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Study on Optimization Model and Algorithm of Flight Assignment

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Abstract: Considering the features of domestic flight assignment which is vulnerable to the effects of changes in market demand, this study tries to establish the model which aims at balanced utility of aircraft, making the flying time is as close as possible to the expected time of aircraft. In order to solve problem of the model, it designs an expert rule-based heuristic algorithm, which can achieve optimized flight assignment quickly. Finally, it adopts the actual flights data of airline and analyzing the examples, compared with the ant colony algorithm. It can further illustrate the model and algorithm.

Key words: Production plan, flight assignment, expert rules, heuristic algorithm

INTRODUCTION

With the rapid development of domestic aviation, the scales of aircraft fleets and the airlines are increasingly expanded, which causes a higher demand for the efficiency of flights scheduling of airlines. While at present, the establishment of production plan still depends mainly on the traditional manual work or the work partly done by machine. Therefore, it is the key for to succeed among airlines by working out practical flights schedules quickly and efficiently, making full use of airplanes.

Many foreign scholars did a lot of research on this aspect: Rexing *et al.* (2000) proposed the concept of "Time Window" and worked out a comprehensive model for assigning different types of aircrafts and the schedule of aircrafts. Rosenberger and Sriram and Haghani (2003) also studied on dynamical assignment and the adjustment of the airplanes of different types under the circumstance of abnormal flights, respectively. Erling and Rosin (2002), Gronkvist (2005) created the Constraint Programming Model for assigning the airplanes and proposed column generation method and so on. But due to the fact that most airlines abroad are ran in the way of flight bank, which means that the task of the airplanes are almost the same every day, which is different from the domestic airplanes with single-hub way of operation (the flights assignment is different everyday). Thus, it is impossible for the system of flights assignment of airplanes abroad to be completely put into use in domestic airlines.

For domestic research, they are mainly done by these researchers as follows. Zhu *et al.* (2007) researched on weekly airplane assignment with different types according to the formulation features of domestic air routes network and flight planning. Scholars of Sun Hong and Du Wen et al [6] mainly focused on three aspects, namely, research on flight assignment and algorithm which be based on orders of flight dispatching instructions, the minimum number of airplanes needed and the number of flights needed in normal circumstances. Li and Qin (2010) mainly researched on the constraints of terminal connections and over station connections, established the Optimization Model of flights strings and created a genetic algorithm with self-flexibility. However, they did not take it into consideration that the domestic flights are easily affected by the demands of the market and always fluctuated. Therefore, according to this feature of the domestic flights, this study tries to assign tasks to flights within a fleet on the prerequisite of determining flight tasks, making sure that the weekly practical flying schedules of each flight in the aircraft fleet are almost exactly in accordance with the scheduled ones, by using heuristic algorithm based on expert rules. The aim is to make full use of airplanes and improve profits of airlines.

FLIGHT ASSIGNMENT ANALYSIS

The essence of flight assignment is to consider the constraints of capacity and dispatching instructions of every aircraft and assign specific aircraft, based on flight plan published by marketing department..he purpose is to obtain the maximum economic profit on the premise of flight regular running.

The flight planning is the concrete form of air transport and production plan and the main basis of organizing daily production activities of airline. Normally, the establishment of air transport and production will create flight time table after the prediction of air routes

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transportation by marketing department to establish flight plans. On this basis, flight assignment is conducted and dispatching schedule is created. Next procedure is aircrew pairing, which is to classify the specific flight crew into several groups according to matching principles. Finally, the air production plan can be conducted, that is, the task of everyday every flight will be assigned by which aircraft and completing the task by whom. Flight assignment plays very important role in the whole flight plan, which makes aircraft operation safely and reasonably, cooperating with flight plan and maintenance plan. The basic constraints of flight assignment are as follows:

- Meet the requirements of flight planning, namely, the flight is consistent with corresponding type of assigning airplane; the destination airport of assigning flight pairing is consistent with the departure airport; and the over station time cannot be less than the minimum connection time
- Meet the unique requirement, that is, every flight should and can only assign one aircraft to complete the task and every aircraft can complete one flight task at most in the same period
- Meet the mutual matching requirement. It mainly refers to flight assignment should meet the requirement of flight maintenance and cannot assign tasks to the flight repaired in nearby airport

The three requirements are the basic constraints which must be satisfied in flight assignment. This study chooses the balanced aircraft utility as optimized direction on the condition of meeting the constraints. Less tasks should be assigned to the flights repaired in nearby airports and more tasks should be assigned to the flights which do not need repairing as possible. It tries to establish optimized model of flight assignment, making full use of aircrafts and improving the operation profits of airline on the premise of fight safety.

OPTIMIZATION MODEL OF FLIGHT ASSIGNMENT

The aim of imitation is to achieve that the flight time can be close to the planning time at the most extent, on the basis of meeting the restriction of the basic flight assignment. The constrains of practical flight time is relatively strict for those repaired in nearby airports. However, for other flights, we adopt the principle of balanced assignment. That is, the practical flight time of each flight this week is as average as possible. In order to simplify the statement of model, the exceptional case of repairing all the flights in nearby airports will not be considered and all the flights are expected to be assigned.

$$s = \left(\sum_{i=1,j=1}^{i=m,j=7} C_{ij} \right) / m \tag{1}$$

Since all the flights are connected in a natural way, normally, we can use the connections among flights to make a flight loop of every flight which can meet the restriction of over station connection by using proper algorithm (the destination airport in this flight loop is the same as the departure airport of the last flight and the destination airport of the last flight is the initial airport of the first flight). It is going to change the flight time table into flight plan which is matched with the number of flight by the processing above.

Suppose to get the flight plan, which is, dividing a week flights into group m which is matched with the flight number m. That is, the problem of flight assignment is turned into the distribution of flight loop. In every assignment period which is generally seven days, the daily m flight groups are assigned to m flights, by which the practical flight time of every flight can be as close to the planning flight time as possible within the assignment period. The concrete description of assignment model is as follows:

$$f = \min \sum_{i=1}^{N} \left| t_{fly} - t_{sed} \right| \tag{2}$$

$$st. \sum_{k=1}^{m} \sum_{j=1}^{n+1} X_{ij}^{k} = 1 (\forall i) \tag{3}$$

$$t_{di} X_{ij}^{k} \geq (t_{ai} + GT) X_{ij}^{k} \ (\forall k, i, j) \tag{4}$$

$$O_j \bullet x_{ijk} = D_i \bullet x_{ijk} \ \forall i, j \in F, k \in P \tag{5}$$

In formula, N: the number of flight loops; M: the number of flight; F: the set of assigning flight loops, F = {1, 2, 3, ..., N} $|F| = N$; P: the set of all the assigning flights, V= { 1,2,3,...,M} $|P| = M$;O_i: the departure airport of the first flight in flight loop j; D_i: the destination airport of the last flight in flight loop i; t_{di}: the departure time of the first flight in flight pairing i; t_{ai}: the destination time of the last flight in flight pairing i; GT: the minimum over station time of the connections among flight pairings.

Formula (2) is an objective function, which shows that the D-value between practical and expected flight time is the minimum. It is evaluated according to the minimum cost (the root-mean-square between weekly and expected flight time of every flight), that is:

$$\overline{Cost'} = \frac{1}{n}\sqrt{\sum_{i=1}^{10}(P_i - \bar{P})^2}$$

Formula (3) is to meet unique constraint, i.e., each flight can only be assigned one plane. In this formula:

$$X_k = \begin{cases} 1 & \text{(flight k completes the task of flight loop j after fliight i)} \\ 0 & \text{(others)} \end{cases}$$

it is a decision variable; formula (4) is the over station time separation, assigned to arbitrary flight k of adjacent flight loops i and j, which must be satisfied; formula (5) guarantees that the destination and departure airports must be the same one, which is conducted by the same flight and successive two flight strings.

ALGORITHM DESIGN

The problem needed solving is how to assign the flights in a fleet on the premise of the determination of flight tasks, which is a complicated NP-Hard problem. The difficult point of solving the NP-Hard problem is to find out an optimal result by adopting what kind of searching rules and comparing the evaluation of function values. Heuristic algorithm rule is to establish rule system, mainly including the searching process of route planning and the optimal decision process on the prerequisite of objective value, based on meeting the flight assignment constraints.

Route searching rules: The route searching rules are based on flight assignment constraints. If it can meet:

$$\left(\sum_{k=1}^{m}\sum_{j=1}^{n+1} X_{ij}^{k} = 1\right)$$

&&

$$\left(t_{di}X_{ij}^{k} \geq (t_{ai} + GT)X_{ij}^{k}\right)$$

&&

$$\left(O_j \bullet x_{ijk} = D_i \bullet x_{ijk}\right)$$

then it enters the searching process; according to constraints rules:

$$\sum_{k=1}^{m}\sum_{j=1}^{n+1} X_{ij}^{k} = 1$$

suppose all the flights stop to be repaired at the nearby airports in the model; meanwhile, according to the constrains of connection time:

$$t_{di}X_{ij}^{k} \geq (t_{ai} + GT)X_{ij}^{k}$$

the searching route designed is a Monday flight loop connected with a Tuesday flight loop and a Tuesday flight loop connected with a Wednesday flight loop, in turn to Sunday flight loop. And the Sunday flight loop connects with next Monday flight loop. The cycle period is seven. Thus, it can be concluded that within this searching route, all the flight loops meet the constraints of connection time and every flight meets the constrains of terminals connection.

Optimized decision rules: The optimized decision rules are the rules based on the requirement of objective function values, while the decision rules are on the prerequisite of meeting the objective function values:

$$f = \min\sum_{i=1}^{N}\left|t_{fly} - t_{sed}\right|$$

Besides, in order to make data management convenient and reduce the computation time, it establishes a linked list to save objective function values, in which the address indicators point at the order of flights and data indicator the corresponding flights time:

$$\text{COMPARE } (f_1, f_2, \ldots f_n) \Rightarrow \min f_i \,(i \in n)$$

The algorithm flow: The algorithm flow diagram is shown as Fig. 1.

It describes as follows:

- Arrange all the flight in the fleet successively from short to long in accordance with weekly flight time and rearrange them from long to short in accordance with Monday flight time
- Recalculate the weekly flight time of every flight in the fleet and arrange them from short to long
- Fix the assignment result of Monday and arrange the flight time of Tuesday from long to short successively. The rest can be done in the same manner. And repeat the procedures (2) and (3) until Sunday and rearrange to finish the circulation
- Find out the flights with the longest and shortest flight time according to weekly flight time
- Formulate searching rules to exchange the flights with the longest and shortest flight time according to daily flight time on Monday and recalculate the weekly flight time of they two
- Repeat procedure (4) until every flight cannot be exchanged on Monday. This circulation can be ended

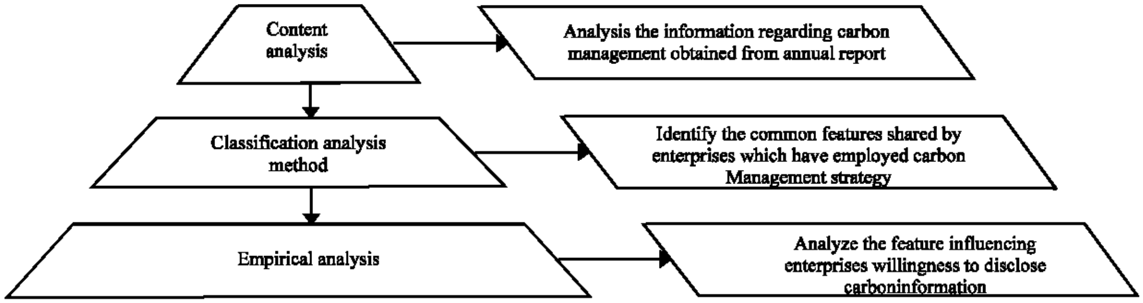

Fig. 1: The flow diagram of heuristic algorithm

- Compare the root-mean-square between weekly and expected flight time of every exchanged flight. The standard is the minimum root-mean-square. Successively, the circulation can be ended until the finishing of exchanging optimization on Sunday
- According to route searching rules, determine the second longest and shortest weekly flight time and repeat procedure (2),(3) and (4) in turn. The same searching rules are used for the flights with third and fourth longest and shortest weekly flight time. The procedure will be ended when flights assignment on Sunday in the last circle cannot be exchanged
- Stop and print the final result

SIMULATION STUDY

In order to verify the plane assignment optimization model and algorithm, the simulation study of an airline with a fleet of 10 aircrafts and 70 flight loops is conducted here. Assuming that the flight time of each aircraft is from 3 to 10 hours, then we generate an integer between 210 (min) to 600 (min) randomly for each flight loop to represent the flight time (minute).

The initial data are shown in Table 1. The first column represents the number of aircraft; The columns from the second to the eighth represent the flight time generated by flight loops randomly; The ninth column represents the flight time of a flight loop for a week for a certain aircraft; The last column is the expected time of each aircraft.

After algorithm, we get the optimized assignment result, shown in Fig. 2. In order to facilitate the examination, a program was made to visual document. The operating results are shown in screenshot 2:

According to the figure above, the minimum cost is:

$$\overline{Cost'} = \frac{1}{n}\sqrt{\sum_{i=1}^{10}(P_i-\overline{P})^2} = 3.99$$

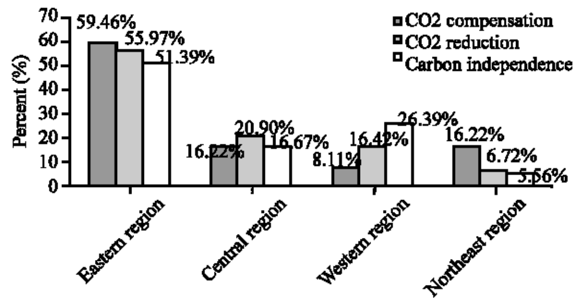

Fig. 2: Aircraft assignment results by heuristic algorithm

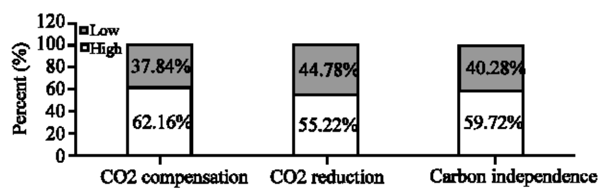

Fig. 3: Distribution of dependence degree (low and high) in term of specific strategy

From the figure above, it can be seen that the D-value differences are fairly big for the weekly and expected flight time per aircraft before sorting. The weekly flight time of Aircraft B2 is far beyond the expected time, which may cause the aircraft to be repaired in advance and increase the maintenance cost. While the weekly flight time of Aircraft B8 is far away from expected flight time, which means the aircraft is not fully utilized, reducing the airline's profit. After sorting through the algorithm processing, the weekly flight time per aircraft fluctuates based on the expected flight time and the fluctuation is very small. Thus the desired objective is achieved, which makes the flight time as close to expected flight time as possible. Therefore, the airline's economic profit can be improved by making full use of each aircraft.

Table 1: Proportion of sample enterprises in terms of carbon information disclosure

INC	Total samples	Samples without information disclosure	Samples with information disclosure	Percent of samples with information disclosure (%)
Manufacture	183	82	101	55.19
Wholesale and retail trade	45	42	3	6.67
Mining	32	14	18	56.25
Finance, insurance	22	16	6	27.27
Electricity, gas	18	4	14	77.78
Transportation, storage	15	8	7	46.67
Architecture	15	8	7	46.67
Real estate	12	12	0	0.00
IT	9	7	2	22.22
Social service	8	8	0	0.00
Others	6	3	3	50.00

Table 2: Carbon management strategies and measures

CO2 management strategy ------------------ Measure Measure taken	CO2 compensation Acquisition of additional CO2 emission capacity through emission trading (%)	Investment in CO2 emission offsetting projects (%)	CO2 reduction Addition of enhanced or improvement of existing CO2 emitting production processes (%)	Design of new improvement of existing have lower CO2 emissions during production and use (%)	Carbon independence Addition of new and improvement of existing carbon free production processes (%)	Design of new or improvement of existing products that are carbon free during production and use (%)
Recently/currently	35.14	29.73	49.25	41.79	23.53	23.53
Definitely planned for future	16.22	16.22	14.18	18.66	17.65	15.69
Probably in future	43.24	16.22	21.64	20.90	39.22	31.37
Not mentioned	5.41	37.84	14.93	18.66	19.61	29.41

Table 3: Descriptive statistics of public age and number of employees

CO2 management strategy types	Variable	Observed value	Minimum	Maximum	Mean	Standard deviation
CO2 compensation	Public age	37	2	19	11.73	5.373
CO2 reduction	Public age	134	2	22	11.34	5.241
Carbon independence	Public age	72	2	22	12.25	5.218
CO2 compensation	No. of employees	37	995	552810	46102.92	114042.8
CO2 reduction	No. of employees	134	146	447401	36182.91	70729.31
Carbon independence	No. of employees	72	146	66497	16552.44	17085.26

Table 4: Basic descriptive statistics of variables

Variables	Observation	Minimum	Maximum	Average	Standard deviation
Prob (disclose)	365	0.00	1.00	0.4411	0.49720
Size	365	0.22	1.15	0.8076	0.11813
ISO	365	0.00	1.00	0.6055	0.48942
INC	365	0.00	1.00	0.3671	0.48268
ROA	365	-0.13	0.48	0.0539	0.05826
IOR	365	0.05	0.99	0.6001	0.22076

Table 5: Correlation analysis on variables

	Prob (disclose)	Size	ISO	INC	ROA	IOR
Prob (disclose)	1	0.148**	0.164**	0.365**	-0.043	0.091*
Size	0.148**	1	-0.052	0.081	-0.032	0.184**
ISO	0.164**	-0.052	1	0.208**	0.153**	-0.115*
INC	0.365**	0.081	0.208**	1	0.017	0.043
ROA	-0.043	-0.032	0.153**	0.017	1	0.149**
IOR	0.091*	0.184**	-0.115*	0.043	0.149**	1

**Represents the significant correlation at level 1%, *Means significant correlation at level 5%

Table 6: Significance test of integral regression equation

R	R^2	Adjusted R^2	Standard deviation	f-value	Significant level
0.409	0.167	0.156	0.45687	14.418	0.000

Here are the results from other scholars by using DV-Based AS, as is shown by Table 2.

According to the data in Table 2, the minimum cost of is:

Table 7: Regression coefficients and their significance degree

				Colinearity statistic	
Model	Coefficient	t-value	p-value	Allowance	Variance increase factor
(Constant)	-0.210	-1.199	0.231		
Size	0.465	2.244	0.025	0.955	1.047
ISO	0.124	2.429	0.016	0.911	1.097
INC	0.338	6.631	0.000	0.945	1.058
ROA	-0.653	-1.544	0.123	0.945	1.058
IOR	0.185	1.637	0.102	0.922	1.085

$$\overline{\text{Cost}'} = \frac{1}{n}\sqrt{\sum_{i=1}^{10}(P_i - \overline{P})^2} = 11.1$$

Compared to the minimum cost 3.99 obtained by heuristic algorithm in this thesis, the optimization results are evident.

CONCLUSIONS

Based on the analysis of the workflow of flight assignment, the assignment optimization model is established. Under the premise of security, make the practical flight time as close to the planned flight time as possible, which can make full use of aircraft and finally maximize the economic benefit of airline. At the same time, the expert's heuristic algorithm achieves a rapid solution. Finally, by simulating the actual data, the results show that the model and the algorithm established in the thesis are feasible. The organizational effect of flight assignment is good, which can be assigned quickly and dynamically, consequently, improving the automatic level in production and assignment of airlines. In addition, the algorithms designed in this thesis can be further optimized in the future studies.

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