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A Multi-CBR Algorithm Based on Comprehensive Evaluation for Operation Planning of Helicopter

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ABSTRACT Case-based reasoning (CBR) is an effective reasoning technology. The core idea of CBR is using past experience and expert knowledge to solve new problems. Operation planning of helicopter mainly relies on the experiences of the decision-maker, so CBR is an effective reasoning technology which can be used in the operation planning. Two key issues, evaluation method and case adaptation, are widely focused in CBR method. However, the existing CBR is not suitable for non-numeric optimization problem such as operation planning, because it belongs to small sample size problem. To solve this problem, the comprehensive evaluation based multi-CBR (CEB-mCBR) method is proposed in this paper, which can be used for operation planning of helicopter. According to the comprehensive evaluation theory, similar historical case set of the target case is established, and the historical operation plans are ranked. On this basis, the optimum initial plan for the target case is generated by the case screening CBR model. Then the solution element screening CBR model is further put forward to solve the issue of case adaptation. The CEB-mCBR method comprises multi-CBR (case screening CBR and solution element screening CBR) and combination evaluation method. It can integrate expert experience and human thinking better, especially when solution space is limited. Finally, through a case study analysis, the multi-CBR model can generate a feasible solution for the target case, and the solution elements can be adjusted according to the situation in the actual operation, which can improve the efficiency of operation planning while keeping the safety, economy and operating efficiency.

INDEX TERMS Comprehensive evaluation, case adaptation, helicopter, multi-CBR, operation planning.

I. INTRODUCTION

At present, helicopter is widely used in complex and varied operational environment. And making operation plan is an important part of helicopter operation. Considering the management of a large fleet, traditional operation planning mainly relies on the experience of decision makers, which needs in-depth quantification and improvement. With the development of data collecting and processing technologies, the historical operational information of helicopter can be stored in a constant form. Therefore, based on the data of historical operation cases, how to use the historical cases as reference to generate a feasible operation plan for the current task is the topic of this paper.

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Case-based reasoning (CBR) is an important reasoning technology in the field of artificial intelligence. Its core idea is that people use past experience and knowledge to solve new problems. When people meet a new problem, their common reaction is looking for the similar problem in the experience base, and taking the solution from the similar problem in the past. Then the solution from the similar problem is taken as the starting point to solve the actual problem, and people obtain the solution of the new problem through corresponding modification. Much research on historical information reuse and CBR has been done. CBR technology has been applied in decision-making problems of various fields, such as explainable prediction of chronic renal disease generating [1], alternative for environmental emergency preparedness systems [2], [3], trustworthiness evaluation and revision of classification [4], machining parameters selection [5] and RH control model with higher accuracy [6]. Even though CBR technology has been studied and applied for many years, different CBR models applied in certain fields cannot be well reused in other fields. Evaluation method and case adaptation are two key issues of CBR method. The former is the basis of weight calculation for similar cases selection and ranking, and the latter determines whether the solution of similar cases can be reused by new problems.

In order to make evaluation method more suitable for the problems studied, many researchers have applied intelligent algorithms to CBR model, such as artificial neural networks (ANN) [1], genetic algorithm (GA)[2], [6], [7], random forest (RF) [8], decision tree (DT) [9], and so on. However, under the condition of small sample, these intelligent algorithms are inapplicable for such operation planning problem which is non-numeric optimization. And in order to reduce the impact of method selection on the evaluation results, a series of comprehensive evaluation methods [10], [11] proposed can improve the accuracy and reliability of the evaluation conclusion. Therefore, combining subjective weight with objective weight [12]–[16] is an effective means for weight calculation in small sample size problem. When it is ranking problem, the idea of maximizing deviation [17], [18] could be introduced into the comprehensive ranking of cases. Combination weight and comprehensive ranking all belong to comprehensive evaluation method.

Jian and Zhe [19] analyzed operational plan generated by CBR, nevertheless there are still some relevant problems to be addressed: the adaptability and accuracy of the plan are not satisfactory. Up to now, case adaptation in CBR is basically based on other algorithms [20]–[22] which are obviously not suitable for operation plan adjustment, because the solution space of operation plan adjustment is limited and belongs to non-numeric optimization problem. Therefore, aiming at operation planning of helicopter, the comprehensive evaluation based multi-CBR (CEB-mCBR) method is proposed in this paper to solve this problem in operation planning of helicopter. With the comprehensive evaluation theory, the weight determination in establishment of similar historical case set and ranking for historical operation solutions are solved, and the optimum initial plan for the target case is generated by the case screening CBR model. Then in order to better integrate expert experience and human thinking—adjusting solution elements in similar options, the solution element screening CBR model is further put forward to complete case adaptation, which can be named multi-CBR with the case screening CBR model. To the authors' knowledge, research on multi-CBR only focuses on the retrieval of initial solution of target case [23]–[25]. A case study analysis illustrates that the CEB-mCBR model can generate a feasible operation plan for a target case, and the security and reliability of generated plans are verified by cross validation, which demonstrates that the CEB-mCBR model has high practical value.

The rest of this paper is organized as follows. The case space for operation planning of helicopter and the specific application of CEB-mCBR in this problem are given in Section II. Then the definition of the CBR model for generating preliminary operation plan is given in Section III, and the CBR model for case adaptation are further put forward in Section IV. In Section V, an example and cross validation are analyzed to illuminate the feasibility and effectiveness of this proposed method. The last section concludes this paper and offers the future work.

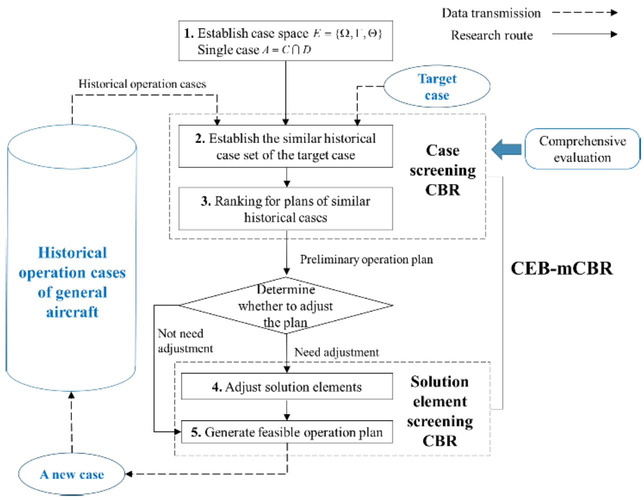

FIGURE 1. The logical structure of CEB-mCBR method.

II. OPERATION PLANNING OF HELICOPTER WITH MULTI-CBR

As mentioned earlier, even though CBR models applied in different fields cannot be well reused in other fields, the basic principles and rules of case-based reasoning are universal [26]. For this reason, the aim of this paper is to generate operation plan through retrieval [27] and reuse of similar historical cases.

To make CBR method more suitable for operation planning of helicopter, this paper proposes the comprehensive evaluation based multi-CBR (CEB-mCBR) method. The multi-CBR contains case screening CBR and solution element screening CBR. On the basis of establishing case space, the case screening CBR is used to generate preliminary operation plan of the target case with comprehensive evaluation, and the solution element screening CBR is used to complete plan adjustment. The logical structure of this method is illustrated in Fig.1.

A. ESTABLISHMENT OF CASE SPACE

For such problems applying CBR method, it is started by establishing case space $E=\{\Omega,\Gamma,\Theta\}$, Ω and Γ are attribute space and solution space respectively. Θ is the combination of process subspace, algorithm subspace and rule subspace that constitutes the trace solution set. For a single case $A=C\cup D$, A is a historical case, C is the condition attribute set, D is the decision attribute set, namely, the solution element set. The target case to be solved is actually a special case in which the solution element set is an empty set.

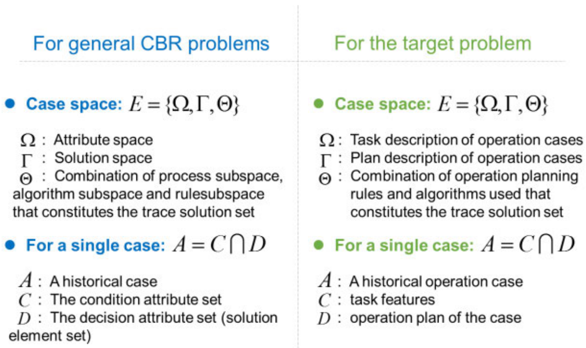

FIGURE 2. **Comparisons between general CBR problems and the target problem.**

TABLE 1. **Indexes of condition attribute set of an operation case.**

Index	Value
Category	operation category
User	police or non-police
longitude	median value of longitude
latitude	median value of latitude
Time span	(Job start month, Job end month)

For the target problem of this research, Ω and Γ are task description and plan description of operation cases respectively. Θ is the combination of operation planning rules and algorithms used that constitutes the trace solution set. For a single operation case $A = C \cup D$, A is a historical case, C is the task requirements and features, and D is operation plan of the case.

The comparisons between general CBR problems and the target problem are shown in Fig.2.

1) CONDITION ATTRIBUTE SET OF HELICOPTER OPERATION CASES

According to the actual operation, the condition attribute set of an operation case is defined as the task features of the case, which mainly includes the following items:

Category: such as aviation forest protection, power line inspection and aerial patrol.

User of the aircraft: it is classified as police or non-police.

Operation area: it refers to the latitude and longitude range of the operation area, generally taking the median value, this feature reflects the working terrain topography of operation area.

Time span: accurate to the month, such as March 2019 —June 2019, this feature reflects the climate of operation environment.

So similar cases can be retrieved according to the five indexes in the following table.

2) DECISION ATTRIBUTE SET OF HELICOPTER OPERATION CASES

The decision attribute set (solution element set) of an operation case is defined as the operation plan of the case, which should include: solution elements (aircraft, crew and equipment used in the operation), attributes of solution elements (for plans selection and ranking).

TABLE 2. **Decision attribute set of an operation case.**

Solution element	Attributes of solution element			
Aircraft	Airworthiness	Total service hours	Health status	Average using cost
Captain	Age	Total flight hours	Health status	Salary expenses
Co-pilot	Age	Total flight hours	Health status	Salary expenses
Aerial machinist Navigator Operator	Their attribute has little effect on the plans selection and ranking			
Equipment	Using cost of equipment			

TABLE 3. **Indexes for operation plans ranking.**

Solution element	Indexes for operation plans ranking			
Aircraft	Airworthiness	Total service hours	Health status	Average using cost
Captain	Age	Total flight hours	Health status	Salary expenses
Co-pilot	Age	Total flight hours	Health status	Salary expenses

B. CASE SCREENING CBR

In the CBR problem, the calculation of similarity matrix between the target case and historical cases is an important part. This paper uses the similarity calculation method of k-nearest neighbor (k-NN) [28] to calculate the similarity between the target case and historical cases.

When calculating the similarity between the target case and historical cases, we should not only consider the relative importance of each index, but also refer to the amount of information contributed by the historical cases. In view of the merits and demerits of analytic hierarchy process (AHP) and entropy weight, the method of weighted integration [29] is adopted to get the combination weight. Coefficients of weight determination is an extreme value problem in restricted condition, and it is solved by Lagrange multiplier method.

After weight determination, the similarity between the target case and historical cases can be given. Historical cases with high similarity will be extracted as suitable cases, and similarity threshold [30] is set to extract suitable historical cases.

For similar historical cases, the corresponding decision attribute sets are reusable operation plans for the target case. The utility value of an operation plan is mainly considered from two aspects: safety and economy, and every solution element has its own evaluation indexes. Thus, an operation plan has 12 evaluation indexes as given in Table.3 to select the most effective operation plan.

At the same time of introducing the idea of maximizing deviation, 4 ranking methods adopted in comprehensive ranking are TOPSIS(Technique for Order Preference by

Similarity to an Ideal Solution) [31], COPRAS(Complex Proportional Assessment) [32], MOORA(Multi-objective Optimization by Ratio Analysis) [33] and PROMETTEE (Preference Ranking Organization Method for Enrichment Evaluations) [34].

Finally, the operation plan with the maximum comprehensive ranking value is the preliminary operation plan of the target case.

C. SOLUTION ELEMENT SCREENING CBR

After generating the preliminary operation plan of the target case, the plan needs further adjustment in most instances. Reasons for adjustment may include:

- Task requirements
- The selected aircraft has performed or temporarily performed other tasks, or the aircraft schedule conflicts caused by the annual inspection arrangement, etc;
- Leave and resignation of personnel;
- More than one aircraft may be required to perform the target task;
- Other emergencies such as damage and failure of aircraft or equipment.

When the above situations occur, the solution elements in the preliminary operation plan must be adjusted and replaced accordingly. In CBR method, this is called case adaptation. Case adaptation can be divided into single case adaptation and combined case adaptation according to the adjustment object. If the adjusted case only references the most similar historical case, it is called single case adaptation [35]. If the solution element set is a composite solution generated by several similar historical cases, it is called combined case adaptation [36].

According to the scale of solution element adjustment, single case adaptation can be divided into empty adjustment, conversion adjustment and induced adjustment [35]. A solution element to be adjusted is just replaced and not deleted or added in helicopter operation. Therefore, on the basis of alternative adjustment method, another independent CBR model is used to complete case adaptation.

This CBR model still find solution from historical cases with k-NN and TOPSIS. The difference between this CBR model and case screening CBR is that its solution object is the element to be adjusted in the operation plan.

III. CBR MODEL FOR GENERATING INNITIAL OPERATION PLAN

A. ESTABLISHMENT OF SIMILAR HISTORICAL CASE SET

1) DATA PREPROCESSING

Suppose that there are $\boldsymbol{n}$ indexes of condition attribute set in a case and $\boldsymbol{m}$ historical cases, so the historical cases set is $S_Z = \{Z_1, Z_2, \cdots, Z_m\}$, where Z_i represents the *ith* historical case. The index value vector of the *ith* historical case Z_i is $z_i = (x_{i1}, x_{i2}, \cdots, x_{in})$, $i = 1,2,\cdots, m$. The normalized Z_i is $\overline{z_i} = (z_{i1}, z_{i2}, \cdots, z_{in})$, and Min-Max Normalization [37] is selected as normalization method. Similarly, the normalized index value vector of the target case is $\overline{z_t} = (z_{t1}, z_{t2}, \cdots, z_{tn})$.

In this way we obtain the normalized index value matrix of historical case set as (1):

$$\overline{Z}_{m\times n} = \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1n} \\ z_{21} & z_{22} & \cdots & z_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ z_{m1} & z_{m2} & \cdots & z_{mn} \end{bmatrix} \quad (1)$$

2) CALCULATION OF SIMILARITY VALUE BETWEEN THE TARGET CASE AND HISTORICAL CASES

To calculate the similarity $\mathrm{Sim}(Z_t, Z_i)$ between the target case Z_t and a historical case Z_i, the similarity $\mathrm{Sim}_j(Z_t, Z_i)$ between Z_{tj} and Z_{ij} and the corresponding weight ω_j, the equation can be written as (2):

$$\mathrm{Sim}(Z_t, Z_i) = \sum_{j=1}^{n} \omega_j \cdot \mathrm{Sim}_j(Z_t, Z_i) \qquad i = 1, 2, \cdots, m, j = 1, 2, \cdots, n \quad (2)$$

where $\mathrm{Sim}(Z_t, Z_i) \in [0, 1]$ and $\sum_{j=1}^{n} \omega_j = 1$.The greater the $\mathrm{Sim}(Z_t, Z_i)$ value, the higher the similarity between Z_t and Z_i, that is, the higher the reference value of the historical case to the target case.

According to (2), the calculation of $\mathrm{Sim}(Z_t, Z_i)$ mainly involves the calculation of $\mathrm{Sim}_j(Z_t, Z_i)$ and the determination of ω_j. Considering the values of indexes having different types, the calculation formula of $\mathrm{Sim}_j(Z_t, Z_i)$ is divided into numerical and text types as described by (3) and (4):

Numerical type:

$$\mathrm{Sim}_j(Z_t, Z_i) = \exp\left(-\left|z_{ij} - z_{tj}\right|\right) \quad (3)$$

Text type:

$$\mathrm{Sim}_j(Z_t, Z_i) = \begin{cases} 1, & z_{tj} = z_{ij} \\ 0, & z_{tj} \neq z_{ij} \end{cases} \quad (4)$$

where $i = 1,2,\cdots, m, j = 1, 2, \cdots, n$.

Thus, the similarity matrix of all historical cases and the target case can be obtained, as shown:

$$Sim_{m\times n} = \begin{bmatrix} \mathrm{Sim}_1(Z_t, Z_1) & \mathrm{Sim}_2(Z_t, Z_1) & \cdots & \mathrm{Sim}_n(Z_t, Z_1) \\ \mathrm{Sim}_1(Z_t, Z_2) & \mathrm{Sim}_2(Z_t, Z_2) & \cdots & \mathrm{Sim}_n(Z_t, Z_2) \\ \cdots & \cdots & \cdots & \cdots \\ \mathrm{Sim}_1(Z_t, Z_m) & \mathrm{Sim}_2(Z_t, Z_m) & \cdots & \mathrm{Sim}_j(Z_t, Z_m) \end{bmatrix} \quad (5)$$

Next, it's time to determine the corresponding weight ω_j of each index of condition attribute set.

3) WEIGHT DETERMINATION

In view of the shortcomings of subjective weight determination and objective weight determination, we combined Analytic Hierarchy Process (AHP) and entropy weight to

TABLE 4. Judgment matrix.

C	c_1	c_2	$\cdots$	c_n
c_1	c_{11}	c_{12}	$\cdots$	c_{1n}
c_2	c_{21}	c_{22}	$\cdots$	c_{2n}
...	$\cdots$	$\cdots$	$\cdots$	$\cdots$
c_n	c_{n1}	c_{n2}	$\cdots$	c_{nn}

TABLE 5. RI value.

n	RI	n	RI
1	0	6	1.24
2	0	7	1.32
3	0.58	8	1.41
4	0.90	9	1.45
5	1.15	10	1.49

determine the combination Weight. The specific steps are as follows:

Step 1: Weight determination by AHP.

(a) Constructing judgment matrix:

At first, the judgment matrix $C = (c_{ij})_{nn}$ is obtained by pairwise comparison of various indexes (Table.4), c_{ij} indicates the importance of index i to index j. In this paper, 1∼ 9 scale law is used to express the importance of index i to index j (same, slightly, obviously, strongly and extremely important).

(b) Find the weight vector:

Using the square root method or ANC to calculate the eigenvector of matrix C_{nn}, we can normalize the eigenvector to get the subjective weight vector $\omega_a = [\omega_{a1}, \omega_{a2}, \cdots, \omega_{an}]^T$, and then calculate the maximum eigenvalue $\lambda_{\max}$.

(c) Consistency test:

In order to ensure that the judgment matrix is reasonable, the consistency test shall be carried out for the judgment matrix, as shown in (6). When CR is greater than or equal to 1, the judgment matrix needs to be modified. RI is the index of average random variable, which is taken as shown in Table.5.

$$CR = \frac{\lambda_{\max} - n}{RI(n-1)} \tag{6}$$

Step 2: Weight determination by Entropy Method.

(a) Normalization of indexes:

In section III.A.1), we have obtained the normalized index value matrix $\overline{Z}_{m\times n}$ of historical cases set as (1).

(b) Calculating the proportion p_{ij} of the jth index value in the ith case:

$$p_{ij} = \frac{z_{ij}}{\sum_{i=1}^{m} z_{ij}}, \quad i = 1, 2, \cdots, m, \; j = 1, 2, \cdots, n \tag{7}$$

(c) Calculating the entropy value e_j and difference coefficient g_j of each index:

$$e_j = -k \sum_{i=1}^{m} p_{ij} \ln p_{ij} \quad 0 \le e_j \le 1 \tag{8}$$

$$g_j = 1 - e_j \tag{9}$$

In (8), $k = \ln(m) - 1$.

(d) Calculating the information weight coefficient μ_j, namely, correction coefficient:

The equation that describes μ_j of the jth index is as follows:

$$\mu_j = \frac{g_j}{\sum_{j=1}^{n} g_j} \tag{10}$$

At this point, the objective weight vector $\omega_e = [\omega_{e1}, \omega_{e2}, \cdots, \omega_{en}]^T = [\mu_1, \mu_1, \cdots, \mu_n]^T$ can be obtained.

Step 3: Integration of subjective and objective weight.

The combination weight vector ω_c:

$$\omega_c = \alpha\omega_a + \beta\omega_e \tag{11}$$

The complete steps of weight integration are as follows:

(a) The optimal model based on weighted was performed in order to determine the comprehensive coefficients α and β:

$$\max Z = \sum_{i=1}^{m}\sum_{j=1}^{n} \mathrm{Sim}_j(Z_t, Z_i) \cdot (\alpha\omega_{aj} + \beta\omega_{ej}) \tag{12}$$

$$s.t \alpha^2 + \beta^2 = 1, \quad \alpha > 0, \beta > 0 \tag{13}$$

(b) To satisfy(13), the optimal solution of model (12) is (14) and (15), as shown at the bottom of the page.

This model is an extreme value problem in restricted condition. We could use Lagrange Multiplier Method to solve it, which is described by (16):

$$L = \sum_{i=1}^{m}\sum_{j=1}^{n} \mathrm{Sim}_j(Z_t, Z_i) \cdot (\alpha\omega_{aj} + \beta\omega_{ej}) + \frac{\lambda}{2}(\alpha^2 + \beta^2 - 1) \tag{16}$$

$$\alpha^* = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} \mathrm{Sim}_j(Z_t, Z_i)\omega_{aj}}{\sqrt{\left(\sum_{i=1}^{m}\sum_{j=1}^{n} \mathrm{Sim}_j(Z_t, Z_i)\omega_{aj}\right)^2 + \left(\sum_{i=1}^{m}\sum_{j=1}^{n} \mathrm{Sim}_j(Z_t, Z_i)\omega_{ej}\right)^2}} \tag{14}$$

$$\beta^* = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} \mathrm{Sim}_j(Z_t, Z_i)\omega_{ej}}{\sqrt{\left(\sum_{i=1}^{m}\sum_{j=1}^{n} \mathrm{Sim}_j(Z_t, Z_i)\omega_{aj}\right)^2 + \left(\sum_{i=1}^{m}\sum_{j=1}^{n} \mathrm{Sim}_j(Z_t, Z_i)\omega_{ej}\right)^2}} \tag{15}$$

where λ is Lagrange multiplier.

Setting $\frac{\partial L}{\partial \alpha} = 0$, $\frac{\partial L}{\partial \beta} = 0$:

$$\begin{cases} \sum_{i=1}^{m}\sum_{j=1}^{n} \mathrm{Sim}_j(Z_t, Z_i)\omega_{aj} + \lambda\alpha = 0 \\ \sum_{i=1}^{m}\sum_{j=1}^{n} \mathrm{Sim}_j(Z_t, Z_i)\omega_{ej} + \lambda\beta = 0 \end{cases} \tag{17}$$

Equation (13) and (17) were combined (18), as shown at the bottom of the page.

α^* and β^* was normalized to satisfy $0 \le \omega_{cj} \le 1$ and $\sum_{j=1}^{n} \omega_{cj} = 1$:

$$\overline{\alpha} = \frac{\alpha^*}{\alpha^* + \beta^*}, \quad \overline{\beta} = \frac{\beta^*}{\alpha^* + \beta^*} \tag{19}$$

As is clear from (15)(14)(19), α and β could be determined:

$$\begin{cases} \overline{\alpha} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} \mathrm{Sim}_j(Z_t, Z_i)\omega_{aj}}{\sum_{i=1}^{m}\sum_{j=1}^{n} \mathrm{Sim}_j(Z_t, Z_i)\cdot(\omega_{aj}+\omega_{ej})} \\ \overline{\beta} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} \mathrm{Sim}_j(Z_t, Z_i)\omega_{aj}}{\sum_{i=1}^{m}\sum_{j=1}^{n} \mathrm{Sim}_j(Z_t, Z_i)\cdot(\omega_{aj}+\omega_{ej})} \end{cases} \tag{20}$$

With this, the comprehensive weight vector is $\omega_c = \overline{\alpha}\omega_a + \overline{\beta}\omega_e = [\omega_{c1}, \omega_{c2}, \cdots, \omega_{cn}]^T$.

4) HISTORICAL CASES EXTRACTION

If $\mathrm{Sim}(Z_t, Z_i)$ was greater than or equal to similarity threshold ξ computed by (21), the case Z_i would be extracted into similar historical case set $S_{sim} = \{Z_i|\mathrm{Sim}(Z_t, Z_i) \ge \xi, i = 1, 2, \cdots, m\}$:

$$\xi = \tau \cdot \max_{1\le i\le m} \{\mathrm{Sim}(Z_t, Z_i)\}, \quad 0<\tau \le 1 \tag{21}$$

where $0 < \tau \le 1$. The value of τ is given by the decision-maker based on experience or historical data. The larger τ is, the higher the similarity between the extracted historical cases and the target case is.

B. COMPREHENSIVE EVALUATION RANKING FOR HISTORICAL OPERATION PLANS

Based on the indexes for operation plans ranking in Table.3, we can evaluate and sort the operation plan of each case in S_{sim}, so as to select the operation plan with the highest utility value as the preliminary operation plan of Z_t.

Generally, ranking methods determine the ranking results by calculating the ranking reference value. Suppose the weight vector of n single ranking methods in combination method is $\omega_r = [\omega_{r1}, \omega_{r2}, \cdots, \omega_{rn}]^T$, then the combined ranking value of the *ith* evaluation object $O_i(i = 1, 2, \cdots, m)$ can be obtained as:

$$F_i = \omega_{r1}f_{i1} + \omega_{r2}f_{i2} + \cdots + \omega_{rn}f_{in} \tag{22}$$

where $f_{ij}(j = 1, 2, \cdots, n)$ is normalized ranking reference value for the jth sorting method. In multi-attribute decision-making, if the ranking values of a ranking method for all decision-making objects are not different, the weight of this evaluation method is small. Otherwise, if the ranking method for all decision-making objects has a large difference between the evaluation values, this evaluation value will play a greater role in the comprehensive ranking of decision-making objects, and its weight will be large.

Under the the jth ranking method, d_{ijt} is the deviation between the ith evaluation object O_i and the tth evaluation object $O_t(t = 1, 2, \cdots, m)$:

$$d_{ijt} = |f_{ij} - f_{tj}| \tag{23}$$

So the total deviation between O_i and O_t under the combined sorting method is:

$$d_{it} = \sum_{j=1}^{n} \omega_{rj} |f_{ij} - f_{tj}| \tag{24}$$

The total deviation of all the evaluation objects is:

$$D = \sum_{i=1}^{m}\sum_{t=1}^{m}\sum_{j=1}^{n} \omega_{rj} |f_{ij} - f_{tj}| \tag{25}$$

Under the comprehensive ranking method, the weight vector $\omega_r = [\omega_{r1}, \omega_{r2}, \cdots, \omega_{rn}]^T$ should be such that the total deviation of all the evaluation objects is the largest.The equation that describes the model is as follows:

$$\max D = \sum_{i=1}^{m}\sum_{t=1}^{m}\sum_{j=1}^{n} \omega_{rj} |f_{ij} - f_{tj}|$$
$$s.t. \sum_{j=1}^{n} \omega_{rj}^2 = 1$$
$$\omega_{rj} > 0, \quad j = 1, 2, \cdots, n \tag{26}$$

The model in (26) is similar to the optimal model in (12), which can be processed by Lagrange Multiplier Method to

$$\lambda = -\sqrt{\left(\sum_{i=1}^{m}\sum_{j=1}^{n} \mathrm{Sim}_j(Z_t, Z_i)\omega_{aj}\right)^2 + \left(\sum_{i=1}^{m}\sum_{j=1}^{n} \mathrm{Sim}_j(Z_t, Z_i)\omega_{ej}\right)^2} \tag{18}$$

TABLE 6. Indexes used to select similar elements.

Solution element		Indexes used to select similar elements				
Aircraft		The same aircraft type				
Captain		Operation category	Aircraft type	Operation area	The other pilot of the crew	Type of flight license
Co-pilot		Operation category	Aircraft type	Operation area	The other pilot of the crew	Type of flight license
Optional equipments		Generally do not need adjustment				
Other crew members	Aerial machinist	Operation category			Aircraft type	
	Navigator	Operation category			Operation area	
	Operator	Operation category			Aircraft type	

TABLE 7. Attributes used to evaluate elements.

Solution element	Attributes used to evaluate elements			
Aircraft	Airworthiness	Total service hours	Health status	Average using cost
Captain	Age	Total flight hours	Health status	Salary expenses
Co-pilot	Age	Total flight hours	Health status	Salary expenses
Other crew members	No evaluation Indexes			

obtain:

$$\omega_{rj} = \frac{\sum_{i=1}^{m}\sum_{t=1}^{m}|f_{ij}-f_{tj}|}{\sqrt{\sum_{j=1}^{n}(\sum_{i=1}^{m}\sum_{t=1}^{m}|f_{ij}-f_{tj}|)^2}} \tag{27}$$

Normalizing ω_{rj} :

$$\overline{\omega_{rj}} = \frac{\sum_{i=1}^{m}\sum_{t=1}^{m}|f_{ij}-f_{tj}|}{\sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{t=1}^{m}|f_{ij}-f_{tj}|} \tag{28}$$

And then the combined ranking value of O_i is:

$$F_i = \omega_{r1}f_{i1} + \omega_{r2}f_{i2} + \cdots + \omega_{rn}f_{in} \tag{29}$$

So if $F_i = \max_{1\le i\le m}\{F_i\}$, the *ith* evaluation object $O_i(i = 1, 2, \cdots, m)$ is the operation plan with the highest utility value. In this paper, the 4 single ranking methods (TOPSIS, COPRAS, MOORA, PROMETTEE) are common so we don't introduce these methods in detail here. As a representative ranking method in multiple attribute decision making, TOPSIS method will be detailed in Section IV.

IV. CBR MODEL FOR CASE ADAPTATION

Because of the change of solving object, the case space of this CBR model is different from the one in Section II. The core idea of this CBR model is still to select similar options by retrieving every historical case.

For a solution element to be adjusted, $A = C \cup D$, A is a historical case, C is the value of corresponding indexes in Table.6, whereas D is the solution element of this historical case and the value of corresponding attributes in Table.7.

- Aircraft: the type of aircraft generally does not change and aircraft is adjusted in the same type;
- Pilots: captain and co-pilot will be screened according to the operation category, aircraft type, operation area, the other pilot of the crew and type of flight license in the historical cases that they have performed;
- Operation equipment is determined according to the demand of the operation task, and there is no need for adjustment.
- Other crew members like Aerial Machinist, navigator, operator are screened by the nature of their work.

The definition of some attributes in table.7 are as follows:

Airworthiness of aircraft:
0: normal
1: The station license is about to expire
2: Station license expired
3: Invalid airworthiness certificate status

Health status of aircraft: time since last annual inspection, unit: month

Health status of pilot: time since last health check-up, unit: day

Salary expenses of pilot: it is defined by salary grade 0-7
0: the highest level
7: the lowest level

A. ADJUSTMENT OF SINGLE SOLUTION ELEMENT

Let's first discuss this situation that just one solution element needs adjustment.

1) SCREENING SIMILAR ELEMENTS OF THE SOLUTION ELEMENT TO BE ADJUSTED

Similar to the case screening in the previous CBR model, data processing of the indexes in Table.6 should be carried out firstly. Only the index value of operation area is numerical, so only this index value needs normalization. The similarity calculation function of two elements is k-NN as before, the difference is that the CBR model is relatively simple, so the weight of each index is not set:

$$\mathrm{Sim}(E_t, E_i) = \sum_{j=1}^{n}\mathrm{Sim}_j(E_t, E_i)$$
$$i = 1, 2, \cdots, m, j = 1, 2, \cdots, n \tag{30}$$

E_t is the solution element of target case to be adjusted, and E_i is the same solution element of the *ith* historical case. So for captain and co-pilot, $n = 5$, and for other crew members, $n = 2$. The calculation formula of $\mathrm{Sim}_j(E_t, E_i)$ is also divided into numerical and text types as described by (3) and (4).

Then, the 5 elements with the largest similarity value from historical cases are selected as similar solution elements.

2) RANKING FOR SIMILAR SOLUTION ELEMENTS

Then similar to the CBR model for generating preliminary operation plan, similar solution elements are sorted and the best one will replace the element to be adjusted. Limited by data, crew members except for pilots don't have evaluation indexes as illustrated in Table.7, and the evaluation method is TOPSIS Also because the CBR model is relatively simple.

Step 1: Constructing standard evaluation matrix.

According to different natures of all the indexes, ranking attributes in Table.7 are divided into profit type and cost type. As opposed to profit type, the lower the cost attribute value, the better for the ranking result.

For aircraft, airworthiness, total service hours, health status and average using cost are all cost attributes. For captain and co-pilot, profit attributes are total flight hours and salary expenses grade, and cost attributes are age and health status. Min-Max normalization is also selected as normalization method, but the process of the two types of attributes are different.

Profit attributes:

$$x_{normalization} = \frac{x - Min}{Max - Min} \tag{31}$$

Cost attributes:

$$x_{normalization} = 1 - \frac{x - Min}{Max - Min} \tag{32}$$

Suppose that there are $\boldsymbol{n}$ attributes of solution element to be adjusted and $\boldsymbol{m}$ similar solution elements to be sorted. Standard evaluation matrix is obtained:

$$T = \begin{bmatrix} t_{11} & t_{12} & \cdots & t_{1n} \\ t_{21} & t_{22} & \cdots & t_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ t_{m1} & t_{m2} & \cdots & t_{2n} \end{bmatrix} \tag{33}$$

Step 2: Constructing weighted standard evaluation matrix.

The entropy weight method is used to calculate the weight of each attribute. On this basis of (33), the weighted standard evaluation matrix is constructed as (34):

$$Y = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{2n} \end{bmatrix} \tag{34}$$

$$y_{ij} = w_j \cdot t_{ij}, \quad i = 1, 2, \cdots, m, \; j = 1, 2, \cdots, n \tag{35}$$

Step 3: Ideal solution and negative ideal solution.

The ideal solution and negative ideal solution are calculated according to (36) and (37) respectively.

$$y^+ = \{y_1^+, y_2^+, \cdots, y_n^+\} = \left\{\max_i y_{ij} | i = 1, 2, \cdots, m\right\} \tag{36}$$

$$y^- = \{y_1^-, y_2^-, \cdots, y_n^-\} = \left\{\min_i y_{ij} | i = 1, 2, \cdots, m\right\} \tag{37}$$

Step 4: Euclidean distance from every similar solution element to ideal solution and negative ideal solution.

$$Ed_i^+ = \sqrt{\sum_{j=1}^{n} (y_{ij} - y_j^+)^2} \tag{38}$$

$$Ed_i^- = \sqrt{\sum_{j=1}^{n} (y_{ij} - y_j^-)^2} \tag{39}$$

Step 5: Relative approach degree of every similar solution element to the ideal solution

Relative approach degree R_i is calculated as shown in

$$R_i = Ed_i^- / (Ed_i^- + Ed_i^+) \tag{40}$$

The higher R_i is, the better the *ith* similar solution element is, otherwise was worse. In the above steps, $n = 4$.

Some solution elements of different historical cases are the same, for example, the same pilot participated in more than one operation task. So there may be repeated similar solution elements, but it does not affect the calculation of R_i, therefore it does not affect the final ranking result.

B. ADJUSTMENT OF MULTIPLE SOLUTION ELEMENTS

In accordance with the rules of the operation plan, if there are two or more Solution elements to be adjusted at the same time, the priority of solution element adjustment shall be:

Aircraft > Captain > Co-pilot > Operation equipment > Other crew members.

The solution elements to be adjusted can be adjusted separately according to the priority order, and the CBR model of each solution element adjustment is the same as that of the single element in Section IV-A.

Then, the adjusted solution elements are combined to form a new solution element set for the target case, so as to complete the adjustment of the optimal plan.

V. RESULTS AND ANALYSIS

In this section, to show the detailed steps of plan generation, the feasibility of this CEB-mCBR method is verified through an air forest protection task in Harbin, China in autumn. Then cross validation is adopted to illustrate the effectiveness of the generated plans.

A. INPUTS

All the data in this paper are from the operation control management system of China Flying Dragon General Aviation

TABLE 8. Indexes value of condition attribute set for the target case.

Index	Value
Category	Aviation Forest Protection
User	non-police
longitude	116.28° N
latitude	40.15° E
Time span	(Sept, Oct.)

TABLE 9. Choosing types of aircraft.

Task requirements		Suitable types of aircraft
Required payload	1500 kg	MI-26TC
Crew members	5	MI-171
Required cruise speed	200 km/h	AC-311
Minimum anti-wind capability	10 m/s	Z-11
Required voyage	600 km	

TABLE 10. Simplified model of indexes value.

Index	Value	Simplified model
Category	Aviation forest protection	HH
	Air spraying	HP
	Marine monitorin	HJ
	Air patrol	KX
	Akortificial precipitation	RJ
	Aerial Advertising	KG
	Aerial prospecting	HT
	Scientific experiment	KS
User	Non-police	0
	police	1
longitude	Example: 122.58 ° N - 122.78° N	122.68
Latitude	Example: 39.1 ° E - 40° E	39.45
Operation time span	Example:(May, October)	(5,10)

(CDGA) CO., LTD. From 2018 to 2019, there are 56 operation cases of helicopter which covers a variety of operation categories.

B. CASE STUDY

The indexes value of condition attribute set for the air forest protection task is given in Table.8.

In practical operation, suitable types of aircraft should be chosen first of all by the requirements of the target task. The result is shown in Table.9, there were four types of aircrafts meeting the requirements.

1) CALCULATION OF SIMILARITY MATRIX

As shown in Table.10, the indexes values of condition attribute set are translated into simplified model.

Because all the operation cases in this study are in China, the longitude is east longitude and the latitude is north latitude. If the job task continues to the next year, add 12 to the job end month value.

16 historical cases using the 4 suitable types of aircraft (Table.9) could be screened out to form historical case set, so

TABLE 11. Simplified model of condition attribute sets.

Case	Operation category	User	longitude	Latitude	Operation time span
Z_1	HH	0	101.85	27.71	[1, 3]
Z_2	HH	0	115.87	23.90	[1, 1]
Z_3	HH	0	115.81	28.6	[1, 3]
Z_4	KX	1	117.00	31.445	[2, 12]
Z_5	HH	0	115.87	23.90	[12, 12]
Z_6	HH	0	115.81	28.6	[11, 12]
Z_7	HH	0	115.87	23.90	[11, 12]
Z_8	HH	0	120.61	48.00	[3, 10]
Z_9	HH	0	121.34	51.25	[4, 10]
Z_{10}	HH	0	101.85	27.71	[1, 4]
Z_{11}	KX	1	112.27	34.39	[1, 12]
Z_{12}	KX	1	117.00	31.445	[1, 2]
Z_{13}	HH	0	115.81	28.6	[1, 3]
Z_{14}	HH	0	120.61	48.00	[3, 10]
Z_{15}	KS	0	121.34	51.25	[8, 10]
Z_{16}	HH	0	114.00	30.32	[5, 10]
Z_t	HH	0	116.28	40.15	[9, 10]

TABLE 12. Judgment matrix of indexes.

	Category	User	longitude	Latitude	Operation time span
Category	1	5	8	8	3
User	1/5	1	4	4	1/3
longitude	1/8	1/4	1	1	1/5
Latitude	1/8	1/4	1	1	1/5
Operation time span	1/3	3	5	5	1

we could obtain the simplified model of condition attribute sets of historical cases.

The normalized similarity value matrix of all historical cases can be obtained:

$$\overline{Sim}_{16\times 5} = \begin{bmatrix} 1 & 1 & 0.0000 & 0.3202 & 0.0890 \\ 1 & 1 & 1.0000 & 0.0000 & 0.0000 \\ 1 & 1 & 0.9940 & 0.4015 & 0.0890 \\ 0 & 0 & 0.9687 & 0.6801 & 0.4435 \\ 1 & 1 & 1.0000 & 0.0000 & 0.6783 \\ 1 & 1 & 0.9940 & 0.4015 & 0.7516 \\ 1 & 1 & 1.0000 & 0.0000 & 0.7516 \\ 1 & 1 & 0.6439 & 0.7682 & 0.6626 \\ 1 & 1 & 0.5856 & 0.4428 & 0.7184 \\ 1 & 1 & 0.0000 & 0.3202 & 0.1399 \\ 0 & 0 & 0.6707 & 1.0000 & 0.3970 \\ 0 & 0 & 0.9687 & 0.6801 & 0.0425 \\ 1 & 1 & 0.9940 & 0.4015 & 0.0890 \\ 1 & 1 & 0.6439 & 0.7685 & 0.6626 \\ 0 & 0 & 0.5856 & 0.4428 & 1.0000 \\ 1 & 1 & 0.8216 & 0.5664 & 0.7795 \end{bmatrix} \tag{41}$$

2) WEIGHT DETERMINATION AND HISTORICAL CASES EXTRACTION

(a) Weight determination by AHP:

According to judgment matrix (Table.12) provided by China Flying Dragon General Aviation CO.,LTD, subjective

TABLE 13. Combination weights of indexes.

Index	ω_a	ω_e	ω_c
Category	0.5126	0.3455	0.3886
User	0.1418	0.3580	0.2071
longitude	0.0488	0.1186	0.1069
Latitude	0.0488	0.1186	0.1069
Operation time span	0.2481	0,0592	0.1905

TABLE 14. Similarity calculation between the target case and historical cases.

Case	Similarity calculation between Z_t and Z_i
Z_1	0.6469
Z_2	0.7026
Z_3	0.7619
Z_4	0.2608
Z_5	0.8318
Z_6	0.8881
Z_7	0.8458
Z_8	0.8730
Z_9	0.8425
Z_{10}	0.6566
Z_{11}	0.2543
Z_{12}	0.1844
Z_{13}	0.7619
Z_{14}	0.8730
Z_{15}	0.5076
Z_{16}	0.8926

weight vector ω_a can be obtained :

$$\omega_a = [0.5126, 0.1418, 0.0488, 0.0488, 0.2481]^T$$

$CR = 0.0392 < 0.1$, so the judgment matrix passes consistency test.

(b) Weight determination by Entropy Method:

According to the normalized data in Table.11, objective weight vector ω_e can be obtained:

$$\omega_e = [0.3455, 0.3580, 0.1186, 0.1186, 0.0592]^T$$

(c) Combination weight vector:

By inserting ω_a, ω_e and matrix (41) in (20), coefficients α and β can be obtained:

$$\overline{\alpha} = 0.4829, \overline{\beta} = 0.5171$$

Through similarity calculation between Z_t and Z_i shown in Table.14 and τ which is set to 0.95, there are 7 cases in the similar historical case set including Z_5, Z_6, Z_7, Z_8, Z_9, Z_{14}, Z_{16}.

3) COMPREHENSIVE EVALUATION RANKING FOR HISTORICAL OPERATION PLANS

Indexes values for plans ranking of 7 similar historical cases are extracted as shown in table.15, it is remarkable that in many cases there is no co-pilot, so the corresponding indexes values are "NONE". The definition of every index in table.15 are as follows:

r_1- Total service hours

r_2- Airworthiness of aircraft

0: normal

1: The station license is about to expire

2: Station license expired

3: Invalid airworthiness certificate status

r_3- Health status of aircraft: time since last annual inspection, unit: month

r_4- Average using cost of aircraft (per month)

r_5- Age of captain

r_6- Total flight hours of captain

r_7- Health status of captain: time since last health check-up, unit: day

r_8-Salary expenses of captain, it is defined by salary grade 0-7

0: the highest level

7: the lowest level

r_9- Age of co-pilot

r_{10}- Total flight hours of co-pilot

r_{11}- Health status of co-pilot: time since last annual inspection, unit: day

r_{12}-Salary expenses of co-pilot, it is defined by salary grade 0-7

0: the highest level

7: the lowest level

According to indexes values in table.15, we could obtain the ranking reference values shown in table.16:

The result in table.17 shows that the operation plan of Z_{14}(the sixth similar case) has the maximum comprehensive utility value, which is the preliminary operation plan of Z_t as shown in table.18.

4) CASE ADAPTATION

The target case needs a co-pilot to assist in the operation, so the co-pilot should be adjusted on the basis of CBR model for case adaptation. Operation plan of the target case after case adaptation is shown in table.19.

If other solution elements need to be adjusted, they should be adjusted separately according to the priority order. Then, the adjusted solution elements could be combined to form a new solution element set for the target case, so as to complete the adjustment of the preliminary operation plan. These are the adjustment results in table.20, some solution elements have more than one alternative for managers to refer to.

C. CROSS VALIDATION

To verify the effectiveness of the generated plans, 56 historical operation cases of helicopter are cross verified, cross validation steps are as follows:

Step 1: Generating the new operation plan of every historical case.

Take the $ith(i \leq 56)$ case as the target case and the rest historical cases as the case base, so as to generate the new operation plan P_i^{cv} of the ith case. Therefore, every historical case have P_i^{cv} and its original operation plan P_i^{ori}.

TABLE 15. Indexes values for plans ranking of 7 similar historical cases.

Case	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	r_{12}
Z_5	1160	0	4	375.0	44	2768.0	493	2	NONE	NONE	NONE	NONE
Z_6	1595	0	14	375.0	38	2852.5	251	0	NONE	NONE	NONE	NONE
Z_7	1160	0	4	375.0	44	2768.0	493	2	NONE	NONE	NONE	NONE
Z_8	1160	0	4	375.0	44	2768.0	493	2	NONE	NONE	NONE	NONE
Z_9	1595	0	14	375.0	54	5956.0	290	0	NONE	NONE	NONE	NONE
Z_{14}	1160	0	4	375.0	45	3670.0	245	0	NONE	NONE	NONE	NONE
Z_{16}	1595	0	14	375.0	54	5956.0	290	0	33	819.5	251	5

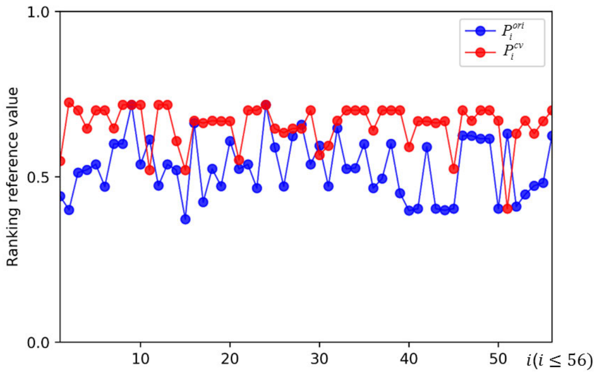

FIGURE 3. Ranking reference values of P_i^{cv} and P_i^{ori}.

TABLE 16. Ranking reference values for the 4 ranking methods(not normalized).

Evaluation method	Evaluate value
TOPSIS	$f_T^* = (0.5436, 0.4450, 0.5436, 0.5436, 0.4383, 0.5376, 0.4383)$
COPRAS	$f_C^* = (0.2319, 0.0872, 0.2319, 0.2319, 0.1238, 0.5013, 0.2867)$
MOORA	$f_M^* = (0.0944, 0.0944, 0.0944, 0.0944, 0.0944, 0.0944, 0.0944)$
PROMETTEE	$f_P^* = (1.7394, -2.2166, 1.7394, 1.7394, -2.3820, 1.7623, -2.3820)$

TABLE 17. Comprehensive evaluation result.

Evaluation method	Weight	Comprehensive evaluation result
TOPSIS	0.3789	$F = (0.8406, 0.0393, 0.8406, 0.8406, 0.0214, 0.9786, 0.1165)$
COPRAS	0.2417	
MOORA	0.0000	
PROMETTEE	0.3793	

TABLE 18. The preliminary operation plan of the target case.

Solution element		Results
Aircraft type		MI-26TC
Aircraft number		B-7807
Captain		L.Q. Tao
Co-pilot		NONE
Equipment		Fire bucket
Other crew members	Aerial machinist	Y.X. Yang
	Navigator	L.L. Yuan
	Operator	C. Zhang

TABLE 19. Operation plan of the target case after case adaptation.

Solution element		Results
Aircraft type		MI-26TC
Aircraft number		B-7807
Captain		L.Q. Tao
Co-pilot		J. Lv
Equipment		Fire bucket
Other crew members	Aerial machinist	Y.X. Yang
	Navigator	L.L. Yuan
	Operator	C. Zhang

TABLE 20. Alternatives for adjustment.

Solution element		Alternatives
Aircraft number		B-7802
Captain		Y.J. Zhang, J. Lv, Y.L. Jia
Co-pilot		J. Lv, Y.L. Jia
Equipment		Fire bucket
Other crew members	Aerial Machinist	H.L. Wen, S.C. Zhang
	Navigator	Y.D. Liu, X.L. Qu
	Operator	Y. Chen, Z.H. Zou, Z.H. Zou

Step 2: Generating the new operation plan of every historical case.

Based on the indexes for operation plans ranking as shown in table.3, P_i^{cv} and P_i^{ori} of 56 historical operation cases are sorted by TOPSIS method. The higher the ranking reference value is, the higher the utility value of the plan is. The results are shown in Fig.3.

D. DISCUSSION

The feasibility and effectiveness of this method will be discussed from the following aspects:

1) CASE STUDY ANALYSIS

(a) Historical case set of the target case

The 7 similar cases Z_5, Z_6, Z_7, Z_8, Z_9, Z_{14}, Z_{16} are all air forest protection tasks, and their operation areas are all in the northeast of China, which are close to Harbin. What is more the operation time span of air forest protection is very seasonal, so the influence of terrain and climate on actual operation and operation modes can be used for reference by the target case.

(b) The preliminary operation plan of the target case

Aircraft: MI-26TC is widely used in air forest protection, and the selected aircraft B-7807 has been used for such tasks and is in good condition

Captain: the operation cases L.Q. Tao performed appear several times in similar historical case set of the target case, and his flight history reveals that he has rich operation experience to deal with possible emergencies in forest protection task.

Equipment: fire bucket is a essential equipment for forest protection task.

Aerial machinist: Y.X. Yang has been in charge of MI-26TC and has a good understanding of this aircraft's performance and structure.

Navigator: L.L. Yuan is very familiar with this kind of terrain in Harbin, so he is suitable for navigation.

Operator: C. Zhang has carried out many forest protection tasks, and he is skilled in the operation of fire bucket.

However, there is no co-pilot in the operation plan of Z_{14}, so case adaptation is needed

(c) Operation plan of the target case after case adaptation

The co-pilot J. Lv can equal L.Q. Tao in operation experience and driving skills. More importantly, the two pilots have cooperated several times, so they will have a better cooperation in the operation process. That's why we introduce this index (the other pilot of the crew) into the CBR model for case adaptation. To our knowledge, this is the first study to deal with case adaptation by another independent CBR model.

Confirmed by the operation management personnel of CDGA, the final operation plan of target case shown in table.19 is feasible and can be directly applied in practical task.

2) CROSS VALIDATION ANALYSIS

As the results shown in Fig.3, there are 50 historical cases in which the ranking reference value of P_i^{cv} is higher than the ranking reference value of P_i^{cv}. According to the ranking reference values of P_i^{cv} and P_i^{ori}, it can be concluded that the new plans are better than the original ones in security and reliability.

VI. CONCLUSION

Aiming at the problem that existing CBR is not suitable for operation planning of helicopter, this paper proposes an multi-CBR algorithm based on comprehensive evaluation (CEB-mCBR), which integrates the case screening CBR and solution element screening CBR. The case screening CBR can fully retrieve historical operation cases and generate the optimum preliminary plan for the target case. Then also by retrieving historical operation cases, the solution element screening CBR model can adjust the preliminary plan.

It can be seen that the multi-CBR model can generate feasible operation plan of helicopter, from the generated plan confirmed by CDGA of an air forest protection task. In addition, compared with other optimization algorithms, the CEB-mCBR can integrate expert experience and human thinking better, especially for such non-numeric optimization problems with a small sample size.

In future research, considering the uncertainty of operation area and flight path for helicopter, the integration with risk analysis will be concentrated on. In this way, the early warning of possible risks in operation can be given, which further improves the safety of helicopter operation. It requires further improvement of the multi-CBR algorithm to provide risk prediction based on similar historical cases. In terms of data collection, risk data about operation cases are needed. Another important problem is that although only common single aircraft operation is considered in this paper, the CEB-mCBR algorithm can also be extended to multi-aircraft cooperative operation according to the basic principle of algorithm and the data format of historical cases. Meanwhile, historical information reuse and case-based reasoning theory can also be applied to mission planning in helicopter maritime search and rescue (MSAR) field [38].

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