A Benefit Verification of Network Sharing among Multiple Flight Schools: Based on the Construction of a Centralized Scheduling Method for Cross-country Training Plans

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Abstract: To enhance the cross-country training capability and reduce its training cost, a network sharing-oriented centralized scheduling method for multiple flight schools was proposed. The basic idea is as follows. First a connection network model for cross-country routes was constructed to search every training subject's feasible flight itinerary set using in-depth algorithm with the consideration of all minimum implementation requirements of every cross-country training subject in CCAR 141 for each flight school. Second, a model with the objective of minimizing total operating cost (including all flight schools) was established, in which the number of every cross-country training subject flowing on the corresponding feasible flight itinerary for each flight school was regarded as decision variables. Several limitations, including that each flight subject training demand of every flight school must be met and the number of flights flowing on each cross-country route must not exceed the capacity of the corresponding route, were treated as constraints. An example of 3 flight schools with 72 totally flight subjects is used to verify the feasibility of the model. The result shows the total operating cost has 8% improvement as opposed to the use of every flight school scheduling their flight training schemes alone.

Keywords: general aviation; cross-country scheme; centralized scheduling; connection network; in-depth search algorithm

1 INTRODUCTION

Scheduling cross-country training for flight school refers to determine the flight demand of each cross-country training subject flows in sequence through the airports (namely flight itinerary plan) within a network on the basis of meeting the minimum implementation requirements of each cross-country training subject stipulated by CAAC (namely the Civil Aviation Administration of China) regulations in a given cross-country network structure, training demand, flight capacity of each cross- country route etc., such that the total operating cost of completing all cross-country training needs are minimized. The shortage of flight training airspace has seriously affected the training of air transport pilots in flight schools. To solve this problem, Civil Aviation Administration of China proposes a concept of cross-country network sharing among multiple flight schools and asks them to implement centralized scheduling the

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cross-country training plans. Therefore, it's of great practical significance to provide an effective centralized scheduling method to ease the tense trend of training airspace and improve the overall economy of flight school.

In related research, Li Jingwei designed a simulation flight training architecture based on cloud computing to improve the utilization rate of simulation flight training resources [1]. Tian Jing and Wang Yu have established an optimization model of general trainer fleet configuration based on weighted directed graph, attempting to reduce the training cost of general trainer fleet [2, 3]. Based on the linear programming and dynamic programming models, Niu Tong solved the problem of optimal allocation of flight instructors, airspace and route use resources during training [4]. Chen Yaqing et al. established a route coupling capacity model and a flight delay cost model attempt to reduce the flight delay cost as well as improve airspace utilization [5]. Dahai Liu and Melissa A. Findlay used the discrete event simulation method to establish a resource scheduling model to evaluate the impact of changes in the resources available to students in the flight training equipment module on flight training [6]. It can be found that few reports are concentrated on the related research of cross-country training plan scheduling.

Therefore, in section 2, a connection network model of cross-country routes is firstly proposed and then used to search each training subject's feasible flight itinerary set by using in-depth algorithm in which all minimum implementation requirements of each cross-country training subject in CCAR 141 for each flight school are taken into account. Then a model with the objective of minimizing total operating cost was established, in which the number of each cross-country training subject flowing on the corresponding feasible flight itinerary for each flight school was regarded as decision variables. Several limitations, including that each flight subject training demand of every flight school must be met and the number of flights flowing on each cross-country route must not exceed the capacity of the corresponding route, were treated as constraints. Finally, section 3 provides a empirical example to verify the feasibility of the model.

2 METHODOLOGY

2.1 Description of cross-country training subjects

According to CCAR Part 141 Pilot Schools Certification Regulation [7], civil aviation cadets need to go through the four training phases of the private pilot license course, Instrument Reference course, the commercial pilot license course and the airline transport pilot license course in sequence, and each stage has a minimum training requirement limit, the specific limitations are:

Subject 1: The cross-country flight time is not less than 3 hours.

Subject 2: A total flight distance of a cross-country training exceeds 100 nautical miles.

Subject 3: A cross-country flight time is not less than 5 hours.

Subject 4: The total distance of a single flight is not less than 150 nautical miles, in which at least 2 landing points are stopped and the straight-line distance of one leg is not less than 50 nautical miles, or a single flight with a total distance is not less than 100 nautical miles, in which 3 landing points are stopped and the straight-line distance of one leg is not less than 50 nautical miles.

Subject 5: Fly no less than 250 nautical miles along routes or air traffic control guided routes, and have a straight-line distance of no less than 80 nautical miles for one flight segment.

Subject 6: A cross-country flight during the day and night is not less than 2 hours, respectively, and the total straight-line distance is not less than 100 nautical miles.

Subject 7: Three landing points for cross-country flights with at least one landing point and the starting point of takeoff at a straight line distance of not less than 250 nautical miles, or not less than 20 hours of cross-country flights, including one cross-country flight with a total distance of not less than 300 nautical miles and two landing points, one of which is at least 80 nautical miles from the starting point of takeoff.

Subject 8: A cross-country flight of not less than 5 h and at least 3 full stop landings as PF (operator pilot).

2.2 Construction of a connection model

All airports that can be used for cross-country training are defined as network nodes, we denote these nodes as V . Define the flight school as a flight training base as a network node, denoted as V^c.The connection network for cross-country training routes is constructed based on each airport node, denoted as $M=(V,X,W)$. For any two nodes that can perform cross-country training, the linear distance between nodes is denoted as $w^d(i,j)$, the flight distance required by the cross-country flight is denoted as $w^f(i,j)$, the airspace available capacity of the flight segment between airports is denoted as $w^c(i,j)$, the linear distance between the cross-country airport and the starting takeoff point is denoted as $w^{od}(i,j)$ and define the above four elements as arc weights for directed arcs, which is denoted as $W=\{w^d(i,j),w^f(i,j),w^c(i,j),w^{od}(i,j)\,|\,v_i,v_j\in V\cup V^c\}$. The specific steps of constructing the network are as follows:

Step 1: Define a virtual source node v_s and the directed arc $x(s,j)$ which is used to point from the virtual node v_s to the flight school node v_j $(\exists v_j\in V^c)$. This directed arc is defined as a (virtual) source arc. The arc weight is $w(s,j)=[0,0,0,0]$;

Step2: For any flight school node v_i, point to cross-country airport node v_j with v_i directed arc $x(i,j)$ and $\exists v_i\in V^{c}, v_j=\{v_j\in V, i\neq j\}$. This arc is defined as the origin arc. The arc weight is $w(i,j)=[w^d(i,j),w^f(i,j),w^c(i,j),w^{od}(i,j)]$;

Step 3: Initialize the number of airport layers L that the training route flows through, which is the depth limit of the search.

Step 4: $L = L+1$. For any airport node $v_i(v_i \in V)$, point to airport node v_j with v_i directed arc $x(i,j)$,and $\exists v_j = \{v_j \in V, i \neq j\}$. This arc is defined as the bridging arc. The arc weight is $w(i,j) = [w^d(i,j), w^f(i,j), w^c(i,j), w^{od}(i,j)]$;

Step 5: For any airport node $v_i(v_i \in V)$, point to flight school node v_j with v_i directed arc $x(i,j)$,and $\exists v_j = \{v_j \in V^c, i \neq j\}$. This arc is defined as the arrival arc. The arc weight is $w(i,j) = [w^d(i,j), w^f(i,j), w^c(i,j), w^{od}(i,j)]$;

Step 6: Define a virtual sink node v_t, the directed arc $x(i,t)$ is used to point from the flight school node v_i to the virtual sink node v_t and $\exists v_i \in V^c$. This directed arc is defined as a (virtual) terminating arc. The arc weight is $w(i,t) = [0,0,0,0]$;

The connection network model for cross-country routes is shown in Fig.1.

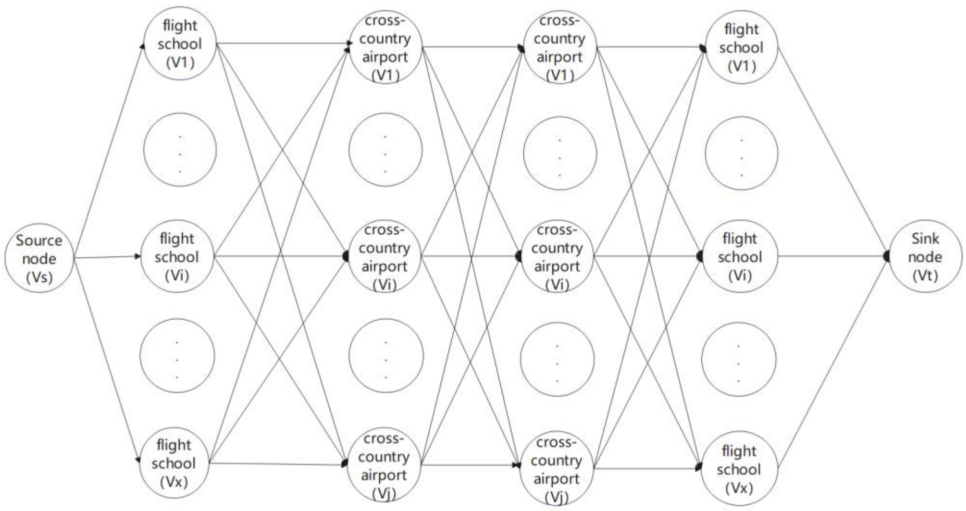

Fig. 1 The connection network model for cross-country routes

2.3 Design of In-depth algorithm

Basing on the above theoretical model, we use the in-depth search algorithm to realize the feasible set of implementation routes of each cross-country training subject. In-depth search algorithm false code is shown in Fig.2:

```
Input:G/*G is the training airport map          //Enter the training airport node data
Input:N/*N is the number of training subjects
                                                 //Enter the number of transfer training subjects
Void DFSGraph(G,k){
    Set flag ←[ ]                                //Instantiate array flag to hold all nodes
    For node ∈ G do
        If flag[node]==false then               //If the node is not accessed
            DFS(G,node,flag)                    //Do a deep search
            way=[flag node]                     //Record the search path
        End If
            For n ∈ N do
            If way satisfies the conditions of subject n then
                                                //If the path meets the requirements of subject n
                Print way                       //Recording a feasible path
            End If
        End For
    End For
}
Void DFS(G,node,flag){                          //The exit of the recursion
If flag[node]==true then                        //If the node is accessed
    Return                                      //Return
visited(node)                                   //Access to the node
    flag[node]=true                             //Tag node
    adjL=getadjL(node)                          //Gets the set of neighboring nodes of node node
    For adjN ∈ adjL do                          //Perform the following steps for each adjacent node
        If flag[adjN]!=true then                //If an adjacent node is not accessed
            DFS(G,adjN,flag)                    //Then in-depth search algorithm starts from this node
        End If
    End For
}
```

Fig.2 Design of In-depth algorithm

2.4 Mathematical model

According to the above ideas, the feasible set of training routes of the transfer training subject is obtained, denoted as $F(n)$. For the convenience of explanation, the demonstrative operator λ_{mnk}, wherein $\lambda_{mnk} = \begin{cases} 1, m \in F(n) \\ 0, m \notin F(n) \end{cases}$, is further defined to judge whether the cross-country training route m starting from the flight school k belongs to the cross-country training subject n.

In order to minimize the operation cost of cross-country training, the objective function can be expressed as:

$$\min \sum_{k \in K} \sum_{m \in M} \sum_{n \in N} \lambda_{mnk} c_{mnk} x_{mnk} \tag{1}$$

Where c_{mnk} represents the unit operating cost of flight school k training subject n once on the cross-country training route m;

In order to meet the cross-country training capability in the future, each flight aviation school will set the demand for training subjects every day to ensure that the number of completed training is no less than the expected number Q_{nk}, as shown in Formula (2).

$$\sum_{m \in M} \lambda_{mnk} x_{mnk} \geq Q_{nk}, \forall n \in N, \forall k \in K \tag{2}$$

Due to the constraints of training subjects, military and civil aviation activities and other factors, the capacity of any flight segment in a period of time is always limited, as shown in Formula (3).

$$\sum_{m\in M}\sum_{n\in N}\sum_{k\in K}\delta_{my_{ab}}\lambda_{mnk}x_{mnk} \le B_{y_{ab}} \quad (3)$$

Where $B_{y_{ab}}$ represents the maximum capacity on segment y_{ab} ,and

$$\delta_{my_{ab}} = \begin{cases} 1, & \text{the cross-country route m contains segment } y_{ab} \\ 0, & \text{the cross-country route m does not contain segment } y_{ab} \end{cases}$$

Formula (4) is the value range of decision variables.

$$x_{mnk} \ge 0, \forall m \in M, \forall n \in N, \forall k \in K \quad (4)$$

3 EMPIRICAL EXAMPLE

Select 3 flight schools and 8 other available training airports in an area (numbered from 1 to 11, with numbers 1, 2 and 5 indicating the selected flight school) Tab.1 shows the flight distance and straight-line distance between the two airports (These data from "Great Circle Mapper"). The hourly cost of training for subjects 1 to 6 is 2,500 yuan, for subject 7 is 3,500 yuan and for subject 8 is 5,000 yuan.

Tab. 1 Flight/straight line distance (nautical miles)

	1	2	3	4	5	6	7	8	9	10	11
1	0/ 0	110/ 40	144/ 74	161/ 91	146/ 76	194/ 124	173/ 103	221/ 151	186/ 116	260/ 190	325/ 255
2	110/ 40	0/ 0	165/ 95	142/ 72	105/ 35	207/ 137	199/ 129	181/ 111	160/ 90	230/ 160	365/ 295
3	144/ 74	165/ 95	0/ 0	153/ 83	193/ 123	121/ 51	104/ 34	258/ 188	181/ 111	249/ 179	296/ 226
4	161/ 91	142/ 72	153/ 83	0/ 0	142/ 72	167/ 97	184/ 114	185/ 115	98/ 28	172/ 102	379/ 309
5	146/ 76	105/ 35	193/ 123	142/ 72	0/ 0	227/ 157	227/ 157	145/ 75	148/ 78	209/ 139	400/ 330
6	194/ 124	207/ 137	121/ 51	167/ 97	227/ 157	0/ 0	114/ 44	282/ 212	189/ 119	242/ 172	305/ 235
7	173/ 103	199/ 129	104/ 34	184/ 114	227/ 157	114/ 44	0/ 0	293/ 223	211/ 141	275/ 205	269/ 199
8	221/ 151	181/ 111	258/ 188	185/ 115	145/ 75	282/ 212	293/ 223	0/ 0	169/ 99	186/ 116	475/ 405
9	186/ 116	160/ 90	181/ 111	98/ 28	148/ 78	189/ 119	211/ 141	169/ 99	0/ 0	143/ 73	408/ 338
10	260/ 190	230/ 160	249/ 179	172/ 102	209/ 139	242/ 172	275/ 205	186/ 116	143/ 73	0/ 0	474/ 404
11	325/ 255	365/ 295	296/ 226	379/ 309	400/ 330	305/ 235	269/ 199	475/ 405	408/ 338	474/ 404	0/ 0

The above data was used to construct a connection network model for cross-country routes, and feasible cross-country training routes for each training discipline of the three flight schools obtained by in-depth search algorithm. Based on actual operational experience, the unit hourly capacity of the airspace between the given airports is shown in Tab.2.

Tab. 2 Unit hourly capacity of airspace in the segment between the two airports

Segment airspace capacity (aircraft)	1	2	3	4	5	6	7	8	9	10	11
1	0	8	10	11	10	14	12	16	13	18	23
2	8	0	12	10	7	15	14	13	11	16	26
3	10	12	0	11	14	8	7	18	13	18	21
4	11	10	11	0	10	12	13	13	7	12	27
5	10	7	14	10	0	16	16	10	10	15	29
6	14	15	8	12	16	0	8	20	13	17	22
7	12	14	7	13	16	8	0	21	15	20	19
8	16	13	18	13	10	20	21	0	12	13	34
9	13	11	13	7	10	13	15	12	0	10	29
10	18	16	18	12	15	17	20	13	10	0	34
11	23	26	21	27	29	22	19	34	29	34	0

It can be analyzed from the actual flight training data of the flight school every day, the total number of subjects trained by each flight school in a day is about 20. Therefore, the number of cross-country training requirements for each subject set in this paper is 3.

3.1 Results and Analysis

On the python+GUROBI platform, the above data are brought into the optimization model of cross-country flight training, and the joint training results of the three flight colleges under the premise of resource sharing were obtained, which are listed in Tab.3.

Tab. 3 Flight School resource sharing training program

Flight School 1	Subject	Times	Flight School 2	Subject	Times	Flight School 3	Subject	Times
1-7	1	3	2-3	1	3	5-3	1	3
1-2	2	3	2-5	2	3	5-2	2	3
1-3	4	3	2-4	4	3	5-4	4	3
1-4	5	3	2-9	5	3	5-3	5	3
1-2	6(day)	3	2-1	6(day)	2	5-4	6(day)	3
1-4-8-1	3	3	2-4	6	1	5-4-7-5	3	3
1-3-11-1	7	3	2-6-9-2	3	3	5-1-11-5	7	3
1-3-10-1	8	3	2-3-11-2	7	3	5-4-9-5	8	3
			2-3-6-2	8	2			
			2-4-5-2	8	1			
1-2	6 (night)	3	2-1	6 (night)	3	5-4	6 (night)	3

It can be found that the program meets the minimum implementation requirements for all types of cross-country subjects, as well as the requirements of the three flight academy training subjects and the capacity limits of the cross-country paths, so the results are considered reasonable and feasible. The total training cost is approximately 920587.9 yuan.

3.2 Comparison and Analysis

The navigable points corresponding to the flight school 1 are airport 3, airport 6 and airport 11; The navigable points corresponding to flight School 2 are airport 4, airport 8 and airport 11; The navigable points corresponding to flight School 3 are airport 7, airport 9, airport 10 and airport 11. On the premise of the three flight schools independently cross-country training, the scheme of training the same requirements is shown in Tab.4.

Tab. 4 Flight school independent training program

Flight School 1	Subject	Times	Flight School 2	Subject	Times	Flight School 3	Subject	Times
1-4	1	3	2-8	1	3	5-10	1	3
1-3	2	3	2-4	2	3	5-9	2	3
1-3	3	3	2-4	3	3	5-9	4	3
1-3	4	3	2-4	4	3	5-10	5	3
1-6	5	3	2-8	5	3	5-9	6(day)	3
1-3	6(day)	3	2-4	6(day)	3	5-7-9-5	3	3
1-3-11-1	7	1	2-4-11-2	7	1	5-7-11-5	7	3
1-11-3-1	7	2	2-11-4-2	7	2	5-9-10-5	8	3
1-3-11-1	8	3	2-4-8-2	8	3			
1-3	6 (night)	3	2-4	6 (night)	3	5-9	6 (night)	3

It can be found that the programme meets the minimum implementation requirements for all types of transitional subjects and the requirements of the training subjects of the three flight schools, and the capacity limit of the cross-country path, so the results are considered reasonable and feasible. But the total training cost is 1001676 yuan. Comparing the cost obtained by two different training methods, the total cost of cross-country training under resource sharing is about 8% lower than the total cost of independent training of each flight school.

With the increase in the demand for training subjects of each flight school, the total cost of each flight school's training under the condition of resource sharing is compared with the total cost under the condition of independent training, and the trend of cost reduction rate is shown in Fig.3.

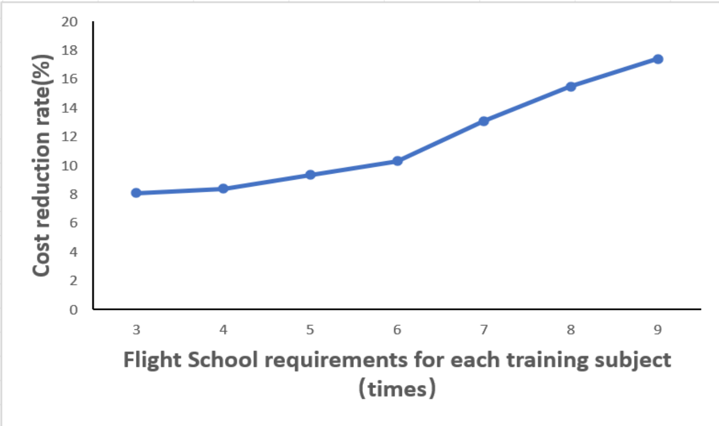

Fig. 3 Trend chart of cost reduction rate

As can be seen from the above analysis, with the increasing demand for training subjects in each flight school, the gap between the total training cost under resource sharing and the total cost of independent training in each flight school is getting larger. That is, with the gradual increase of training demand, the economic benefits brought by resource sharing become more significant.

4 CONCLUSION

In order to improve the cross-country training capability and reduce the cost of cross-country training, this paper proposes a rapid generation method of cross-country training route plan based on the concept of cross-country route sharing. Three flight schools and eight cross-country airports were selected to build a cross-country route connection network model for cross-country route resource sharing, and an in-depth search algorithm is used to obtain feasible routes set for various cross-country training subjects. The model of route planning allocation for multi-school cross-country training is constructed. The results of the case show that the method is feasible and effective.

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