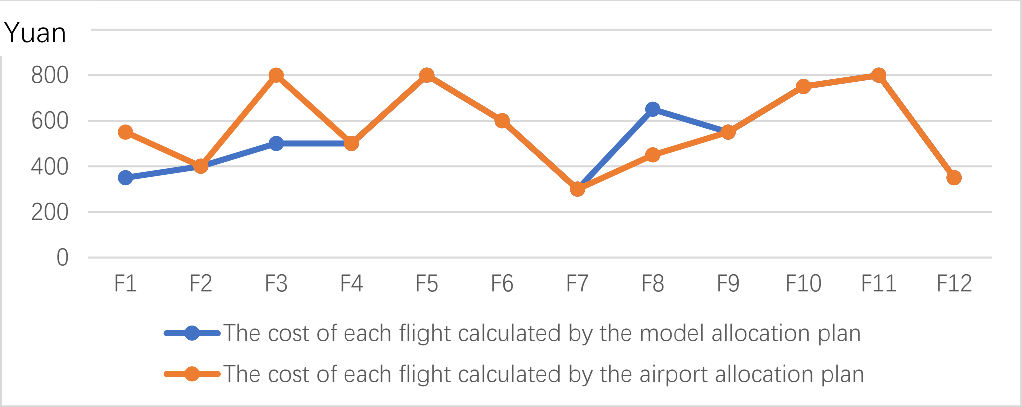

Figure 6. Comparison of the cost of 12 flights between the two plan.

From Figure 6, it can be seen that the airline cost of F1 and F3 flights in the model allocation plan is lower than the actual airport allocation plan. In particular, the airline cost of F3 flights in the model allocation plan saves 300 yuan compared with the actual airport allocation plan.

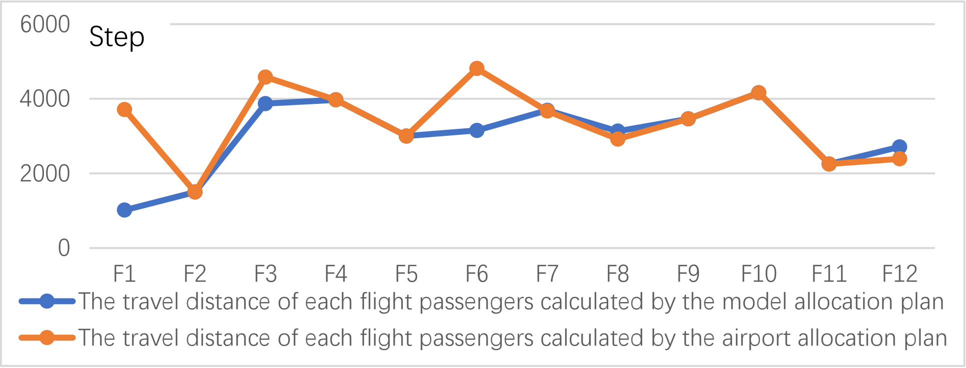

Figure 7. Comparison of travel distances of 12 flights between the two plan.

From Figure 7, it can be seen that the passenger walking distance for flights F1, F3 and F6 in the model allocation scheme is significantly lower than the actual airport allocation scheme. Among them, the passenger walking distance of flight F1 is lower than the actual airport allocation scheme by 2692 steps, which is convenient for passengers and also improves the service quality of airlines.

Through the research of this case, an example of 12 flights at Lanzhou Zhongchuan International Airport is cited for model application analysis. The results of the calculation using the simulation degradation algorithm show that the total objective function of the model allocation scheme is 40.67% lower than that of the actual airport allocation scheme, in which the model allocation scheme has 4512 fewer steps than the actual airport allocation scheme in terms of passenger travel distance. In terms of airline cost, the model allocation scheme is 300 yuan lower than the actual airport allocation scheme. In stand usage efficiency, the model allocation scenario has 1 less stand than the actual airport allocation scenario. Meanwhile, the occupancy time of stand 113 in the model allocation scheme is higher than that of the actual airport allocation scheme by 3 hours, which not only reduces the number of stands used, saves parking resources, but also improves the efficiency of using some stands.

5. Conclusions

A mathematical model with the shortest travel distance for passengers, the lowest cost for airlines and the efficiency of stand usage as the optimization objective is constructed, and the simulated annealing algorithm was used to solve the optimization model. At the same time, through the application of the actual case of Zhongchuan international airport, the calculation results showed that the parking space model constructed in this paper and the actual parking space allocation of the airport. Compared with the scheme, it reduces the travel distance of passengers by a total of 4512 steps, reduces the airline cost by 300 yuan, saves 1 parking space, and at the same time saves parking space resources and improves the utilization efficiency of the parking space. The model studied in this paper can better optimize passenger travel distance, airline cost and stand usage efficiency. In summary, this study has high practical application value and is expected to be used in airport stand pre-allocation decision in the future.

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Conflicts of interest

There is no conflict of interest to declare.

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