Analysis on the Allocation Optimization of Airport Baggage Turntable

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Abstract. The rapid growth of my country's civil aviation passenger traffic has led to increasingly tight operating resources in the terminal. In order to optimize the operating efficiency of the baggage turntable for arriving passengers, the simulated annealing algorithm is used in the baggage claim carousel allocation. According to the set objective function model, the simulated annealing algorithm solution process is designed and the solution process is simulated. According to the comparison between the obtained results and the results of the first-come-first-served distribution method, it is shown that the simulated annealing algorithm has a better result than the first-come, first-served distribution method and meets the target requirements. It provides a way to alleviate the airport baggage claim carousel allocation problem and a feasible way to use efficiency.

Keywords: terminal building, passenger baggage turntable, simulated annealing algorithm, passenger baggage

1. Introduction

Since the reform and opening up, the rapid economic growth of our country has led to the great development of the aviation industry. From 2000 to 2019, my country’s airport passenger traffic increased from 67,216,600 to 65,993,400, and the annual air passenger traffic increased by more than 10.4% year-on-year [1]. At present, most of the airport baggage claim carousels in my country basically maintain their original scale, and the increase in throughput has aggravated the difficulty and complexity of the baggage claim problem. Therefore, optimizing the baggage claim problem is of great significance to airlines and airports.

Rogers Lui, Ravinder Nanda and James J. Browne [2] developed a computer simulation model to analyze the passenger and baggage flow in the International Arrivals Building (IAB) at JFK International Airport in New York. Through analysis, Martel and Seneviratn[3] found that the relevant factors affecting the service level of the baggage claim area are mainly system processing time, fluctuations in service level, area setting, passenger density per area, baggage claim conveyor belt and claim capacity, auxiliary resources The installation of equipment and lanes. After studying the baggage claim area, De Neufville and Odoni [4] found that the baggage claim carousel is the most critical factor in the operation efficiency of the baggage claim area relative to the area and layout of the baggage claim area. De Barros and Wirasinghe [5] studied the planning of the baggage claim area...
in the paper, and provided a calculation method to determine the area used by the new large aircraft passengers in the baggage claim area at that time. And found that the luggage of tourists traveling in groups has an important impact on the luggage claim area. Lu Xun, Zhu Jin-fu, Tang Xiao-wei [6] calculated the length of the passenger baggage claim carousel based on the existing static baggage claim carousel model, which could not meet the current increase in the number of flights, and did not consider the difference in aircraft type, passenger load factor and the amount of luggage carried by passengers. A multi-flight and multi-baggage claim model is proposed. Later, Lu Xun [7] conducted an in-depth analysis in the baggage claim area, and obtained the optimized baggage claim carousel allocation method through the constructed baggage claim model and simulation solution. Dong Jing-feng [8] found that when the luggage was placed on the turntable, it was not neatly placed, which made it difficult to retrieve the luggage and slowed the speed of luggage handling. Therefore, a calculation method of luggage image preprocessing, handle recognition, angle calculation and rotation is proposed to design a scanning and recognition rotating device for checked luggage, which can rotate the luggage handle to face the passenger.

From the above research results, it can be found that in the baggage claim area, the baggage claim carousel is gradually analyzed, because the operation problem of the baggage claim carousel has an important impact on the operating efficiency of the baggage claim area and is related to the overall operating efficiency. It is very necessary to extract the carousel allocation research. Therefore, this paper uses the simulated annealing algorithm to optimize the baggage claim carousel allocation problem, and the calculation results are analyzed with examples to verify the effectiveness of the algorithm designed in this paper.

2. Model establishment

2.1. Assignment method of baggage claim carousel

At present, there are two common ways to assign baggage turntable at airports: one-to-one mode, that is, one flight is for one baggage turntable; one-to-many mode, where one baggage turntable is assigned to multiple flights. The current airport is mainly a combination of these two methods, so this article assumes that the baggage turntable allocation is based on these two methods.

2.2. Establishment of objective function

Based on the baggage allocation method of the flight, it is concluded that the passengers on the flight will also go to the corresponding carousel to wait for their baggage. Therefore, the balance when the flight is allocated to the turntable is the first to alleviate passenger congestion, avoid excessive baggage on a certain turntable, and improve operational efficiency. To be considered. Therefore, the objective function of the carousel assignment problem in this paper is the load balance of the baggage claim carousel [7], and the proposed baggage carousel allocation model is as follows:

\[
f = \min_{j \in V} \max_{i \in U} \sum_{i \in U} X_{ij} V_i\]

s.t. \[\sum_{j=1}^{N} x_{ij} = 1, \forall i \in U, \quad x_{ij} \in \{0,1\}\]

\[\sum_{i \in I} x_{ij} v_j \leq v_{\max}, k \in U, j \in V\]

Equation (1) indicates that the number of baggages on the turntable with the largest number of baggages is as small as possible to achieve the goal of balancing the load of each pickup carousel.
Equation (2) means that each arriving flight can only be allocated on one turntable, and the value is 0 or 1. The baggage of the \( i \)-th flight is considered. If it is allocated to the \( j \)-th carousel, then it is equal to 1, otherwise, it is 0.

Equation (3) shows that in the same time period, a carousel will be occupied by many flights, but the total number of luggage should be lower than the maximum capacity of a turntable.

\[ I_i = \{ p \in U | (p - T_i < 15, p \geq 15) \}, T_i \in U \]

Refers to the arrival time of the \( i \)-th flight, and \( I_i \) refers to the collection of all flights with a difference of less than 15 min between the arrival time of the \( k \)-th flight. Suppose the time taken for a flight to occupy the carousel is 15 minutes.

In this model, the symbols and parameter definitions used are as follows:

- \( U \): Assemble inbound flights within the designated time slot \( T \), \( |U| > 0 \), \( U = \{1, 2, \ldots, M \} \);
- \( V \): Baggage carousel collection can be used in the designated time period \( T \), \( |V| > 0 \), \( V = \{1, 2, \ldots, N \} \);
- \( T_i \): The arrival time of the \( i \)-th flight, \( i \in U \);
- \( v_i \): The number of checked luggage on the \( i \)-th flight, \( i \in V \);
- \( v_{\text{max}} \): The maximum number of baggages that the baggage claim carousel can provide services at the same time within 15 minutes. According to relevant regulations, the number of baggages set by this research is 300 pieces.

3. Design of simulated annealing algorithm for turntable distribution

3.1. Simulated Annealing Algorithm for Assignment Problem

The simulated annealing algorithm (SA) is a general probability algorithm, which was first proposed by Metropolis et al. in 1953 [9]. The principle is similar to that of solid annealing, and the relationship is shown in Table 1. The temperature of the solid to be heated is slowly cooling down. During the cooling process, the particles gradually tend to be ordered, the internal energy decreases, and finally the minimum internal energy reaches a stable ground state at room temperature. When the algorithm terminates, the minimum current solution saved is the optimal objective function value sought. The baggage carousel allocation problem is an NP-hard problem. If the traditional problem can only be solved with special characteristics, the amount of calculation and difficulty will be greatly increased. Therefore, it becomes more and more important to use faster methods to solve such problems. Kirkpatrick et al. introduced the simulated annealing algorithm to the field of combinatorial optimization for the first time in 1983. Because it can effectively approximate the NP-complexity problem, it overcomes the shortcomings of other optimization algorithms that are easy to fall into local optimality and have no strong dependence on initial values. In theory, it is a global optimal algorithm. Based on this, a simulated annealing algorithm will be designed to solve this problem.

### Table 1. Principle relationship

| Physical annealing | Simulated annealing |
|--------------------|---------------------|
| Particle state     | Solution            |
| Lowest energy state| Optimal solution    |
| Dissolution process| Set the initial temperature |
| Isothermal process | Metropolis sampling process |
| cool down          | Decline of control parameters |
| energy              | Objective function  |

3.2. Simulated annealing algorithm implementation

3.2.1. Initial solution. The initial solution in this paper is generated by random number generation. Using the random number generation program in Matlab, a matrix with a row and forty columns with a
value of 1-6 is randomly generated. In this way, one flight can only be allocated to one baggage turntable. The upper constraint is the constraint formula (2).

3.2.2. Objective function design. It can be seen from the constraint formula (3) that within 15 minutes of adjacent flights of a carousel, the total baggage quantity of each flight should be less than 300 pieces. Therefore, a penalty function is introduced. When the constraint is not met, the objective function value will be punished, so that the value of the objective function becomes very large, making the probability of being selected extremely small. The formula is as follows:

$$F = f \times e \cdot \xi \cdot n$$  \hspace{1cm} (4)

In the formula: $e$ is the penalty factor, the value of this article is 10000, $\xi$ is the penalty function, $F$ is the improved objective function.

3.2.3. New solution generation. The generation of new solutions should undergo simple transformations to generate new solutions in the solution space to reduce the time used by the algorithm and meet the real-time allocation requirements. Based on this, the generation of the new solution in this paper selects the following two methods through the random probability:

Second transformation method: randomly select the flights numbers with serial numbers $u$ and $v$ (set $u < v < n$) in the solution, and exchange the turntable values between $u$ and $v$. As shown in table 2.

| solution | Before conversion | After transformation |
|----------|-------------------|---------------------|
| $x_i$    | $1,2,3,\ldots,5,\ldots,4_n$ | $1,2,3,\ldots,5,\ldots,4_n$ |

Three-transformation method: randomly select flights with sequence numbers $u,v$ (set $u < v < n$), $u,v,w$ (set $u \leq v < w$), and insert the flight sequence between $u$ and $v$ after $w$ to visit.

3.2.4. Metropolis new solution acceptance criteria. When solving the value of the objective function, the penalty function is used to constrain. In the simulated annealing algorithm, a commonly used solution acceptance criterion is the Metropolis criterion: If $\Delta E < 0$, then accept the new solution $x_j$ as the new current solution; if $\Delta E > 0$, then the new solution $x_j$ is accepted according to the acceptance probability $P$. The formula is as follows:

$$\Delta E = E (x_j) - E (x_i)$$  \hspace{1cm} (5)

$$P = \begin{cases} 
1, & \Delta E < 0 \\
\exp \left( \frac{-\Delta E}{T} \right), & \Delta E > 0 
\end{cases}$$  \hspace{1cm} (6)

Among them, is the current temperature.

3.3. Operating parameters

Initial temperature $T_0$: Control parameter initial temperature $T_0 = 97$.

Attenuation function $T$: The attenuation function of the control parameter continuous cooling expression $T = T \times a$. $a$ is a constant of the attenuation function, and the value is between 0.5 and 0.99. This article takes 0.99.
Final value temperature $T_f$: The termination temperature is the stopping criterion. Generally, the termination temperature is set as a sufficiently small positive number, and the value is between 0.01 and 5, and the value is 3 in this article.

Markov chain length $L_i$: $L_i$ is the number of cycles, which should be able to achieve a balance in the value of control parameter $T$. This article takes $T$ as 10,000 times.

3.4. Steps of the simulated annealing algorithm

According to the previous design, the algorithm steps are as follows:

Step 1: Let the initial temperature $T=T_0$, and generate an initial solution $x_0$ according to the above-mentioned method, and calculate the corresponding objective function value $E(x_0)$.

Step 2: Let $T$ be equal to the next value $T_i$ in the cooling schedule.

Step 3: Perturb according to the current solution $x_i$, that is, perform an exchange operation to generate a new solution $x_j$, and calculate the objective function value $E(x_j)$ of the new solution to obtain $\Delta E$.

Step 4: Determine whether $\Delta E$ meets the requirements. If $\Delta E < 0$, the new solution will be the current solution; if $\Delta E > 0$, the new solution $x_j$ will accept $\exp \left( \frac{-(E_i - E_j)}{T} \right)$ according to the acceptance probability.

Step 5: When the temperature is $T_i$ value, repeat $L_i$ cycle of disturbance and acceptance, that is, cycle steps 3 and 4 until the requirements are met.

Step 6: Judge whether $T$ reaches the termination criterion. If it is met, stop the calculation and output the optimal objective function solution. If the algorithm ends, if it is not met, then go to step 2 and continue to perform the following loop steps.

The algorithm flow is shown in Figure 1.

![Figure 1. Flow chart of simulated annealing algorithm](image-url)
4. Simulation and analysis of calculation examples
Select a flight between 10:00 and 11:00 at an airport, including 6 baggage claim carousels and 40 flights. Before the flight optimization algorithm is adopted, the carousel allocation is shown in Table 3.

Table 3. First-come, first-served distribution results

| flight number | Turntable number | flight number | Turntable number |
|---------------|-----------------|---------------|-----------------|
| 1             | 1               | 21            | 2               |
| 2             | 3               | 22            | 1               |
| 3             | 2               | 23            | 4               |
| 4             | 2               | 24            | 6               |
| 5             | 4               | 25            | 5               |
| 6             | 4               | 26            | 4               |
| 7             | 5               | 27            | 3               |
| 8             | 4               | 28            | 1               |
| 9             | 3               | 29            | 6               |
| 10            | 4               | 30            | 6               |
| 11            | 5               | 31            | 5               |
| 12            | 2               | 32            | 2               |
| 13            | 4               | 33            | 5               |
| 14            | 3               | 34            | 1               |
| 15            | 1               | 35            | 3               |
| 16            | 5               | 36            | 1               |
| 17            | 2               | 37            | 2               |
| 18            | 6               | 38            | 1               |
| 19            | 6               | 39            | 3               |
| 20            | 5               | 40            | 3               |

Use matlab to solve the designed simulated annealing algorithm, run 6 times, select the optimal objective function value 795, single run time 13.4 seconds, meet the requirements of real-time assignment. The simulated annealing algorithm assignment results are shown in Table 4.

Table 4. Distribution results of simulated annealing algorithm

| flight number | Turntable number | flight number | Turntable number |
|---------------|-----------------|---------------|-----------------|
| 1             | 1               | 21            | 4               |
| 2             | 6               | 22            | 3               |
| 3             | 5               | 23            | 6               |
| 4             | 2               | 24            | 5               |
| 5             | 1               | 25            | 4               |
| 6             | 2               | 26            | 5               |
| 7             | 6               | 27            | 3               |
| 8             | 1               | 28            | 1               |
| 9             | 3               | 29            | 5               |
| 10            | 6               | 30            | 6               |
| 11            | 2               | 31            | 4               |
| 12            | 1               | 32            | 3               |
| 13            | 6               | 33            | 1               |
| 14            | 1               | 34            | 2               |
| 15            | 5               | 35            | 3               |
| 16            | 6               | 36            | 4               |
| 17            | 4               | 37            | 2               |
| 18            | 3               | 38            | 1               |
| 19            | 3               | 39            | 5               |
| 20            | 2               | 40            | 2               |
The results of the two allocation methods are compared and analyzed, and the results are shown in Table 5.

| Turntable number | First come first serve | Simulated annealing algorithm |
|------------------|------------------------|-------------------------------|
| 1                | 913                    | 759                           |
| 2                | 594                    | 792                           |
| 3                | 932                    | 795                           |
| 4                | 761                    | 796                           |
| 5                | 937                    | 790                           |
| 6                | 559                    | 795                           |
| Range of luggage number | 378        | 36                             |
| Variance of baggage quantity | 149197    | 1317                          |

Simulated annealing algorithm is better than the first-come, first-served allocation method, and the optimized results are all lower than the first-come, first-served allocation method, indicating that the simulated annealing algorithm allocates the baggage quantity of each baggage claim carousel more evenly. The expected goal is achieved, which shows the feasibility of using simulated annealing algorithm to assign baggage claim turntable.

5. Conclusion

This paper studies the problem of the passenger baggage turntable in the airport terminal. By improving the assignment model, designing simulated annealing algorithm steps to solve the objective function, and analyzing the original distribution method with examples, it shows the feasibility of the simulated annealing algorithm distribution method. It provides a reference for improving the distribution efficiency of airport baggage turntable.

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