Safety Assessment Model of Deep Submarine Rescue Task

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***Abstract*—The submarine rescue mission is rather difficult with many uncertain factors and other characteristics. The paper use AHP(Analytic Hierarchy Process)and MMEM (man, machine and environment, management) theory to build up safety assessment model ,and then use fusion algorithm of evidence theory to calculate quantified value of system security. It proved to be practical and reliable.**

Keywords-Submarine rescue, AHP, MMEM, theory of evidence

I. INTRODUCTION

Submarine rescue is a high risk project, it is affected by many uncertain factors, and few empirical data can be used. Through risk assessment, decision-making authority can determine whether to carry out the mission, adjust the revisable factors of deep submarine rescue ,and reducing risk.

Many countries put forward a number of widely used analysis and assessment methods, such as event tree analysis, probabilistic risk analysis, fault tree analysis method. D-S evidence reasoning is an uncertainty reasoning method base on evidence theory, It is a kinds of uncertainty reasoning theory which can handle the uncertain knowledge and need weaker axiom support compared with probability analysis, more importantly, evidence theory do not need prior probability and conditional probability density, and is suitable for the safety assessment lack of empirical data [1].

This paper establish the safety assessment index system of deep submarine rescue, combine evidence thero with AHP to calculate the risk of rescue mission.

II. STRUCTURE AND INDEX SELECTION [2]

AHP (Analytical Hierarchy Process) is a system analysis method, it has many advantages such as clear thinking, wide applicability, and promotion, it availably combine the data, expert opinions and judgement of analyst. MMEM (Human, Machine, Environment, Management) system is developed based on the traditional theory of man - machine - environment, it make a full scientific analysis of the basic structure of the system and the system factor.

By Combine AHP and MMEM theory, and keep accordant with the principle of index selection of evaluation system, three levels index system is established as Fig.1 [3]:

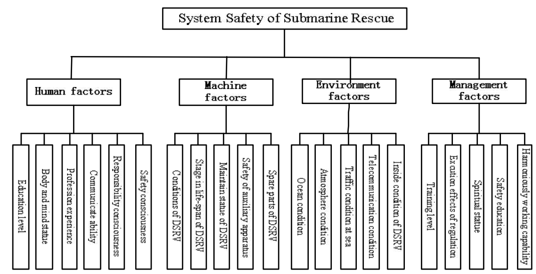

Figure.1 Index system of Safety Assessment Model of Deep Submarine Rescue

The first layer is the system risk of the submarine rescue mission; the second layer is the safety of four major subsystems including man, machine environment, and management. The third layer is bottom elements subject to the subsystem. The principles of index selection such as systematic, representative, hierarchy, comparability and measurability are taken into consideration. The process of index selection is not repeated here.

III. DETERMINATION OF INDEXT WEIGHTS [4]

Index weight reflects its importance in superior index. Different weight will lead to different evaluation results.

The steps of using AHP to determine weights are as following:

1:construct comparative matrix;
2:check up the consistency of comparative matrix;
3: single arrangement of index;
4: total arrangement of index.

As the fusion algorithm used in this paper do not need to consider the bottom index weights subject to the top (system security), therefore the fourth step is not used. The weights of index are shown in the table I:

IV. EVIDENCE COMBINATION [5]

For a issue that need to verdict, assuming all possible results represented by θ.If there is a group of evidence, then you can create a framework in identifying the trust function, which reflects the support degree the batch of evidence to each proposition. If there are multiple batches of evidence, then fusion algorithm can be used to calculate the support degree the several batches of evidence to each proposition in the framework.

Definition 1: Set θ as the frame of discernment, if the set function m meet:

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$$①\ m(\phi)=0;\quad ②\ \sum_{A\subset\theta} m(A)=1 \qquad (1)$$

So m is called the basic probability assignment, $m(A)$ is the basic creditability, which reflects the credibility of proposition. Equation① reflects the degree of the empty set does not produce any credit; Equation② reflects all the credibility of the proposition is 1. What should be noted that: If $m(A) = s,\ s \in [0,1]\ (A \subseteq \theta)$, and except for A, other subset of θ do not produce any credibility, then $m(\theta) = 1 - s$, not $m(\overline{A}) = 1 - s$, that is to say the remaining credibility will be allocated to θ, not to $\overline{A}$.

Definition 2: Set θ the frame of discernment, then:

$$Bel(A) = \sum_{B\subset A} m(B) \quad (\forall A \subset \theta) \qquad (2)$$

$Bel(A)$ is Called the belief function of θ.

Definition 3: If $m(A) > 0$, then A is called the focal element of the belief function, and all of the focal element is called its core.

The above definitions give Dempster combination rule of evidence. Suppose that e_1, e_2 are two pieces of evidence which are independent, their set functions to the framework are m_1 and m_2. Function defined by the following equations:

$$\begin{cases} m_{12}(\phi) = 0 \\ m_{12}(A) = \dfrac{1}{1-k}\displaystyle\sum_{X\cap Y=A} m_1(X)m_2(Y),\ A \neq \varnothing \end{cases} \qquad (3)$$

is called the Dempster combination rule marked by $m_{12} = m_1 \oplus m_2$, it reflects the combined support degree of two pieces of evidence e_1 and e_2 to proposition. $K = \sum_{X\cap Y=\varnothing} m_1(X)m_2(Y)$ is called conflict factor.

Definition 4: If there are three evidence, then their support to proposition is $(m_1 \oplus m_2 \oplus m_3)(A) = (m_1 \oplus m_2)(A) \oplus m_3(A)$, which is commutative and associative, the combination rule of multiple evidences can be get through it.

V. The Evaluation Steps [6]

Firstly evaluation aggregate and its basic probability assignment are given by experts, and then combine all the evidences with the Dempster combination rule of evidence layer by layer, and finally get the value of the security situation of the whole system. Detailed algorithm is shown following：

Step 1: Define the frame of discernment $\theta = H = \{H_1, H_2, H_3, \cdots H_q \cdots H_z\}$, H is a set of security status, and give the safety assessment value P_{H_q} to H_q.

Step 2: Determine basic probability assignment.

$$m(H_q|e_{ij}) = \frac{\omega_{ij}}{\omega_{im}}\alpha_{ij}\beta_{H_q}(e_{ij}) \qquad (4)$$

Where e_{ij} stand for the j th of the i th sub-system e_i, ω_{ij} is the weight of e_{ij}. ω_{im} is the weight of the indicator whose weight is the heaviest in e_i. α_{ij} is the bias coefficient of the key indicator e_{im} which reflects the importance of the key indicator subject to experts, generally, $0.9 \le \alpha_{ij} \le 1$. $\lambda_i = \frac{\omega_{ij}}{\omega_{im}}\alpha_{ij}$ is standardized weight. $\beta_{H_q}(e_{ij})$ is certainty factor of e_{ij} subject to H_q, it is decide by experts and policy makers according to their experiences and preferences.

Basic probability of indicator that is completely unsure is:

$$m(H|e_{ij}) = 1 - \sum_{q=1}^{z} m(H_q|e_{ij}) \qquad (5)$$

it reflects the extent of completely unsure.

Step 3: Calculate the set function of sub-system subject to the frame θ

For the indicators of the subsystem, the above dempster combination rule can be used to calculate the set function of subsystem.

$$m(H_q|e_i) = m(H_q|e_{i1}) \oplus m(H_q|e_{i2}) \oplus \cdots m(H_q|e_{in}) \qquad (6)$$

Step 4: Calculate the set functions of the whole system.

The set function of the whole system can be make out :

$$m(H_q|S) = m(H_q|e_1) \oplus m(H_q|e_2) \oplus \cdots m(H_q|e_n) \qquad (7)$$

Step 5: Using the formula: $P_S = \sum_{q=1}^{z} m(H_q|S)\cdot P_{h_q}$, the quantied value of the security state of the system can be calculated

VI. Examples

Aiming at Deep Submergence Rescue System Safety Evaluation System

established in the first section, frame of discernment is: $H = \{worst(H_1),\ bad(H_2),\ middle(H_3),\ good(H_4),\ best(H_5)\}$, its safety assessment value is

$P(H) = \{P(H_1), P(H_2), P(H_3), P(H_4), P(H_5)\} = \{0.2, 0.4, 0.6, 0.8, 1\}$

basic creditabilities of all indicators are as Table II:

According to the above table, use step 3 to obtain credibility of four subsystems subject to the entire system.

Then use step 4 to obtain set function the whole system.

Finally, use step 5 to obtained from the quantified security status of the entire system

$$P_S = \sum_{q=1}^{z} m(H_q|S)\cdot P_{h_q} = 0.0118\times0.4 + 0.9653\times0.6 + 0.0229\times0.8 = 0.602$$

The results suggest the security status of the submarine rescue mission.

VII. Conclusion

As a useful mathematical method, Evidence theory is widely used in many fields. The paper combine AHP and MEMM evidence theory to buile up an assessment index system, and determine weights of every indicators, then use evidence theory to deal with the uncertainty and calculate the quantified security status of the submarine rescue system. Results show that the assessment model is practical and reliable.

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TABLE I. WEIGHT OF ALL INDICATORS

subsystem	symbol	weight	Index	symbol	weight
Human factors	e_1	ω_1 =0.46	Education level	e_{11}	ω_{11} =0.15
			Body and mind statue	e_{12}	ω_{12} =0.11
			Professional experience	e_{13}	ω_{13} =0.29
			Communicate ability	e_{14}	ω_{14} =0.10
			Responsibility consciousness	e_{15}	ω_{15} =0.23
			Safety consciousness	e_{16}	ω_{16} =0.12
Machine factors	e_2	ω_2 =0.23	Conditions of DSRV	e_{21}	ω_{21} =0.36
			Stage in life-span of DSRV	e_{22}	ω_{22} =0.09
			Maintain statue of DSRV	e_{23}	ω_{23} =0.24
			Safety of auxiliary apparatus	e_{24}	ω_{24} =0.19
			Spare parts of DSRV	e_{25}	ω_{25} =0.12
Environment factors	e_3	ω_3 =0.17	Ocean condition	e_{31}	ω_{31} =0.40
			Atmosphere condition	e_{32}	ω_{32} =0.23
			Traffic condition at sea	e_{33}	ω_{33} =0.09
			Telecommunication condition	e_{34}	ω_{34} =0.16
			inside condition of DSRV	e_{35}	ω_{35} =0.11
Management factors	e_4	ω_4 =0.14	Training level	e_{41}	ω_{41} =0.34
			Excution effects of regulation	e_{42}	ω_{42} =0.16
			Spiritual statue	e_{43}	ω_{43} =0.08
			Safety education	e_{44}	ω_{44} =0.11
			Harmoniously working capability	e_{45}	ω_{45} =0.31

TABLE II. CREDITABILITIES OF ALL INDICATORS

Subsystem	Indicator	$\lambda_i = \frac{\omega_{ij}}{\omega_{im}} \alpha_{ij}$	$m(H_q \mid e_{ij}) = \lambda_i \beta_{H_q}(e_{ij})$					$m(H \mid e_{ij})$
			H_1	H_2	H_3	H_4	H_5	
Human factors e_1	e_{11}	0.470	0	0	0.188	0.282	0	0.530
	e_{12}	0.340	0	0.068	0.136	0.136	0	0.660
	e_{13}	0.900	0	0.450	0.450	0	0	0.100
	e_{14}	0.310	0	0.124	0.124	0.062	0	0.690

	e_{15}	0.710	0	0	0.426	0.284	0	0.290
	e_{16}	0.370	0	0.111	0.148	0.111	0	0.630
Machine factors e_2	e_{21}	0.900	0	0.270	0.450	0.180	0	0.100
	e_{22}	0.230	0	0.046	0.069	0.115	0	0.770
	e_{23}	0.600	0	0.060	0.300	0.024	0	0.400
	e_{24}	0.480	0	0	0.192	0.288	0	0.520
	e_{25}	0.300	0	0.150	0.150	0	0	0.700
Environment factors e_3	e_{31}	0.900	0	0.450	0.270	0.180	0	0.100
	e_{32}	0.520	0	0.208	0.260	0.052	0	0.480
	e_{33}	0.200	0	0	0.080	0.012	0	0.800
	e_{34}	0.360	0	0.252	0.108	0	0	0.640
	e_{35}	0.250	0	0.150	0.100	0	0	0.750
Management factors e_4	e_{41}	0.900	0	0	0.540	0.360	0	0.100
	e_{42}	0.420	0	0	0.210	0.210	0	0.580
	e_{43}	0.210	0	0.042	0.084	0.126	0	0.790
	e_{44}	0.290	0	0.029	0.145	0.116	0	0.710
	e_{45}	0.820	0	0.164	0.164	0.492	0	0.180

TABLE III. CREDITABILITIES OF SUBSYSTEMS

Subsystem	$m(H_q \mid e_i)$					$m(H \mid e_i)$
	H_1	H_2	H_3	H_4	H_5	
e_1	0	0.1708	0.7212	0.0849	0	0.0230
e_2	0	0.1707	0.6271	0.1641	0	0.0381
e_3	0	0.5381	0.3228	0.0949	0	0.0442
e_4	0	0.0203	0.3936	0.5674	0	0.0186

TABLE IV. CREDITABILITIES OF THE WHOLE SYSTEM

System	$m(H_q \mid S)$					$m(H \mid S)$
	H_1	H_2	H_3	H_4	H_5	
S	0	0.0118	0.9653	0.0229	0.0000	0