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Arrival flight scheduling based on rough set theory and fuzzy comprehensive evaluation

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ABSTRACT

The efficient utilization of terminal area airspace and runway resource plays an important role in increasing the efficiency of air traffic flow management (ATFM). Arrival flight scheduling is one of the key parts of making use of this resource, so it is necessary to study the problem of arrival flight scheduling. Considering several influence factorsof actual sequencing processing by controllers and some factors were never considered by previous study,this paper study this problem with fuzzy comprehensive evaluation method, which could trade off the importance of each factor. But the membership function and weight number of each factor were difficult to determine. To solve this difficulty, we used rough set theory to objectively calculate weight number and combined it with fuzzy comprehensive evaluation method. In this paper, we analysearrival flight sequencing process by controllers firstly and propose five influence factors to construct index system, thenrepresent how to use this method to sequence flight and apply this method to a reality case to verify effectiveness and feasibility. The experimental result showsthat arrival-rate is improved and time of delay is decreased obviously.

KEYWORDS

Terminal area; Arrival flight scheduling; Rough set theory; Fuzzy comprehensive evaluation.

INTRODUCTION

With the rapid development of China's aviation transportation industry, the problems of the air traffic flow management grow larger and larger. The delays of flights' take-off and landing have been aroused by increasing air traffic flow and limited resource of terminal area airspace and runway. But the current air traffic control lacks an effectively assistant decision-making tool. According to the expected landing time, the controllers usually command flights landing on the first-come-first-served basis (FCFS), which mainly depends on controllers' experience. Although this method of flight scheduling is easy to operate, it does not involve any optimization and will produce more delays. Therefore, effective methods of arrival flight scheduling are significant to flow management in terminal area. In this respect, domestic and foreign scholars have conducted extensive researches. There are many kinds of method have been put forward to solve this problem, including[1-8] position exchange constraint,depth-first searching algorithm, fuzzy theory,combinatorial optimization method, control theory combined with intelligent algorithm (such as genetic algorithm and ant colony optimization)and so on. But how to describe this problem precisely is the key to scheduling arrival flight.

Fuzzy integrated judge method can balance elements in the process of flight scheduling and make decisions by considering all elements' function. Consequently, fuzzy integrated judge method will be adopted to study the problem of arrival flight scheduling. However, it's hard to objectively determine membership functions and every element's weight. Rough set theory can dig the original flight data and determineattributes' weight all by the regularity of data itself. Accordingly, this paper will combine the rough set theory and fuzzy integrated judge method to study the problem of terminal area arrival flight scheduling. Firstly, the index system of fuzzy integrated judge method will be set up. Then, the process of fuzzy integrated judge based on rough set theory will be introduced. Finally, the simulation result will be provided, and the feasibility and effectiveness of this method will be tested and verified.

ROUGH SET THEORY

Definition 1 A knowledge base is defined as a relationship system $K = (U, R)$,where $U \neq \emptyset$（$\emptyset$ is empty set）is the set of finite objects (the universe),R is a finite set of attributes[9].

Definition 2Tetrad is used to define the information system $S = (U, A, V, f)$, where $U = \{x_1, x_2, \dots, x_n\}$ representsnon-empty set of finite objects, called the universe;$A = \{a_1, a_2, \dots, a_n\}$ is a finite set of attributes; $V = \sum_{a \in A} V_a$ means the set of attributes value;$f: U \times A \to V$represents information function. For every attribute subset B, $\text{ind}\,(B)$ is defined as the indiscernible binary relation (equivalence relation), i.e. $\text{ind}(B) = \{(x, y) | (x, y) \in U^2, \forall a \in B, f(x, a) = f\,(y, a)\}$. $\text{ind}(B)(B \in A)$represents a kind of division, noted as $\frac{U}{\text{ind}}(B)$ or U/B.

Definition 3If a knowledge base$K = (U, R)$,$r \in R$ is a equivalence relation, we called $GD(R)$ as grain size of knowledge $r \in R$.

Definition 4If a knowledge base $K = (U, R)$,$r \in R$ is a equivalence relation, we called $\text{Dis}\,(R)$ as discernibility of knowledge $r \in R$.

$$\text{Dis}(R) = 1 - GD(R) = 1 - \frac{|R|}{|U^2|} = 1 - \frac{|R|}{|U|^2} \quad \textbf{(1)}$$

Supposed$S = (U, A, V, f)$ is information system, $A = C \cup D$, $X \in C$ is aattribute subset, $x \in X$ is a attribute, considerating the importance of x for X, which means that adding the attribute x to X improves the discernibility. If this improvement is heavier, attribute x is more important for X.

Definition 5Supposed $X \in C$ is an attribute subset, $x \in C$ is an attribute,noted $\mu_X(x)$ as the importance of x for X.

$$\mu_X(x) = 1 - \frac{|X \cup (x)|}{|X|} \quad \textbf{(2)}$$

Supposed$\frac{U}{|\text{ind}(X)|} = \frac{U}{X} = \{x_1, x_2, \dots, x_n\}$, then$|X| = |\text{ind}(X)| = \sum_{i=1}^{n} |X_i|^2$.

INDEX SYSTEM

For the terminal area arrival flight scheduling problem, it is assumed that there isonly one airport in the terminal area and its arrival and departure flow has been isolated,only considering thearrival flight. These arrival flights enter terminal areafrom the planed waypoint in different directions,with predetermined approach and landing procedures. Controllers scheduled these arrival flightsbetween the start and stop scheduling boundary sort boundaries to optimize the flight queue order, reduce delays, avoid conflict and ensure flight safety by adjusting the speed and change the approach route. After flight left the stop boundary,the order in the landing queue will not change and will be removed from the schedulingqueue, shown in Figure 1.

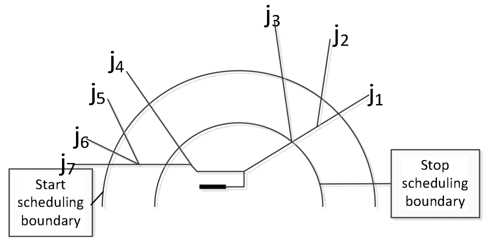

Figure 1 : Terminal area structure

To avoid the collision between the aircrafts or aircraft and obstacles and ensure the flight's safe, efficient and orderly landing at the airport, controllers usually use radar to guide aircrafts entering the terminal area and landing. There are several factors affecting ATC to scheduling flight, which need to be comprehensively considered. But one of difficulty to take into these factors is that they could not be accurately described with the language of mathematics. So we use rough set theory based and fuzzy comprehensive evaluation method arrival flight scheduling model to solve this problem.

Through analysis of a large number of influent factors, these 5 kinds' factors are considered much more important than others. We construct the index system as follow:

The distance to Intermediate approach Fix (IF), noted as S: When flight pass IF, the order in landing queue usually might not be changed. Hence S is a significant factor that influences the order of the approach queue. These flights closed to IF have priority.

The difference of velocity of successive aircrafts, noted as V: At the same altitude, a pair of aircraft have different velocity, the case that the faster aircraft was behind the slower one might lead to a great delay. If the fast one could be queued in front of the slow one, the delay could be decreased effectively. At this situation, changing the order of successive aircrafts which have different velocity could optimize the flight queue.

Standard time separation, noted as T: The time separation of successive aircraft passed final approach fix (FAF) is related to the aircraft type. The international civil aviation organization (ICAO) prescribed the minimum time wake separation under the condition of no wind between two successive different types of aircraft, as shown in TABLE 1. The greater the difference between interval and standard, the greater the chance of adjust flight sequencing. The formula is :

$$T = \frac{\text{ETA(the after one)} - \text{ETA(the before one)}}{\text{the wake separation between the two aircraft}} \quad \textbf{(3)}$$

The importance of flight, noted as P: The more important the flight is, the earlier the flight should be guide to land.

TABLE 1 : The minimal wake separation of different aircraft type (unit : s)

Aircraft type		**The behind aircraft**		
		Heavy（H）	**Large（L）**	**Small（S）**
The before one	**Heavy（H）**	94	114	167
	Large（L）	74	74	138
	Small（S）	74	74	98

The way linked to base leg, noted as L: If the aircraft is in downwind, it could implement delay by extending downwind. This way is convenient and flexible for controller to direct flight in other position of the circle to inset base leg and land. The linked way with base leg could influence the order of arrival sequence.

COMPREHENSIVE EVALUATION METHOD

Establishing the data table based on original data

In order to make use of rough set theory to determine the weight of each evaluation index in the process of aircraft sequencing, the first thing is to establish evaluation index system data table according to the original data.

Establishing a decision table

There might be differences between dimension and order of magnitude evaluation index. In order to eliminate these differences, standardization is needed. Indicators are divided into positive ones and reverse ones according to the change of direction. The greater the value of positive indicator is, the better the indicator is, while the reverse one is the smaller the

better. Due to poor transformation method has the attribute that standardized indexes are transformed in [0, 1] interval, this method is adopted to standardize indexes.[10]
For positive indexes, we have:

$$y_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \quad (4)$$

For reverse indexes, we also have:

$$y_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} \quad (5)$$

Using rough set theory to determine the weight of various evaluation indexes

According to the definition of attribute importance in rough set theory, the importance of evaluation indexes $\mu_X(x)$ is calculated and normalized to be the objective weight of the index[11].

$$\omega_x = \frac{\mu_x}{\sum_{x \in X} \mu_x} \quad (6)$$

Fuzzy comprehensive evaluation

Marking for every index according to evaluation criterion and flight original data, we use fuzzy comprehensive evaluation method to sequence arrival flights.

TABLE 2 : Evaluation of every index

Index	Value of evaluation index				
S	0—5	5—10	10—15	15—20	Above 20
	0.9	0.7	0.5	0.3	0.1
V	40—50	30—40	20—30	10—20	Below 10
	0.9	0.7	0.5	0.3	0.1
T	0 —0.5	0.5—1.0	1.0—1.5	1.5—2.0	Above 2.0
	0.9	0.7	0.5	0.3	0.1
P		1		0	
		0.9		0.5	
L		1		0	
		0.7		0.3	

APPLICATION

The target of arrival flight sequencing is to minimize total arrival delay in terminal area. We usedactual arrival flight data of an airport between 8am to 9am as case to calculate the arrival flight sequencing problem with rough set theory. The original data is shown in TABLE 3.

TABLE 3 : Original data of arrival flight

Flight	Flight	Importance	Velocity（NM/H）	Distance to	Whether passing	Estimated
A1	L	0	200	0	1	9:00:44
A2	L	0	220	3	0	9:01:18
A3	L	0	230	7	1	9:01:58
A4	L	0	220	7	1	9:02:30
A5	L	0	250	13	1	9:04:30
A6	L	1	230	15	0	9:05:20
A7	L	0	220	20	1	9:06:18
A8	H	0	250	20	0	9:08:30
A9	L	0	250	26	1	9:09:22
A10	H	0	250	27	0	9:12:00

Establishing index system of arrival flight

Establishing index system table as TABLE 4 according to TABLE 3, where "↑" represents positive index,"↓"represents reverse index. T is calculated with formula (3); the importance of flight P's value will be 1 if the flight is special plane,otherwise is 0; linked way with base leg L's value will be 0 if the flight pass the downwind, otherwise is 1.

TABLE 4 : Index system data

Flight number	S (↑)	V (↑)	T (↓)	P (↑)	L (↑)
A1	0	…	…	0	0
A2	3	10	0.46	0	1
A3	7	10	0.54	0	0
A4	7	15	0.43	0	0
A5	13	20	1.62	0	0
A6	15	0	0.68	1	1
A7	20	10	0.72	0	0
A8	20	10	1.85	0	0
A9	26	10	0.74	0	1
A10	27	15	1.89	0	0

Discretization and standardization

Dimensions and orders of magnitude of indicators are not consistent in TABLE 4 and need to be standardized and discretized. We standardize positive index S, V and P with formula (4) and reverse index H, D and L with formula (5). If the index is a positive index, the greater the value is, the higher the priority is. And if the index is reverse, the situation is opposite. Index table after discretization is shown in TABLE 5.

TABLE 5 : Decision table of weight

Flight number	S (↑)	V (↑)	T (↓)	P (↑)	L (↓)
A2	1	0	0	0	1
A3	1	0	0	0	0
A4	1	1	0	0	0
A5	1	1	1	0	0
A6	0	0	0	1	1
A7	0	0	0	0	0
A8	0	0	1	0	0
A9	0	0	0	0	1
A10	0	1	1	0	0

Calculating weight of index

Weight calculation process is shown as follows:

Calculate the indiscernibility relation

U⁄ind(R) ={A2,A3,A4,A5,A6,A7,A8,A9,A10}

U⁄ind(R-S) ={{A2,A9},{A3,A7},A4,{A5,A10},A6,A8}

U⁄ind(R-V) ={A2,{A3,A4},A5,A6,A7,{A8,A10}A9}

U⁄ind(R-T) ={A2,A3,{A4,A5},A6,{A7,A8},A9,A10}

U⁄ind(R-P) ={A2,A3,A4,A5,{A6,A9},A7,A8,A10}

U⁄ind(R-L) ={{A2,A3},A4,A5,A6,{A7,A9},A8,A10}

Calculation the importance

Supposed$X=\{V,T,P,L\}$, according to the definition of index importance,computing method of the importance of index S is as follow:

|X|=3^2+1^2+1^2+1^2+1^2+1^2+1^2=15

|X∪{S} |=1^2+1^2+1^2+1^2+1^2+1^2+1^2+1^2+1^2=9

μ _R (S)=1-(|X∪(S)|)/(|X|)=6/15

The same can be obtained$\mu_R(V)=\frac{4}{13}$, $\mu_R(T)=\frac{4}{13}$, $\mu_R(P)=\frac{2}{11}$, $\mu_R(L)=\frac{4}{13}$。

According to the formula (6), each index importance is normalized, after this processing we can get the weight as:

$\omega_S=0.266$, $\omega_V=0.204$, $\omega_T=0.204$, $\omega_P=0.122$, $\omega_L=0.204$

A=（0.266, 0.204, 0.204, 0.122, 0.204）

Sequencing arrival flight

The index is scored according to the indexes of evaluation criteria (TABLE 2) and the single factor evaluation vector is as follows:

R_1=[1, 1, 1, 0.5, 0.3] R_2=[0.8, 0.1, 0.85, 0.5, 0.5]

R_3=[0.7, 0.1, 0.7, 0. 5, 0.3] R_4=[0.65, 0.2, 0.85, 0.5, 0.3]

R_5=[0.5, 0.3, 0.3, 0.5, 0.3]R_6=[0.4, 0.05, 0.6, 0.5, 0.5]

R_7=[0.2, 0.1, 0.55, 0.9, 0.3]R_8=[0.2, 0.1, 0.2, 0.5, 0.3]

R_9=[0.1, 0.1, 0.45, 0.5, 0.5]R_{10}=[0.1, 0.2, 0.2, 0.5, 0.3]

So the index set R for evaluation matrix is:

$$R=\begin{bmatrix} 1 & 0.8 & 0.7 & 0.65 & 0.5 & 0.4 & 0.2 & 0.2 & 0.1 & 0.1 \\ 1 & 0.1 & 0.1 & 0.2 & 0.3 & 0.05 & 0.1 & 0.1 & 0.1 & 0.2 \\ 1 & 0.85 & 0.7 & 0.85 & 0.3 & 0.6 & 0.55 & 0.2 & 0.45 & 0.2 \\ 0.5 & 0.5 & 0.5 & 0.5 & 0.9 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 \\ 0.3 & 0.5 & 0.3 & 0.3 & 0.3 & 0.5 & 0.3 & 0.3 & 0.5 & 0.3 \end{bmatrix}$$

By multiplying the weighting matrix Ausing rough sets theory with index evaluation matrix R, we can get the fuzzy comprehensive evaluation matrix:

$$B=R\times A^T=\begin{bmatrix} 0.7965 \\ 0.5695 \\ 0.4714 \\ 0.5092 \\ 0.3773 \\ 0.4502 \\ 0.3078 \\ 0.2362 \\ 0.3017 \\ 0.2301 \end{bmatrix}$$

Comparing the values of matrix, the order of flight in landing queue can be obtained. It is because the greater the value is, the flight order should be near the top. Under the case of mininaltotal delay and considering minimal separation constrain, the sequencing result is A1, A2, A4, A3, A6, A5, A7, A9, A8, A10. Comparison the result calculated by rough set theory based fuzzy comprehensive evaluation method with FCFS, shown as TABLE 6, the total delay time reduces from 700 seconds to 676 seconds. From TABLE 6, we can know that the order of flight A4 and A3 is exchanged, because velocity of A4 is faster than A3; the order of flight 5 and A6 is exchanged too, because A6 is special plane and has higher priority.

Besides, the order of flight A8 and A9 is also exchanged because of their different aircraft types, which means different wake separation. By changing the order of the two aircrafts can decrease the separation.

CONCLUSION

This paper mainly studies the fuzzy comprehensive evaluation based on rough set theory and the application this algorithm in arrival aircraft sequencing. Considering the minimum safety time interval between successive flights, estimated time of arrival, flight importance, distance to IF, speed and linked way with base leg, this algorithm is more close to the actual operation condition and effectively simulates the process of reasoning and decision-making of controller. Calculation of index weight is completely based on the data, which is more objective. The result of experiment verifies the effectiveness and feasibility of this method. The total delay time of system is decreased and arrival-rate of runway is improved.

TABLE 6 : Result of sequencing

Original data		FCFS result				Comprehensive evaluation result			
Flight number	ETA	Order	STA	Delay/s	Total delay/s	Order	STA	Delay/s	Total delay/s
A1	9:00:44	A1	9:00:44	0	0	A1	9:00:44	0	0
A2	9:01:18	A2	9:01:58	40	40	A2	9:01:58	40	40
A3	9:01:58	A3	9:03:12	74	114	A4	9:03:12	42	82
A4	9:02:30	A4	9:04:26	116	230	A3	9:04:26	148	230
A5	9:04:30	A5	9:05:40	70	300	A6	9:05:40	20	250
A6	9:05:20	A6	9:06:54	94	394	A5	9:06:54	144	394
A7	9:06:18	A7	9:08:08	110	504	A7	9:08:08	110	509
A8	9:08:30	A8	9:09:22	52	556	A9	9:09:22	0	509
A9	9:09:22	A9	9:11:16	114	670	A8	9:10:54	144	648
A10	9:12:00	A10	9:12:30	30	700	A10	9:12:28	28	676

REFERENCES

[1] R.G.Dear; The dynamic scheduling of aircraft in the near terminal area. Cambridge, Mass.: Flight Transportation Laboratory, Massachusetts Institute of Technology, **(1976)**.

[2] H.N.Psaraftis; A dynamic programming approach to the aircraft sequencing problem. Cambridge, Mass.: Massachusetts Institute of Technology, Flight Transportation Laboratory, **(1978)**.

[3] J.E.Robinson, T.J.Davis, D.R.Isaacson; Fuzzy reasoning-based sequencing of arrival aircraft in the terminal area, AIAA Guidance, Navigation and Control Conference, 1-11 **(1997)**.

[4] A.P.Saraf, G.L.Slater; An efficient combinatorial optimization algorithm for optimal scheduling of aircraft arrivals at congested airports, Aerospace Conference, IEEE, IEEE, 11 **(2006)**.

[5] X.B.Hu, W.H.Chen; Receding horizon control for aircraft arrival sequencing andscheduling, Intelligent Transportation Systems, IEEE Transactions on, **6(2)**, 189-197 **(2005)**.

[6] X.H.Xu, B.J.Huang; Study of fuzzy integrated judge method applied to the aircraft sequencing in the terminal area, ActaAeronauticaetAstronauticaSinica, **22(3)**, 259-261 **(2001)**.

[7] Z.N.Zhang, L.L.Wang; Dynamic Scheduling Algorithm Based on the Flow and Slip-Window in Air Traffic Management. Journal of Transportation Engineering and Information, **2(3)**, 22-25 **(2004)**.

[8] Researchon Comprehensive Evaluation for Aircraft Sequencing Problem in TMAA ccordingto RSTheory, Aeronautical Computing Technique, **40(6)**, 5-9 **(2010)**.

[9] N.Q.Wang, Y.Q.Xue, S.B.Li; Debris Flow Lability Comprehensive Evaluation Model on Rough Set Theory, Research of Soil and Water Conservation, **3,** 47 **(2014)**.

[10] M.J.Li, G.H.Chen, Y.T.Chen; Study on Target Standardization Method of Comprehensive Evaluation, Chinese Journal of Management Science, **z1**, 45-48 **(2004)**.

[11] G.Huang, W.Zhang; Research on Comprehensive Measurement Method Based on Rough Set, Computer Engineering and Application, **40(2)**, 36-38 **(2004)**.