Optimizing Arrival Flight Delay Scheduling Based on Simulated Annealing Algorithm

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Abstract

This paper presents a model based on the simulated annealing algorithm for optimizing arrival flight delays to reduce serious air traffic flight delays. Based on the characteristic of the flights and the thinking of system optimization, this paper builds up dynamic optimizing models of the flight delays scheduling with the objective function of delay cost. The simulated annealing algorithm is also used to solve this problem. This model can reduce the cost and the influence of the delay as much as possible. Data from an airport in China has been used to verify the model.

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1. Introduction

Because the Chinese aviation passenger transportation market is in the period of the high-speed development, and the quantity of arrival flight delays is increasing year by year, it becomes the main management work to raise the ability of adjusting arrival flight delays for the airports and airlines. To solve problems of the arrival flight delays, the widespread ways the local airports are the service postponed instauration currently. For the large airports which rise and fall thousand of flights everyday, this kind of method is not satisfying. On the one hand it controled by the airlines, air flight paths and airports and so on. Arrival flight delays can’t be adjusted in time. On the other hand, the results of this method are a great deal of service piles up on the key flight paths and a great deal of passengers be detained. So a huge damage is bringed to the airlines. For our country, the research of arrival flight delays management is at the beginning step still. A model of optimizing arrival flight delays has been given by MA Zhengping and CUI Deguang [1]. A multi-airport air traffic flow management model was developed...
which considers delay accumulations in the airport network as well as the influence of connecting flights to reduce serious air traffic flight delays by JANG Weiwei and CUI Deguang. When the airport capacity drops due to bad weather or other reasons and delays are unavoidable, the model uses a ground-holding policy and coordinates the departures and arrivals at the airports in the network to reduce delays [2]. And a research of the delay costing problem in the model of the ground service waits has been done by XU Xiaohao and LI Xiong [3]. But in the system layer, the technique of management and optimizing control is lack. In this article, on the foundation of service adjusts theory and models, research the problems of adjusting landing delays. According to the characteristic of the delaying service and the idea of global optimization, builds up dynamic optimizing models of the flight delays scheduling with the objective function of delay cost. Through allowing the biggest delay time restriction, and all the delayed flight services are not permit exceed the time, to ensure that the service delay cost is lowered. At the same time, pays attention to the equity of service landings. According to the characteristic of the model, the simulated annealing algorithm is used to solve this problem. This model can reduce the cost and the influence of the delay as much as possible. Data from an airport in China has been used to verify the model.

2. Setting up the model

In this article, a model of optimizing arrival flight delays is established whose target is to lower the service delay cost. At the restriction of allowing the biggest delay time, it minimums the service delay cost. It can solve two problems mainly to set up the model. The first one is that it can reduce flight delay cost, and the other one is that it can consider the fair for the flight. The way for solving this problem is the flight which has the most delay cost will be given priority landing right. While there should be the permitting maximal delay time for all the flight, the delay time for each flight should not exceed the maximal delay time. This regulation can assure the the fair.

2.1 The assumption and restriction condition for the model

1. Assumption condition

(l) Assumption for limited time. By this assumption, the time is located in one period in one day, the ahead flight condition which has finished is the initialization condition for the study, then the infinite discrete system can be turned into finite discrete system.

(2) Assumption for the gate position. The gate position is adequacy to be assigned to each flight.

(3) Assumption for information complete. In each day, the information about the intending arrival time, takeoff time and the type of the flight are certain.

2. Restriction condition

(l) Landing from the waiting queue to arriving the gate position is one operation. There is no interrupted

(2) The airport has two runways which are parallel

(3) All the flight waiting in the queue can land on the runway one time.

1.2 Setting up the model

Supposing there are M time service landings inside some segment, whose set is \( J = \{ J_i \mid i = 1, 2 \} \). And the set of each service arrives time of waiting for the brigade row is \( DT = \{ DT_i \mid i = 1, 2 \} \), the set of the time of each service landing from the brigade row is \( RT = \{ RT_i \mid i = 1, 2 \} \).

If there is a service landing into terminal area, it gets into the next row time. At the moment \( T_k \), there are \( N_k \) flight services waiting to land. \( T = \{ T_k \mid k = 0, 1, \ldots \} \), the set of flight services \( j = \{ j_k \mid i = 1, 2, N_k \} \), the set of the time of every flight service landing into terminal area \( DT_k = \{ DT_{ki} \mid i = 1, 2, N_k \} \), the set of the anticipates time each flight service landing from the brigade row \( YT_k = \{ YT_{ki} \mid i = 1, 2, N_k \} \).
(1) **Object function**

First, set up static model. The object function in the static model is the minimal delay cost for the flight in one period.

\[ f_i = \min \sum [g(1,1 \ w f_{ki}) + g(1,2 \ m f_{ki}) + g(1,3 \ l f_{ki}) \ YT_{ki} - DT_{ki} \ ] \]

where \( w(jki), m(jki), l(jki) \) are the functions who can judge flight service \( jki \) be heavy, medium or light. \( g(1,1), g(1,2), g(1,3) \) are delay cost in unit time of heavy, medium or light respectively.

Based on static model, set up dynamic model. The object function in the dynamic model is the minimal delay cost for the all flight.

\[ f = \min \sum [g(1,1 \ w j) + g(1,2 \ m j) + g(1,3 \ l j) \ RT_i - DT_i \ ] \]

(2) **Restriction condition for the model**

The main restriction condition for the model is minimal interval time for flight landing. Different type flights have different minimal landing interval time. In this paper, the minimal landing interval time which is regulated by ICAO is adopted.

\[ i = 1, 2 \quad k = 0, 1, \quad N_k ; \]

\( w, m, l \)

\[ YT_{ki} - DT_{ki} \quad TD_{\text{max}} ; \]

\[ RT_i - DT_i \quad TD_{\text{max}} ; \]

\[ RT\_j - RT\_j \geq 2, r(j, j) = 1 \cap c(j) = 1 \cap c(j) = 1 \]

\[ RT\_j - RT\_j \geq 2, r(j, j) = 1 \cap c(j) = 1 \cap c(j) = 2 \]

\[ RT\_j - RT\_j \geq 3, r(j, j) = 1 \cap c(j) = 1 \cap c(j) = 3 \]

\[ RT\_j - RT\_j \geq 2, r(j, j) = 1 \cap c(j) = 2 \cap c(j) = 1 \]

\[ RT\_j - RT\_j \geq 2, r(j, j) = 1 \cap c(j) = 2 \cap c(j) = 2 \]

\[ RT\_j - RT\_j \geq 3, r(j, j) = 1 \cap c(j) = 2 \cap c(j) = 3 \]

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\[ RT\_j - RT\_j \geq 2, r(j, j) = 1 \cap c(j) = 3 \cap c(j) = 3 \]

\[ YT_{ki} - YT_{ki} \geq 2, r(j, j) = 1 \cap c(j) = 1 \cap c(j) = 1 \]

\[ YT_{ki} - YT_{ki} \geq 2, r(j, j) = 1 \cap c(j) = 1 \cap c(j) = 2 \]

\[ YT_{ki} - YT_{ki} \geq 2, r(j, j) = 1 \cap c(j) = 1 \cap c(j) = 3 \]

\[ YT_{ki} - YT_{ki} \geq 2, r(j, j) = 1 \cap c(j) = 2 \cap c(j) = 1 \]

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\[ YT_{ki} - YT_{ki} \geq 2, r(j, j) = 1 \cap c(j) = 3 \cap c(j) = 2 \]

\[ YT_{ki} - YT_{ki} \geq 2, r(j, j) = 1 \cap c(j) = 3 \cap c(j) = 3 \]

Where \( c(j) \) is a judge function. And if flight service is heavy, \( c(j) = 1 \). If \( j \) is medium, \( c(j) = 2 \). If \( j \) is light, \( c(j) = 3 \). \( r(j, j) \) a judge function. If flight services \( j \) and \( j \) land closed together, and \( j \) lands before \( j \), \( r(j, j) = 1 \). \( r(j, j) = 0 \) otherwise.

3. **Simulated annealing algorithm**

The simulated annealing algorithm has the characteristic of high quality, easy to realize and suitable to resolve compounding problem. The most character of this method is that it accepts the ambulation of
aggrandizement enlarging the target function with some probability. So it converges globally.
The simulated annealing algorithm comes from the solid back fire principle. According to Metropolis
Principle[4], the probability of particles tending to balance at temprature $T$ is
\[
\exp\left( \frac{E}{K T} \right).
\]
Where $E$ is inside energy at $T$. $E$ is its variety. $K$ is Boltzmann constant. The process of simulated
annealing algorithm for flight services is as the follows.

(1) Initialization. Give the superior service adjust project as a beginning project.

(2) Setting up annealing temperature $T$, $T=T_{\text{const}} \times n$ where $T_{\text{const}}$ is the beginning temperature. $n$ is the
service amount that need to be assigned. Establish varieties “unimproved” and “unaccepted”. “unimproved” means the times of the worse flight allotment project appearing than the beginning
project. “unaccepted” means the times of the not viable flight allotment project appearing after
commutation.

(3) Searching neighbor. It is a greed calculating way to turn to a search method.

(4) Judging the random research result. If it is reasonable, then calculate of the result(It is usually a
target function.). Otherwise, let “unaccepted” = “unaccepted” + 1. Go to step (3).

(5) Judging exchange, and calculating the probability $P_0 = a \times \exp(- E/(K T))$. Where $a$ and $K$ decide
the choice probability of exchange. If exchange, go to step (6). Otherwise, go to step (3).

(6) Renew the beginning project. If the project is better after exchange than he beginning project,
renew the beginning project. Otherwise, don’t renew the beginning project , and let “unimproved” =
“unimproved” + 1.

(7) If “unimproved” $>$ max “improve” or “unaccepted” $>$ max “accept”, heat temperature factor, namely
$T = \times$reheat. Otherwise, lower temperature factor, namely $T = \times$ d.

(8) Judging whether satisfy the terminate condition. If it isn’t satisfied, go to step (3). Otherwise, stop.

4. Example

Using the date from an airport to validate and analyze the method. The flights are delay for weather
reasons. The method for resume the flight is traditional sequence. Date list for flight delay can be seen in
table 1. Date list include sequence number, type of flight (heavy W, medium M, light L), arriving and
landing time.

Table1 Date list for flight delay

| sequence number | type of flight | Arriving time | Landing time | Delay time | Delay cost(yuan) |
|-----------------|----------------|---------------|--------------|------------|-----------------|
| 1               | L              | 928           | 936          | 8          | 736             |
| 2               | W              | 933           | 938          | 5          | 2490            |
| 3               | L              | 936           | 941          | 5          | 460             |
| 4               | W              | 938           | 943          | 5          | 2490            |
| 5               | L              | 941           | 946          | 5          | 460             |
| 6               | W              | 944           | 948          | 4          | 1992            |
| 7               | L              | 945           | 951          | 6          | 552             |
| 8               | W              | 947           | 953          | 6          | 2988            |
| 9               | M              | 949           | 955          | 6          | 1416            |
| 10              | M              | 950           | 957          | 7          | 1652            |
| 11              | W              | 951           | 959          | 8          | 3984            |
| 12              | M              | 956           | 1001         | 5          | 1180            |
| 13              | W              | 957           | 1003         | 6          | 2988            |
| 14              | W              | 1006          | 1006         | 0          | 0               |
| 15              | M              | 1008          | 1008         | 0          | 0               |
Using the model set up in this paper, let $TD_{\text{max}}=30\text{min}$, give an anew queue for delay flight, the result can be shown in Table 2

**Table 2: A new queue for flight delay**

| Sequence number | Type of flight | Arriving time | Langing time | Delay time | Delay cost (yuan) |
|-----------------|----------------|---------------|--------------|------------|------------------|
| 1               | L              | 928           | 941          | 13         | 1196             |
| 2               | W              | 933           | 936          | 3          | 1494             |
| 3               | L              | 936           | 943          | 7          | 644              |
| 4               | W              | 938           | 938          | 0          | 0                |
| 5               | L              | 941           | 1003         | 20         | 1840             |
| 6               | W              | 944           | 945          | 1          | 498              |
| 7               | L              | 945           | 1003         | 18         | 1656             |
| 8               | W              | 947           | 947          | 0          | 0                |
| 9               | M              | 949           | 949          | 0          | 0                |
| 10              | M              | 950           | 953          | 3          | 708              |
| 11              | W              | 951           | 951          | 0          | 0                |
| 12              | M              | 956           | 956          | 0          | 0                |
| 13              | W              | 957           | 958          | 1          | 498              |
| 14              | W              | 1006          | 1006         | 0          | 0                |
| 15              | M              | 1008          | 1008         | 0          | 0                |
| 16              | L              | 1008          | 1019         | 11         | 1012             |
| 17              | M              | 1009          | 1010         | 1          | 236              |
| 18              | M              | 1013          | 1013         | 0          | 0                |
| 19              | W              | 1016          | 1016         | 0          | 0                |
| Total           |                |               |              | 78         | 9782             |

From Table 2, we can see the new delay cost is 9782 yuan when $TD_{\text{max}}=3$. Compared with the old way, the cost reduce 61%. The light flight delay cost is 6348 yuan. The light flight delay cost is 6348 yuan. The medium-sized flight delay cost is 944 yuan. The heavy flight delay cost is 2490 yuan. The main delay cost distribute on light flight and heavy flight.

The total flight delay time is 78min. Compared with traditional sequence way, the delay time also reduce. The light flight delay time is 69min. The medium-sized flight delay cost is 4min. The heavy flight delay cost is 5min. The main delay time distribute on light flight.

5. Conclusion

This paper presents a queue and attemper model for flight delay to minimal delay cost. The simulated annealing algorithm is also used to solve this problem. Compared with the traditional flight delay sequence method, this model is effective and easy to implement. It also can reduce the cost and the influence of the delay as much as possible.

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