Research on vessel formation emergency operation scheme optimization based on fuzzy decision theory

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Abstract: This paper focusing on the whole process of the vessel formation scheme optimization, and combined with the vessel emergency operation requirements and characteristics, constructs the vessel formation emergency operation index system. Based on fuzzy decision theory, the paper presents the determining method for quantitative and qualitative indexes relative membership degree and weight in the index system. The fuzzy optimization model and the fuzzy recognition model are used for optimization decision. The scientifical-ness and feasibility of the fuzzy decision theory in solving military problems are proved.

Introduction

Vessel formation as countries deal with maritime crisis the main fighting force, according to the different tasks, the maximize marshalling mode formation flexibility and mobility characteristics, in order to operation capability at sea to make up the formation of strong to meet the emergency operation requirements. Formation composition optimization decision factors, including quantitative and qualitative objectives. The fuzzy decision theory provides new scientific basis and methods for solving of military problems.

Construction of vessel formation emergency operation optimization index system

Emergency operation has strong sudden, short arms response time, high response speed characteristics. Formation of emergency operation index system is different with conventional naval warfare. The formation of emergency operations system consists of detection system, attack system, information processing system and personnel quality and training level.

Detection equipment is an important part of the formation emergency operations system, constitute the basis for the formulation of operational scheme of the mastery of the sea dynamics.

Attack system including missile system and the naval gun system, emergency operation depends mainly on the use of anti-ship missile damage targets at long range. Naval gun is used to expand the results of battle and develop of victory.

Emergency operation with real-time and sudden strong, formation must have fast, accurate and uninterrupted information processing ability for guarantee operation missions.

Personnel play a crucial role in emergency operation system, formation personnel quality and training level as fuzzy factors need to focus on the analysis.

Specific index system as shown in figure 1:

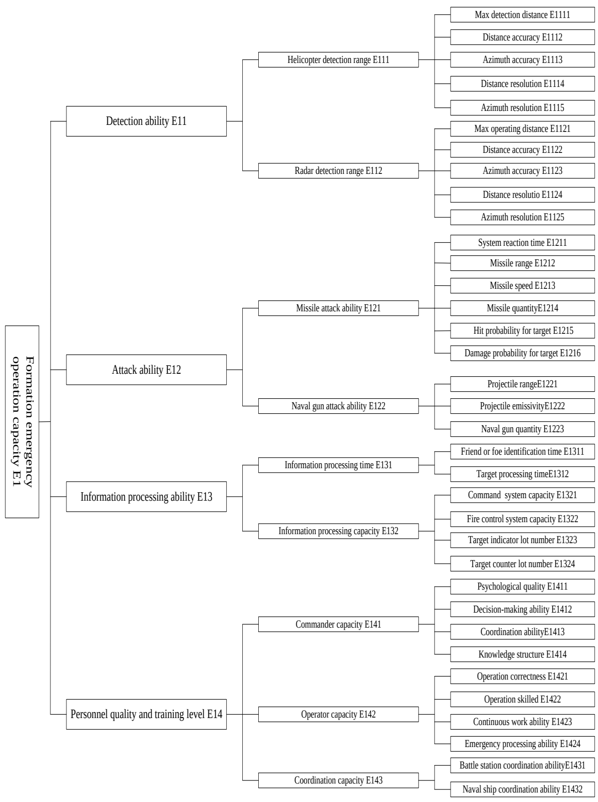

Fig.1 Formation emergency operation index system

Relative membership degree determining method

The fuzzy decision analysis of the forming scheme according to the fleet emergency response capabilities evaluation needs to clear the relative membership degree of every evaluation objective. In those evaluation objectives for fleet emergency response capabilities, the objective characteristic value of E11, E12 and E13 can be indicated with exact value, and to these objectives we can use given formula to get their relative membership degree; E15 is fuzzy and it does not has a quantitative characteristic value, to these qualitative objectives, we can use the comparison of the superiority between each other to determine their relative membership degree.

Quantitative indexes Relative membership degree determining method. Suppose the fleet forming scheme decision set is D, $D=\{d_1,d_2,\cdots d_n\}$,and we use m targets to evaluate the fleet combat capability, so they can form a evaluation target set P, $P=\{p_1,p_2\cdots p_m\}$.Target i is one quantitative objective with characteristic value in P. Each scheme in set D has characteristic value towards target i, Define the maximal characteristic value $\max(x_i)$ and the minimum characteristic value $\min(x_i)$ as the upper bound and lower bound of characteristic value of target i, the two bounds constitutes the two poles of reference system, so we can get the formula [1] of relative membership degree for Target i:

To the benefit targets:

$$r_{ij}=\frac{x_{ij}-\min(x_i)}{\max(x_i)-\min(x_i)} \qquad (1)$$

To the cost targets:

$$r_{ij} = \frac{\max(x_i) - x_{ij}}{\max(x_i) - \min(x_i)} \qquad (2)$$

x_{ij} ——Characteristic value from scheme j to quantitative target i .

$\max(x_i)$、$\min(x_i)$ -- The maximal and minimum characteristic value from all schemes to quantitative target i .

When the variation range of target characteristic value is small, we can indicate the concept of relative membership degree as follows:

To the benefit targets：

$$r_{ij} = \frac{x_{ij}}{\max(x_i) + \min(x_i)} \qquad (3)$$

To the cost targets：

$$r_{ij} = 1 - \frac{x_{ij}}{\max(x_i) + \min(x_i)} \qquad (4)$$

r_{ij} is the relative membership degree from scheme j to target i , and $\max_j x_{ij}$ means the maximal characteristic value of decision set target i , the $\min_j x_{ij}$ shows the minimum one, and $\bar{x}$ shows the median one.

For illustration, take E111 (Helicopter detection distance) as example, we need to optimize one from five forming schemes, showed in Tab.1

Tab 1 Characteristic value of composition plan for formation

Target		Quantitative target characteristic value				
		1	2	3	4	5
E111	E1111	300	250	250	200	300
	E1112	20	80	80	120	20
	E1113	0.20	0.30	0.30	0.36	0.20
	E1114	40	150	150	120	40
	E1115	1.60	2.50	2.50	3.00	1.60

The results are in Tab.2：

Tab 2 Relative membership degree to quantitative target

Target		Quantitative target relative membership degree				
		1	2	3	4	5
E111	E1111	0.50	0.42	0.42	0.33	0.50
	E1112	0.85	0.38	0.38	0.08	0.85
	E1113	0.61	0.41	0.41	0.29	0.61
	E1114	0.76	0.12	0.12	0.29	0.76
	E1115	0.60	0.38	0.38	0.25	0.60

Qualitative indexes Relative membership degree determining method. First using the two element comparison method[2]for the superiority qualitative sorting of forming scheme decision set D for operation capability evaluation target set P qualitative target t_i, ${}_i a_{kl}$ said the importance of qualitative ranking scheme k and scheme l. We can get forming scheme for fuzzy qualitative target t_i the superiority of two element comparison matrix:

$$A_i = \begin{bmatrix} {}_i a_{11} & {}_i a_{12} & \cdots & {}_i a_{1n} \\ {}_i a_{21} & {}_i a_{22} & \cdots & {}_i a_{2n} \\ & & \vdots & \\ {}_i a_{n1} & {}_i a_{n2} & \cdots & {}_i a_{nn} \end{bmatrix} = ({}_i a_{kl}) \qquad (5)$$

According to the order, through forming scheme and fuzzy qualitative target t_i two element comparison, we can get superiority of two element comparison ordered matrix B_i:

$$B_i = \begin{bmatrix} {}_i b_{11} & {}_i b_{12} & \cdots & {}_i b_{1n} \\ {}_i b_{21} & {}_i b_{22} & \cdots & {}_i b_{2n} \\ & & \vdots & \\ {}_i b_{n1} & {}_i b_{n2} & \cdots & {}_i b_{nn} \end{bmatrix} = ({}_i b_{jk}) \qquad (6)$$

According to matrix B_i, we can structure the ordered phase and matrix of forming scheme decision set D for fuzzy qualitative target t_i:

$$C_i = \begin{bmatrix} 1 & {}_i b_{12}/{}_i b_{21} & \cdots & {}_i b_{1n}/{}_i b_{n1} \\ {}_i b_{21}/{}_i b_{12} & 1 & \cdots & {}_i b_{2n}/{}_i b_{n2} \\ & & \vdots & \\ {}_i b_{n1}/{}_i b_{1n} & {}_i b_{n2}/{}_i b_{2n} & \cdots & 1 \end{bmatrix} \qquad (7)$$

Quantify the forming scheme of decision set D for fuzzy qualitative target t_i relative membership degree vector. The formula is:

$${}_i r_j = \frac{1 - {}_i b_{1j}}{{}_i b_{1j}}, \quad 0.5 \le {}_i b_{1j} \le 1 \qquad (8)$$

Take E1432 (naval ship coordination ability) as an example, introduce qualitative target relative membership degree determining method:

Through scheme 1~5 for naval ship coordination ability two element comparison, the consistency check scaling matrix is:

$$B_{E1432} = \begin{bmatrix} 0.5 & 0.5 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 1 & 1 & 0.5 & 1 & 1 \\ 1 & 1 & 0 & 0.5 & 0 \\ 1 & 1 & 1 & 1 & 0.5 \end{bmatrix} \qquad (9)$$

According to scaling matrix elements of each row summation, the 5 schemes priority sorting is: d_3, d_5, d_4, d_1, d_2. d_1 and d_2 has the same sequence number.

Based on d_3 standard, compared the superiority one by one, we can get: d_3 is slightly superior to d_5, d_3 is obviously superior to d_4, d_3 is very superior to d_1 and d_2. According to reference[3], 5 schemes relative membership degree vector for naval ship coordination ability E1432 is $c_{E1432} = (0.25, 0.25, 0.67, 0.43, 0.54)$.

Target weight determining method

This article use expert investigation method to determine the weight. With 5 experts, weight of each expert is w_i, so the relative weight is $w_i' = \frac{w_i}{\sum_{k=1}^{5} w_k}$, $\sum_{i=1}^{5} w_i' = 1 \quad i = 1,2,3,4,5$ 。

Suppose we turn to the expert group for the investigation for the weight of some target in the operation capacity evaluation target. We can build a Five-level fuzzy language scale, including "Extremely important", "important" , "middle", "unimportant", "inconsequential". Transform the expert group opinions into corresponding x_i, and according to its relative weight w_i', and then Use the following formula, to achieve the target weight y :

$$y = \sum_{i=1}^{5} w_i' \cdot x_i \qquad (10)$$

Take E122 (Formation naval gun attack ability) as an example, supposed the normalized relative weight vector of ten experts is: $w' = (0.3,0.3,0.2,0.1,0.1)$. Table 3 shows the fuzzy tone factor and membership degree.

Tab.3 Fuzzy tone factor and membership degree

Fuzzy tone factor	membership degree
Extremely important (A)	0.87
important (B)	0.71
middle (C)	0.50
unimportant (D)	0.29
inconsequential (E)	0.13

The expert group opinions towards E122 are showed in Tab.4. Using formula (10), the weight of naval gun attack ability is:

Tab 4 Target weight

Target	Expert group investigation					The normalized weight
	1	2	3	4	5	
E1221	B	B	A	A	B	0.34
E1222	A	A	B	B	B	0.37
E1223	B	B	C	C	C	0.29

Formation forming scheme Optimization

Take E131 (The processing time) as example, based on some relative data in Tab.5, using Fuzzy optimization theory model[4], and take $\alpha = 1$、$p = 2$, we can get the relative membership degree of E131 and E132 about the scheme.

$$_1\mathrm{u} = (0.7178,1.0000,1.0000,1.0000,0.7178)$$
$$_2\mathrm{u} = (0.7879,0.9448,0.9112,0.9600,0.8686)$$

Tab 5 Relative membership degree for information processing ability

Third layer target	Third layer target weight	Forth layer target	Forth layer target weight	Scheme Relative membership degree				
				1	2	3	4	5
E131	0.4859	E1311	0.4321	0.667	0.667	1.000	1.000	1.000
		E1312	0.5679	0.750	0.750	1.000	1.000	1.000
E132	0.5141	E1321	0.2656	0.950	0.750	1.000	0.900	1.000
		E1322	0.2673	0.800	0.750	0.950	0.900	1.000
		E1323	0.2665	0.954	0.923	1.000	0.923	0.923
		E1324	0.2006	0.813	0.750	0.875	0.937	1.000

Take third layer target weight and E131、E132 relative membership degree about scheme into 5-level fuzzy recognition model [5] and the level characteristic formula[6], Parameters used $\alpha = 1$、$p = 2$:

$$H = (2.318, 2.597, 3.724, 3.365, 3.842)$$

The Ranking results for the schemes are :Scheme 5, Scheme 3, Scheme 4, Scheme 1, Scheme 2, the optimal solution is scheme 5.

This method uses all relative membership degree information of class variables. Obviously, its decision result meetsthe actual circs better.

Conclusion

The scheme decision on vessel formation emergency operation has typical characteristics such as multi-level,multi-attribute,multi objective and non structural. This paper used fuzzy optimization theory into solving the scheme decision problems, the results proved the scientificalness and feasibility of this method. The method and its result have certain reference to the decision optimization problem solving incomplex military field

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