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The optimization of flight landing sequence

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Abstract: The rational flight landing sequence has very important influence on the service of airlines, airports and air traffic controller. The discrete optimization problem can be seen as one machine scheduling problem with distinct starting and finishing time and the objective: the minimization of tardy flight problem. Because of this NP-hard complexity, ant colony optimization (ACO) is utilized to solve it. Firstly the formulation is proposed, then a transition probability and 2-opt local search strategy is defined. After the pheromone is updated according to the quality of solutions, the efficient solution will be achieved. Finally, an instance of flight landing sequence is demonstrated to compare ACO's better performance with traditional FCFS.

Keywords: flight landing sequence, FCFS, ant colony optimization

1. Introduction

The key function of the airport is to land or take-off for airplanes safely and on time, so the flight landing sequence problem is very important to promote the efficiency of operations. The core of landing sequence is to decide the right and reasonable order of the arriving airplanes.

There is usually one special runway for landing for the reason of safety if the airport has two runways. From the viewpoint of scheduling theory, the flight landing earliest starting time is the time entering the local airspace and latest finishing time is the ticket time, which are both pre-determined. The processing time is the landing operation time. So the landing sequence problem can be described as one machine scheduling problem. Because the airline will pay for the landing operation, parking place and the continuous utilization of airplane, the flight lands later than the ticket time, the fee will be charged. So the objective is to minimize the number of tardy flight.

The traditional and still adopted method is First Come First Serve (FCFS), but it's clear that this method is not high robust, then there are several papers discussing the problem. Wang proposes the Sliding Sequencing Window algorithm in arrival airplane scheduling in terminal area which doesn't search all sequence generated by whole sequence, but search possible positions of sequence (Wang,2003). Li discusses the same problem in the terminal area, and establishes a mathematical model according to the aircraft-wake separation which is solved by A algorithm (Li,2003). Jia sets up an ALS model and proposed a Hybrid Algorithm of Colonial Selection Algorithm and Receding Horizon Control(CSA-RHC)based on this model (Jia,2009). Lee presents a dynamic programming algorithm for determining the minimum cost arrival schedule, given aircraft-dependent delay costs, which is possible to determine various tradeoffs in terminal-area operations, such as maximum throughput and minimum average delay (Lee,2009). Hu reports on the application of genetic algorithms (GAs) to tackle the ASS problem in multi-runway systems which uses the following relationship between aircraft to construct chromosomes (Hu, 2009). Bai researches on the coordination model with dynamic and open for arrival/departure airport dispatching system using software coordination technology (Bai,2007). Koulams firstly rearch on the single machine problem with different release time (Koulamas,1996), and Wan solve this type of problem with Tabu Search method (Wan,2004). Because of NP-hard complexity, the paper will propose Ant Colony Optimization (ACO) to solve the problem.

2. Mathematical Model

The minimization of tardy flight problem with time period is described: There are n flights i1,i2,…,ij,…,in to land, the earliest starting time and latest finishing time is $[s_{i_j}, l_{i_j}]$, the landing processing time is p_{i_j} . if the actual completing time is earlier than latest time, this means that the flight lands on time, the tardiness $U_{i_j} = 0$, otherwise, $U_{i_j} = 1$, so the objective is $\min \sum_{j=1}^{n} U_{i_j}$.

3. ACO Algorithm

ACO is a stochastic heuristic searching technology proposed by Dorigo (Dorigo, 1992), which has been applied on many problem. In ACO algorithm every ant performs random walk in a construction graph, and builds up a solution step by step going through several probabilistic decisions until a solution is found. A walk consists of several "node to node" moves and these moves are performed according to the pheromone values. With the addition to the value of pheromone the ants will usually be guided by some problem specific heuristic for evaluating the possible decisions.

As shown in Fig. 1, in order to construct a feasible solution, the ants successively choose one flight from the collection of the non-scheduled and append it to the current subsequence, until all flights are scheduled. In the meantime job idle times are optimized.

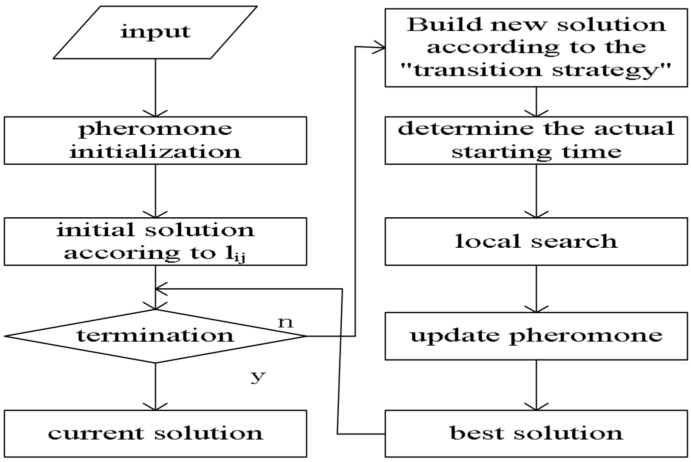

Fig. 1: Process of ACO algorithm

3.1 Initialization

In order to describe the flight landing sequence problem, define a landing sequence as a route having n nodes, for example, one permutation of n: 5,4,…,ij,,,in. the jth node which ant passes is ij and that means flight ij will landing on the jth sequence. During the ant's route, the remaining nodes are the collection of non-scheduled flights, then each route represents one solution after ant's movements. At the beginning, the ant makes the random choice on route, with the accumulation of pheromone on the route which has the least punishment, then all the ants will choose the optimal route finally.

3.2 Transition Probability

During the searching process, each ant gets a solution, i.e., a feasible solution. Then the ant will utilize some specific heuristic information as the pheromone on the nodes. This heuristic parameter defined as ηji and the pheromone is defined as τji, which evaluate the strength where flight ij is on the jth node (sequence).

Transition probability Pji(t) means the probability where flight ij is on the jth node (sequence). The ant will select the next node which has the maximal sum of heuristic parameter and pheromone according to the policy. So

$$P_{ji} = \begin{cases} \dfrac{([\tau_{ji}]^{\alpha} \cdot [\eta_{ji}]^{\beta}}{\sum_{h \in \Omega}([\tau_{jh}]^{\alpha} \cdot [\eta_{jh}]^{\beta}} & i \in \Omega \\ 0 & i \notin \Omega \end{cases}$$

Where Ω is the set of non-scheduled flights, and α, β are parameters that control the relative weight of pheromone and local heuristic. α=0 means the choice policy is only heuristic information, none of prior choice node and β=0 means the choice is only by the pheromone which will introduce stagnation. Here, ηji is given as

$$\eta_{ji} = \frac{1}{\xi_1 \cdot [\max(0, T + p_i - l_i)] + \xi_2 \cdot \dfrac{(l_i - s_i)}{p_i}}$$

Where T is current completing time, ξ_1, ξ_2 are the weights to adjust the two components. It is clear that if the flight i can be landing on jth position between time si and li, ηji will reach maximum that means this heuristic information will schedule the flight to the position where it will be on time as soon as possible.

3.3 Local Search Rule

Local search policy will adjust the position of current sequence in order to optimize the solution with less computational effort. Here 2-opt method will be used which requires the adjacent nodes to exchange the position.

3.4 Local Trail Update

After an ant makes a choice and adds a flight to the existing sub-sequence, local trail update will be done. The corresponding pheromone trail update formulation is:

$$\tau_{ji}(t+1) = (1-\rho) \cdot \tau_{ji}(t) + \rho \cdot \Delta\tau_{ji}(t)$$

$$\Delta\tau_{ji}(t) = \sum_{k=1}^{m} \Delta\tau_{ji}^{k}(t)$$

Here ρ ∈ (0,1) is to control the pheromone strength for avoiding finite accumulation. $\Delta\tau_{ji}^{k}(t)$ is the remaining pheromone on the trail (j,i) for ant k, where initial time $\Delta\tau_{ji}(t) = 0$. And $\Delta\tau_{ji}^{k}(t)$ called ant-density system is defined as.

$$\Delta\tau_{ij}^{k}(t) = \begin{cases} \dfrac{Q}{l_i} & \textit{if flight i is scheduled in position j for ant k} \\ 0 & \textit{otherwise} \end{cases}$$

Q is the parameter adjusting $\Delta\tau_{ji}^{k}(t)$ to be normal value.

Evaporation will decrease the pheromone on the trails where ants don't pass in this iteration, then:

$$\tau_{ji}(t+1) = (1-\rho)\cdot\tau_{ji}(t)$$

When all ants have finished the route and construct a feasible solution, the pheromone continues to update globally. Because the different quality of solution, only routes which are better than other solutions can contribute to the route's pheromone accumulation. So which s is the so-called global update rule are introduced:

$$\tau_{ji}(t+1) = (1-q)\cdot\tau_{ji}(t) + q / \sum_{j=1}^{n} U_{i_j}$$

3.5 Terminating Condition

The algorithm stops when a certain number of generations has been done or the best found solution has not changed for several generations.

4. Case Study

Experiments will be proposed to validate the algorithm which is coded with Matlab 6.5. there are 10 flights, then an integer processing time pj from the uniform distribution U[1,100]; the earliest starting time si from the uniform distribution U[1, P], where P is the total processing time (P=∑pj). the latest finishing time li of each flight i is generated from the uniform distribution U[si, si+pi+0.5P]. In the experiments, the setting of parameters is very import, the results shown that α=1, β=5, ρ=0.1, Q=100, q=2, ξ1=10 and ξ2=1 are the best choices of these parameters. The table 1 shows the performance of the traditional FCFS and ACO algorithm.

Table 1: Performance of the FCFS and ACO

No.of flight	s_i	p_i	l_i	FCFS's sequence	ACO's sequence
1	5	96	161	3	10
2	44	58	105	10	3
3	20	19	92	4	2
4	20	5	56	5	1
5	1	95	132	1	9
6	27	26	201	7	6
7	32	37	74	8	7
8	38	6	279	9	5
9	25	55	176	6	4
10	1	89	162	2	8
Number of tardy flight				9	4

The results shows that the number of tardy flight is 9 with FCFS, meanwhile the same objective of ACO is 4, so it's clear that the proposed method in the paper is more reliable than experienced FCFS rule.

5. Conclusion

The flight landing sequence problem is very important to promote the efficiency at airports. The core of landing sequence is to decide the right and reasonable order of the arriving airplanes. Because the traditional method FCFS has some disadvantages, ACO algorithm which has been applied to various applications, and proved to be powerful by very good results is introduced in the paper. The structure of algorithm and parameters are discussed in details, such as transition probability, local search rule, trail update policy, etc. The case study shows that ACO is suitable to this landing sequence problem and the result is better than FCFS, so it can overcome the FCFS's shortcoming.

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