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The Quality Evaluation Method of Instrument Flight Procedure Design Scheme based on Fuzzy Linguistic Assessments

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Abstract

The quality of Instrument Flight Procedure Design Scheme (QIFPDS) is directly related to the terminal area airspace capacity, quality, efficiency of air traffic management, and even the safety of aircraft. Hence, the evaluation of QIFPDS has great significance in real life. However, the evaluation of QIFPDS in real work is mainly done by experts through their specific knowledge and experience, which usually leads to a bias result and inevitably contains subjectivity and arbitrary defects. In this paper, a multi-attribute group decision-making method is proposed. This method makes full use of evaluation information; objectively and effectively evaluate QIFPDS. Also in this paper, a mathematical model for this method is introduced and a detailed step to solve this model is listed. At the end of this paper, an example is given to show the effectiveness and feasibility of the method.

Keywords: *fuzzy linguistic assessment, multi-attribute group decision-making, quality of instrument flight procedure design scheme (QIFPDS)*

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1. Introduction

The design of instrument flight procedure is directly related to the safety of the aircraft flight, air traffic management efficiency and the utilization rate of airport airspace; and at the same time, instrument flight procedure design plays a very important role in the airport site selection, airport construction, navigation facility layout and long-term planning [1-3]. Instrument flight procedure design contains arrival procedure, instrument approach procedure (including the missed approach procedure), departure procedure, holding procedure, etc. In practice, after a procedure designer submits the program of the instrument flight procedure design, decision makers need to make a scientific and reasonable evaluation on QIFPDS. In fact, the evaluation on QIFPDS is a complicated and comprehensive evaluation process. The complexity is reflected in: (1) many factors; (2) the relationship between factors; and (3) certain fuzziness of factors.

Currently, the evaluation of QIFPDS in real work is mainly done by experts through their specific knowledge and experience and referring to the relevant provisions of international civil aviation organize (ICAO) and Civil Aviation Administration of China (CAAC), which usually leads to a bias result and inevitably contains subjectivity and arbitrary defects. To ameliorate this expert's evaluation method, we propose a multi-attribute group decision-making method in this paper. This method is based on the fuzzy linguistic assessments, and takes advantages of group decision and mathematical statistics. It should be noted that, all the optional schemes of instrument flight procedures presented in this paper can ensure flight safety and meet the obstacle clearance criteria, and conform the existing norms of ICAO and Civil Aviation of China.

2. The Multi-Attribute Group Decision-Making Fuzzy Linguistic Assessment Evaluation Method of QIFPDS

2.1. Method to Determinate Index

The evaluation QIFPDS is comprehensive reflection of multiple indexes, and is determined by multiple attributes; it is a typical multiple attribute decision making problems [1-

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3]. The evaluation index of the QIFPDS is composed of the following five indicators: simplicity, coordination, adaptability, economy and operational conditions [4]. The weight of the evaluation index is obtained by expert scoring method with the form of interval number in this paper. The value of the index is often given in the form of fuzzy linguistic evaluation by experts. This is because the actual assessment of the 5 indicators is difficult to quantify. In this paper, we employ fuzzy linguistic assessment method to obtain the value of index.

2.1.1. Method to Determine the Weight of Index

To obtain a better evaluation of QIFPDS, we apply the interval number judgment method in actual operation. This is to say, suppose we have t experts, each expert judges the importance of the entire index. The importance is in the range of 0 to 100, where 0 is least import and 100 is the most import. So the marking interval is [0,100]. Hence, every index get t judge numbers. Taking the minimum and maximum score of each index, we obtain the weight evaluation results of each index from the t experts.

2.1.2. Indicators Comments Set and the Corresponding Interval Number

To evaluate the fuzzy linguistic qualitative indicators, we can convert the fuzzy linguistic assessments to interval number expressions using Table 1 and Table 2 [5-6].

Table 1. The Value Scale of QIFPDS

Scale	Very good(V_1)	Good (V_2)	Moderate(V_3)	Bad (V_4)	Very bad (V_5)
Value	[0.80,1.0]	[0.60,0. 80)	[0.40,0.60)	[0.20,0.40)	[0,0.20)

Table 2. The Fuzzy Linguistic Assessments and the Corresponding Interval Number

Fuzzy linguistic scale	cost attribute effective attribute	Very good Very bad	Good Bad	Moderate Moderate	Bad Good	Very bad Very good
Interval number expressions		[0,0.2)	[0.2,0.4)	[0.4,0.6)	[0.6,0.8)	[0.8,1.0]

It should be noted that, the 5 evaluation indicators of QIFPDS: simplicity, compatibility, adaptability and economy, belong to the effective attribute; and operational condition belongs to cost attribute.

2.2. A Multi-attribute Group Decision Making Problem based on Fuzzy Linguistic can be Described as Follows [7]

Let Q stands for QIFPDS, and G_j ($j=1,2,\cdots M$) is a set of its attributes. For the Q with respect to the attribute G_j ($j=1,2,\cdots M$), we can obtain the fuzzy linguistic assessments attribute value a_{1j}. Hence, we get a decision matrix $A=\left(a_{1j}\right)_{1\times m}$; Let $w=\left\{w_1, w_2,\cdots w_m\right\}$ be the weight vector of attributes, where $w_i=\left[w_i^-, w_i^+\right]$, $0\le w_i^- \le w_i^+$, and $\sum_{i=1}^{m} w_i^- \le 1$, $\sum_{i=1}^{m} w_i^+ \ge 1$, $\sum_{i=1}^{m} w_i = 1$

2.2.1. Determination of the Index Weights based on Interval Number

The evaluation results, obtained by method 2.1.1 in the form of interval number, can be transferred into normalized matrix using the following formula (1):

$$\begin{cases} r_{ij}^- = a_{ij}^- \Big/ \sum_{k=1}^{m} a_{kj}^+ \\ r_{ij}^+ = a_{ij}^+ \Big/ \sum_{k=1}^{m} a_{kj}^- \end{cases} \tag{1}$$

Then, through a method given in the literature [8], to get the weights of evaluation indexes:

Let target weight vector $W^* = (w_1^*, w_2^*, \cdots, w_n^*)^T$, $\sum_{r=1}^{n} W_r^* = 1$. $\bar{w}_r$ denotes the interval number weight, $\bar{w}_r = [w_r^-, w_r^+]$. The deviation of w_r^* is $d_r^- = w_r^* - w_r^-$, $d_r^+ = w_r^+ - w_r^*$. Because all the interval weights are given by the same system (the same decision maker or decision-making group), approximately, the target weight deviation ratio of the upper bound and lower bound of each weight interval can be considered as constant. That is:

$$d_r^- / d_r^+ = c, \quad \forall \; r \in \{1, 2, \cdots, n\} \tag{2}$$

In formula (2): c stands constant, thus we get:

$$c = \frac{d_r^-}{d_r^+} = \frac{\sum_{r=1}^{n} d_r^-}{\sum_{r=1}^{n} d_r^+} = \frac{1 - \sum_{r=1}^{n} w_r^-}{\sum_{r=1}^{n} w_r^+ - 1} \tag{3}$$

Then we obtain:

$$\begin{aligned} w_r^* &= w_r^- + \frac{c}{c+1} \times \left(w_r^+ - w_r^- \right) \\ &= w_r^- + \frac{1 - \sum_{r=1}^{n} w_r^-}{\sum_{r=1}^{n} w_r^+ - \sum_{r=1}^{n} w_r^-} \times \left(w_r^+ - w_r^- \right) \end{aligned} \tag{4}$$

So, we can determine the target weight via formula (4): $W^* = (w_1^*, w_2^*, \cdots, w_n^*)^T$.

This calculation does not need to adjust the weight vector through the decision matrix. The advantage of this method is easy calculation and operation.

2.2.2. The Values of Comprehensive Evaluation of QIFPDS

The first step is to aggregate all the attribute values of indicator G_j of Q using combined weighted setting value statistic. For the evaluation of an index G_j of QIFPDS (Q), the corresponding evaluation scope is denoted as ξ. The evaluation interval numbers given by the i-th ($i = 1, 2, \cdots, N$) decision-maker is denoted by $\left[u_{j1}^{(i)}, u_{j2}^{(i)} \right]$, and $\left[u_{j1}^{(i)}, u_{j2}^{(i)} \right] \in \xi$.

The second step is to get the average value of G_j of Q based on gravity decision theory. The value is [9]:

$$u_j = \frac{1}{2} \times \frac{\sum_{i=1}^{N} w_i \left[\left(u_{j2}^{(i)} \right)^2 - \left(u_{j1}^{(i)} \right)^2 \right]}{\sum_{i=1}^{N} w_i \left[u_{j2}^{(i)} - u_{j1}^{(i)} \right]} \tag{5}$$

Step three is to get the comprehensive evaluation value vector on each index (attributes) of a QIFPDS.

$$U_G = \left[u_1, u_2, \cdots u_M \right]^T \tag{6}$$

Step four is to calculate the weighted average of the comprehensive evaluation value of QIFPDS.

From the value of r, we can find its interval from Table 1, and then we get its level about QIFPDS.

3. Example

We will verify the feasibility of the method through an example.

3.1. The Determination of Index Weight

Through method in 2.1.1, we get the original evaluation attribute weights of interval number from all experts ([70, 85], [80, 90], [75, 85], [50, 65], [40, 60]).

By using formula (1), we transform the original judgment interval number into normalization interval number ([0.1818, 0.2698], [0.2078, 0.2857], [0.1948, 0.2698], [0.1299, 0.2063], [0.1039, 0.1905])

Using formula (3) and formula (4), we get the weight of the evaluation index: $W^* = (0.2214, 0.2429, 0.2286, 0.1643, 0.1429)^T$.

3.2. The Comprehensive Evaluation Value of the QIFPDS

The 10 personnel of expert group consists flight procedures designer, flight crew, air traffic controllers, flight performance experts, airport management experts etc. Suppose the weight of each expert is the same that is 0.1. Each expert gave the fuzzy linguistic evaluation grade of each evaluation index. According to Table 2, the fuzzy linguistic assessment scale is transformed into interval number shown in Table 3.

Table 3. The Statistical Results About each Evaluation Index of the QIFPDS

	S_1	S_2	S_3	S_4	S_5
1	V_2[0.60,0.80)	V_1[0.80,1.0]	V_1[0.80,1.0]	V_2[0.60,0.80)	V_1[0.80,1.0]
2	V_2[0.60,0.80)	V_3[0.40,0.60)	V_2[0.60,0.80)	V_1[0.80,1.0]	V_3[0.40,0.60)
3	V_1[0.80,1.0]	V_3[0.40,0.60)	V_2[0.60,0.80)	V_1[0.80,1.0]	V_1[0.80,1.0]
4	V_3[0.40,0.60)	V_1[0.80,1.0]	V_2[0.60,0.80)	V_3[0.40,0.60)	V_2[0.60,0.80)
5	V_1[0.80,1.0]	V_3[0.40,0.60)	V_2[0.60,0.80)	V_1[0.80,1.0]	V_2[0.60,0.80)
6	V_2[0.60,0.80)	V_1[0.80,1.0]	V_1[0.80,1.0]	V_2[0.60,0.80)	V_2[0.60,0.80)
7	V_1[0.80,1.0]	V_3[0.40,0.60)	V_3[0.40,0.60)	V_2[0.60,0.80)	V_1[0.80,1.0]
8	V_2[0.60,0.80)	V_1[0.80,1.0]	V_2[0.60,0.80)	V_3[0.40,0.60)	V_3[0.40,0.60)
9	V_3[0.40,0.60)	V_2[0.60,0.80)	V_2[0.60,0.80)	V_1[0.80,1.0]	V_1[0.80,1.0]
10	V_3[0.40,0.60)	V_1[0.80,1.0]	V_3[0.40,0.60)	V_2[0.60,0.80)	V_2[0.60,0.80)

We apply formula (5) to calculate the index comprehensive evaluation value:

$$\bar{u}_1 = \frac{1}{2} \times \frac{0.1\times(0.8^2-0.6^2)+0.1\times(0.8^2-0.6^2)+\cdots+0.1\times(0.6^2-0.4^2)}{0.1\times(0.8-0.6)+0.1\times(0.8-0.6)+\cdots+0.1\times(0.6-0.4)} = 0.70$$

$$\bar{u}_2 = \frac{1}{2} \times \frac{0.1\times(1^2-0.8^2)+0.1\times(0.6^2-0.4^2)+\cdots+0.1\times(1^2-0.8^2)}{0.1\times(1-0.8)+0.1\times(0.6-0.4)+\cdots+0.1\times(1-0.8)} = 0.72$$

$$\bar{u}_3 = \frac{1}{2} \times \frac{0.1\times(1^2-0.8^2)+0.1\times(0.8^2-0.6^2)+\cdots+0.1\times(0.6^2-0.4^2)}{0.1\times(1-0.8)+0.1\times(0.8-0.6)+\cdots+0.1\times(0.6-0.4)} = 0.70$$

$$\bar{u}_4 = \frac{1}{2} \times \frac{0.1\times(0.8^2-0.6^2)+0.1\times(1^2-0.8^2)+\cdots+0.1\times(0.8^2-0.6^2)}{0.1\times(0.8-0.6)+0.1\times(1-0.8)+\cdots+0.1\times(0.8-0.6)} = 0.74$$

$$\bar{u}_5 = \frac{1}{2} \times \frac{0.1\times(1^2-0.8^2)+0.1\times(0.6^2-0.4^2)+\cdots+0.1\times(0.8^2-0.6^2)}{0.1\times(1-0.8)+0.1\times(0.6-0.4)+\cdots+0.1\times(0.8-0.6)} = 0.74$$

We get the comprehensive evaluation value of the vector of each index for QIPDS (Q) of all the decision-makers.

$$\overline{U_X}=\left[\overline{u_1},\overline{u_2}\cdots,\overline{u_M}\right]^T=\left[0.70,0.72,0.70,0.74,0.74\right]^T$$

Using formula (6), we obtain the comprehensive evaluation value on QIPDS (Q) through the combined weighted arithmetic averaging operator calculation.

$$r=0.2214\times 0.70+0.2429\times 0.72+0.2286\times 0.70+0.1643\times 0.74+0.1429\times 0.74=0.7172$$

By referring to Table 1, interval, we can get the comprehensive evaluation of QIPDS (Q), in this example, the level of (Q) is Good.

4. Conclusion

In this paper, we focus on the current situation of the evaluation on the QIFPDS, take into account the actual situation of the complexity and uncertainty of the QIFPDS, adopt the form of interval number attribute weights and fuzzy linguistic assessment indexes, and then create a multi-attribute group decision-making method based on fuzzy linguistic evaluation. By applying this method, we get comprehensive evaluation value of the QIFPDS. This method takes full advantage of each evaluation index information; the evaluation result is objective and reliable. This method also can improve decision-making efficiency, reduce defects of evaluation work, and provide a scientific evaluation of the QIFPDS.)

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