Research on Airline Route Optimization Based on Ant Colony Optimization Algorithm

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Abstract. International route network planning is an important issue in airline management decision. To solve the problem, in this paper the author introduces the concept of optimal air transport route, proposes the ant colony algorithm to solve the network optimization, then the new method for this problem is presented in the paper. At last, a typical simulation study was carried out to illustrate its validity. It is founded that ACO algorithms is reliable and effective for aviation network optimization problems.

1. Introduction
In recent years, with the economic globalization and the increasing demand for long-distance travel, air transport has developed rapidly. Air route network is an important transportation facility for air route transportation and a link between airports. With the rapid development of aviation industry, there are more and more navigable cities. Traditional airline routes are usually limited by ground node cities and are generally designed according to passenger flow. However, with the increase of node cities, the density of routes is getting higher and higher, making the network very complicated. The existing route planning method has poor flexibility and long period. The flight delay or cancellation greatly reduces the utilization rate of airspace. Adverse weather around flight will increase fuel consumption, increase operating costs, and lead to an increase in carbon emissions. Therefore, airline network planning is an effective measure to improve the utilization rate of aircraft, improve airline safety and economy, and carry out energy saving and emission reduction measures.

The essence of route network planning is route planning. The research methods for route planning are as follows: (1) route planning based on rough diagram; (2) grid based path planning; (3) path planning based on analogy. In this paper, ant colony algorithm is introduced to plan the route, and the algorithm is designed and optimized.

2. Problem Formula and Solution to the Problem

2.1. International Air Transport Networks
There are many air transport routes that can be chose from the departure cities to the destination cities. The routes and the cities on the net can be called routes network. Due to the distance is too further away from the departure city to the destinations, the passageways can divided into several levels according with the distance from the origins to the destinations; every level with a few cities can be called city belt and the cities in it can be called nodes. Air travelers travel from one node to the next. For example, there are many cities in Eurasia between China and Britain, these nodes of cities can be divided into a number of
city belts. As shown in figure 1, many cities are located in eastern China, for example, O1, O2, O3, passengers in which are first transported to one of central asia’s city X1, X2, X3, then to one of the european’s cities Z1, Z2, Z3, Z4, then to the Britain cities D1, D2, the traveller's journey is over. These nodes of all the cities and air transport passageways form the transport network.

![Figure1. Passengers transport networks](image)

2.2. Problem Description
The heart of the problem of air transport is the following: by which transport route the comprehensive cost from the origins to the destinations is smallest? The decision-making of the problem is effected by many factors, but in a general way, the cost and the transport distance are positively correlated: the further the transportation distance, the higher the transportation cost, therefore, transportation distance is a factor that must be considered. Because the departure city and the destinations city are so far away, the weight of distance factor weaken, the factors of transport time, transshipment costs and others are installed to strengthen, therefore, it is necessary to consider the comprehensive costs. In this paper, besides the cost, time costs (delays at nodes) and the transfer costs are considered. The factors taken into account can increase or decrease based on the actual needs. Time costs is the expense of waiting at the airport, which can be transferred into economic cost according to the time value of money;Transfer costs are the costs incurred when a passenger changes planes at an airport (if passengers choose to direct fly, the transfer cost is zero). This is a nonlinear combinatorial optimization problem. Application of ACO algorithm, the goal is to choose a transport route thought which the passengers bear the lowest comprehensive cost. The premise of this problem is that the transport supply and the demand between any two cities are in equilibrium.

2.3. Solution Model
Let’s take into account of a transport network with \( n \) city belts, \( e_j \) stands for the city in city belt, \( m_i \) stands for the city number in the belt, \( P_{e_j} = \{t_{e_j}, s_{e_j}\} \) stands for the evaluation index of cost taken place in city \( e_j \), \( t_{e_j} \) stands for time costs and \( s_{e_j} \) stands for transshipment costs; \( c_{e_{ij},e_{pq}} \) stands for the freight between the city \( e_j \) in one city belt and city \( e_{pq} \) in adjacent city belt, where \( i, p = 1, 2, ..., n \), \( j = 1, 2, ..., m_i \), \( q = 1, 2, ..., m_p \), \( C, T, S \) indicate freight, time costs and transshipment costs respectively taken place in the course of transporting goods from the origins to the destinations. The objective of the problem is to choose a group of cites \( F = \{f_1, f_2, ..., f_n\} \), which can obtain min \( C \), min \( T \), min \( S \), then the model can be described as follow:

\[
\min Z = W_1C + W_2T + W_3S
\]
C = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{q=1}^{m_i} c_{ij,(i+1)^q} u_{ij} u_{(i+1)^q} 

T = \sum_{i=1}^{n} \sum_{j=1}^{n} t_{ij} u_{ij} 

S = \sum_{i=1}^{n} \sum_{j=1}^{n} s_{ij} u_{ij}

Where, \( W_k \) (\( k = 1, 2, 3 \)) is weight, \( W_1 + W_2 + W_3 = 1 \), \( u_{ij} = \begin{cases} 1, & \text{transport thought the city } e_{ij} \\ 0, & \text{otherwise} \end{cases} \)

3. Theory of ACA

Ant colony algorithm is based on bionics, which simulates the ant colony behavior. The inspiration for ACO is the behavior of foraging ants. Ants in nature are capable of finding the shortest path from the nest to a food source with out a visual cue, for ants can accomplish complex tasks by exchanging information and collaborating with each other, by observing and studying, it is known that a kind of substance called pheromone plays an important role in path finding. While walking, ants deposit pheromone on the ground. And follow, in probability, pheromone previously deposited by other ants. For a link, the more ants visit it, the more pheromone is deposited on it. Conversely, the more pheromone on it, the larger of the probability it can be chosen by offspring. Thus, the process is characterized as a positive feedback loop. By many generations routing cycle, more ants converge on the shortest path finally. Informally, in ant colony algorithm, the ants work as follows: each ant finds its tour according to the state transition rule, and each ant can find the shortest path rapidly by applying the local updating rule and the global updating rule. Just as the problem described above, the destinations can be seen as the food of ants'. At the beginning of the evolution, all ants are randomly positioned at either one or any of the nodes of the transport network. The transition probability of any ant to an adjacent node from time \( t \) to \( t+1 \) is found by using following equation:

\[ p_{ij,q}(t) = \begin{cases} \frac{\tau_{ij,q}(t)\eta_{ij,q}(t)}{\sum_{q=1}^{m} \tau_{ij,q}(t)\eta_{ij,q}(t)}, & q=1,2,\ldots,m_p \\ 0, & \text{otherwise} \end{cases} \]

Where, \( \tau_{ij,q} \): The intensity of trail on edge \((e_{ij},e_{pq})\) at time \( t \), \( \tau_{ij,pq} \in (\tau_{min}, \tau_{max}) \); \( \eta_{ij,pq} \): The visibility of edge \((e_{ij},e_{pq})\); \( \alpha \): The relative importance of the trail, \( \alpha \geq 0 \); \( \beta \): The relative importance of the visibility, \( \beta \geq 0 \).

The function of the parameters \( \alpha \) and \( \beta \) can be best described as follows: If \( \alpha = 0 \), the job with the shortest processing times are more likely to be selected leading to a classical stochastic greedy algorithm. If on the contrary \( \beta = 0 \), only pheromone amplification is at work which will lead to the pre-mature convergence of the method to strongly sub-optimal solution. Therefore, the transition probability represents a compromise between visibility (the shorter the processing time the higher the probability to choose it) and trail intensity (the higher the traffic on the arc \((e_{ij},e_{pq})\), the higher its attractiveness).

Ants choose the adjacent node by using Eq. (3), and this process continues until all ants accomplish transition to an adjacent node, and this process is called iteration or a cycle. At this point the trail intensity is updated according to the formula Eq. (4)
\[ \tau_{ijpq}(t + n) = (1 - \rho)\tau_{ijpq}(t) + \Delta\tau_{ijpq}(t) \]  \hfill (4)

\[ \Delta\tau_{ijpq}(t) = \sum_{k=1}^{m} \Delta\tau_{ijpq}^k(t) \]  \hfill (5)

In this formula,
\( \rho \): A coefficient that represents the evaporation of trail between time \( t \) and \( t + n \), \( \rho \in [0,1) \)
\( \Delta\tau_{ijpq}(t) \): Total intensity of node \( (e_{ij}, e_{pq}) \) during an iteration of ants
\( \Delta\tau_{ijpq}^k(t) \) is calculated by using Eq (5)
\( m \): Total number of ants
\( \Delta\tau_{ijpq}^k(t) \): The amount of pheromone ant \( k \) deposits on the arcs it has visited. This usually amounts to the value:
\[ \Delta\tau_{ijpq}^k(t) = \frac{Q}{Z(C_k)} \]  \hfill (6)

Where, \( Z(C_k) \) is the length of the tour and \( Q \) is a positive constant. This means that arcs that are used by many ants and are therefore part of short tours, receive more pheromone and are therefore more likely to be chosen by ants in future iterations of the algorithm.

4. Experimental Simulations
Consider a air transport network shown in figure 1, the goal is to make a simulation on the transport route based on ant colony algorithm. The parameters are shown in table 1- table 4.

| Table 1. Freight between cities |
|------------------------------|
| X1  | X2  | X3  |
|---|---|---|
| O1 | 16.23 | 29.01 | 19.51 |
| O2 | 22.95 | 17.7 | 31.12 |
| O3 | 34.51 | 19.62 | 19.57 |

| Table 2. Freight between cities |
|------------------------------|
| Z1  | Z2  | Z3  | Z4  |
|---|---|---|---|
| X1 | 46.6 | 47.6 | 66.3 | 56.4 |
| X2 | 38.6 | 36.7 | 62.2 | 63.9 |
| X3 | 41.9 | 35.0 | 54.7 | 51.2 |

| Table 3. Freight between cities |
|------------------------------|
| Z1  | Z2  | Z3  | Z4  |
|---|---|---|---|
| D1 | 19.0 | 11.8 | 20.2 | 17.4 |
| D2 | 11.7 | 17.0 | 17.8 | 12.6 |
|     | $t_{ij}$ | $s_{ij}$ |
|-----|----------|----------|
| O1  | 7.4      | 2.6      |
| O2  | 7.2      | 2.9      |
| O3  | 6.2      | 2.2      |
| X1  | 12       | 2.8      |
| X2  | 26       | 3.0      |
| X3  | 34       | 2.3      |
| Z1  | 21       | 4.1      |
| Z2  | 18       | 4.5      |
| Z3  | 33       | 4.2      |
| Z4  | 26       | 4.7      |
| D1  | 38       | 6.9      |
| D2  | 16       | 5.8      |

The value of parameters is set as follow: $\alpha = 1$, $\beta = 5$, $\rho = 0.5$, $m = 10$, $Q = 200$, $W_1 = 0.4$, $W_2 = 0.3$, $W_3 = 0.3$.

The results after the computer runs is shown in figure 1.

![Figure 1](image)

**Figure 2.** Curve of optimal solution evolution

It can be figured out that the optimal transport path is from O1, O2 and O3 to D1, D2 is as follows: O1→X1→Z1→D1; O2→X1→Z2→D1; O3→X3→Z3→D2.

5. Conclusion

There are many methods for airline route planning. This paper provides a method of decision model of routes planning based on ACO algorithm, which can provide new technical means for international air transport route planning. The advantage of this method is that it can solve the problem of multi-city route planning which cannot be completed by manual calculation, and it has high efficiency.

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