Fire Extinguishing Systems' State Evaluation Basing on Analytic Hierarchy Process and Dempster-shafer

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***Abstract*—As for a kind of ordered state evaluation problem, it is too much feature and big calculation in the process of multi-attribute decision making, this paper is aimed to the method of DS-AHP and use the convex function to set up its optimization model. Example of the fire extinguishing systems' state evaluation shows this method is simple and efficiency for the multi-attribute decision making furthermore.**

Keywords- Evidential Theory, AHP, Convex Function, State Evaluation

I. INTRODUCTION

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Multi-attribute decision making is an important part of the Modern Decision Making Science, and its essence is as follows: use the existing decision-making information, sort a group that contain a finite number of options and selected the best one through a certain way. The basic model of multi-attribute decision making can be described as: Let's suppose that f_i is a property, X is a collection of options, x_i is an option i , $x_{ij} = f_j(x_i)$ express the property value of the option i under the property f_i ,The Multi-attribute decision making can be expressed as the following: the given decision making unit, the environment and a description of decision rules, to solve:

$$\underset{x \in X}{DR}[f_1(x),..., f_n(x)] \tag{1}$$

Different decision rules DR and set of different options collection X constitute a number of different multi-attribute decision making methods.We can get the conclusions from such a decision-making process, multi-attribute decision making is mainly composed of a few steps as the attribute weights, attribute values and decision making through a certain way to deal with this information.

Analytic Hierarchy Process (AHP) is brought up by the U.S. operations researcher T.L.Saaty in the 70s,it is a multi-objective decision analysis method of associating the qualitative and quantitative analysis, the main idea of AHP is as follows: firstly, according to the overall objective by the nature and requirements of the problem, break the problem into different factors hierarchically, the weights of different factors within the same level can be got the judge through their pairwise comparison between the pairs, then, to the importance of the next level factors, we must consider the level of itself and the weights of the previous level, that is, not only calculating the combined weights, but also calculating the relative weights, lastly get the optimal decision.

With in-depth study of the decision making problem, the influence of the uncertainty phenomenon on the decision have arosed widespread attention in the entire decision-making process. DS evidence combination theory has gained wide application in the decision-making of information fusion, but the DS evidence combination theory itself has many problems, such as evidence from different sources has different reliability and authority, but this widespread phenomenon rarely reflects in the evidence theory. Document [1] put the combination of evidence theory and the AHP, proposed a method of multi-attribute decision making of DS-AHP, which overcome the bottlenecks both encountered in the decision-making process.

II. DS-AHP DECISION MAKING AND ITS OPTIMIZATION

Dempster-Shafer (DS) evidence combination theory is discussing a recognition framework U , which is a finite set of the possible answer or assumption about the proposition independent to each other. Let's suppose that U is a collection of all the possible values to X , and the elements in collection U are mutually exclusive, we call U is a recognition framework to X . By traditional methods we can express as 2^U ,it is a collection to all subclasses belonged to U .DS evidence theory make operations to framework of the identification, and provide the logic in computing the power set elements, and then use these results to complete the uncertainty calculation of the high and low. DS synthesize formula provides a methods to integrate the different evidence, different evidence representing different sources of information, so that abstraction propositions of different levels can be characterized by the evidence. For the assessment of mechanical and electrical equipments condition, the evidence could be the actual measurement data, the experience of experts and other assessment information, in order to use evidence theory to integrate evaluation conclusions of different information sources, the key of the problem is how to integrate these different forms of information to get the state assessment conclusions.

DS evidence combination theory of decision-making has gained wide application in information fusion, it grasps better the problems of the unknown and uncertainty than traditional probability theories. However, DS evidence combination theory has many problems itself, such as the focal explosion of focus caused by evidence combination, the very strict rules of combination, different reliability and authority to different sources of evidence, but this widespread phenomenon reflected very little in the evidence theory. Beynon M.J., who integrate evidence theory and AHP, proposed a DS-AHP multi-attribute decision making method, overcome the bottlenecks both encountered in decision-making process, give full play to the advantages of the both.

In the DS-AHP decision making model, Dempster synthesis method provides a level evidence reasoning model based on the AHP hierarchy, the uncertainty transfers by levels in accordance with combination rules of the D-S, construct the DS -AHP hierarchy model by using the DS-AHP decision-making, regard a finite set composed of all decision-making programs as a evidence theory identification framework Θ ; construct the judgment matrix by the property C_j and the corresponding decision making program; seek the weight vector of the guideline attribute $w_j(j=1,2,...,M)$; finally, see focal elements focus with different attributes as different evidence sources, using evidence combination rule to integrate the credibility function values of all focal element, calculate the reliability function value of each decision program $Bel(\{a_i\})$ and the Plausibility function value $Pls(\{a_i\})$, at last, get the decision-making conclusions[2].

For most of the mechanical and electrical equipments, its technical condition is a gradual progressive degradation process in the service cycle, correspondingly, state its assessment is generally based on the technical specifications in accordance with the pre-defined state level. Because of people's evaluation results to a feature of the same thing should show a trend and continuity, for example, define the status development process of the equipment system as good, a slight deterioration, need item repairs, needs major repairs and so on. Summarize the classification methods into a class of ordered propositions problems, to such ordered proposition, one of its distinguishing feature is that its classification meet the character of "convex"[3].

Suppose $P_1,P_2,...,P_n$ is a collection of ordered propositions， take $P=P_1,P_2,...,P_n$ as the identification framework，Suppose that Bel_1,Bel_2 is two belief functions of the independent evidence, the corresponding basic probability assignment function (probability assignment function), is m_1,m_2 respectively, ω_1,ω_2 are the weights of the two information sources, we can get the following combination function[4]:

$$f(m_1,m_2)(P_i)=\begin{cases}\sum\limits_{1\le k\le i}\{w_1\times m_1(P_k)[1+m_1(\bar{P})]+w_2\times m_2(P_k)[1+m_2(\bar{P})]\}/(g-k+1) & i<g\\ \sum\limits_{1\le k\le g}\{w_1\times m_1(P_k)[1+m_1(\bar{P})]+w_2\times m_2(P_k)[1+m_2(\bar{P})]\}/(g-k+1)+ & \\ \sum\limits_{g+1\le k\le n}\{w_1\times m_1(P_k)[1+m_1(\bar{P})]+w_2\times m_2(P_k)[1+m_2(\bar{P})]\}/(k-g+1) & i=g\\ \sum\limits_{1\le k\le n}\{w_1\times m_1(P_k)[1+m_1(\bar{P})]+w_2\times m_2(P_k)[1+m_2(\bar{P})]\}/(k-g+1) & i>g\end{cases} \tag{2}$$

In the above formula:

$$g=\left\lfloor 0.5\times\sum_{1\le i\le n}\{w_1\times m_1(P_i)[1+m_1(\bar{P})/(1-m_1(\bar{P}))]+w_2\times m_2(P_i)[1+m_2(\bar{P})/(1-m_2(\bar{P}))]\}\times i\right\rfloor \tag{3}$$

$\lfloor\cdot\rfloor$ expresses the greatest integer less than or equal to the function; $m_i(\bar{P})$ expresses the credibility distribution function that is not outside of the framework. Analysis calculation complexity to the set of combination algorithms, suppose that there are k information sources and n elements in the frameworks Θ as the same, then the computation of the combination rule is $O(k\times n)$.

III. ALGORITHM VALIDATION

The identification framework constructed by the document[5] is $U=(o_1,o_2,o_3,o_4,o_5)$, the system uses the three sensors ESM, IR and EO as the information sources to set values for the four basic probabilities, in which $m_{RF}(\cdot)$ and $m_{pw}(\cdot)$ are determined by sensor ESM, as shown in Table I:

TABLE I. THE BASIC PROBABILITY VALUES OF THE THREE SENSORS

	O1	O2	O3	O4	O5	U
$m_{RF}(\cdot)$	0.20	0.40	0.12	0.15	0.00	0.13
$m_{PW}(\cdot)$	0.45	0.05	0.25	0.10	0.00	0.15
$m_{IR}(\cdot)$	0.25	0.30	0.00	0.20	0.00	0.25
$m_{EO}(\cdot)$	0.40	0.40	0.00	0.00	0.00	0.20

Applicate the Dempster combination formula, obtained basic probability values after fusing the three sensors is: $m_{ESM\times IR\times EO}(O_1)=0.58$, $m_{ESM\times IR\times EO}(O_2)=0.33$, $m_{ESM\times IR\times EO}(O_3)=0.03$, $m_{ESM\times IR\times EO}(O_4)=0.05$, $m_{ESM\times IR\times EO}(O_5)=0$, $m_{ESM\times IR\times EO}(U)=0.01$,And get the final decision making result: 01.

In the convex function evidence theory model, firstly, synthesize $m_{RF}(\cdot)$ and $m_{pw}(\cdot)$ based on basic probability assignment in the table, get the synthesized result $m_{ESM}(\cdot)$, then, synthesize $m_{IR}(\cdot)$ and the probability assignment value of $m_{ESM}(\cdot)$, and synthesize the above result and $m_{EO}(\cdot)$, end up with the result $m_{ESM\times EO}(\cdot)$, the other synthesis results of the steps are shown in Table II.

TABLE II. THE VALUES SYNTHESIZED BY THE EVIDENCE OF CONVEX FUNCTION

	O1	O2	O3	O4	O5	U
$m_{RF\times PR}$	0.420	0.212	0.203	0.129	0.00	0.036
$m_{ESM\times IR}$	0.474	0.226	0.137	0.131	0.00	0.033
$m_{ESM\times IR\times EO}$	0.589	0.293	0.045	0.052	0.00	0.021

Analyse the results of the above, we can get the same conclusion that based on the synthesis of convex function evidence theory, the credibility of the judgment is higher than the general evidence synthesis theory, and the operation is more convenient in the synthesis process.

IV. THE APPLICATION OF DS-AHP OPTIMIZATION MODEL ON SHIP FOAM FIRE EXTINGUISHING SYSTEM

Fire and explosion is the second disaster that threat the survival of naval vessel, it is significant to keep the ship fire extinguishing system prepared to keep its state of great. To be able to achieve this goal, above all, we have to assess its state scientifically and effectively. The assessment process to ship foam fire extinguishing system has obvious state-level and multi-attribute feature, do this, you can construct the DS-AHP state assessment model of ship foam fire extinguishing system based on this model.

According to expert's experience, use six indicators tightness (J), fluency (C), the storage time of liquid (T), the liquid height in the tank (H), the high pressure of air in the pipe (P1) , medium pressure of the air (P2) of the ship foam fire extinguishing systems to assess the status of fire extinguishing system. Use the detection devices to check the tightness of the system, the results can be judged directly from the devices. The fluency can be tested by transporting compressed air into the foam fire extinguishing system. Open the valve and the controller in right order manually, we can attest the pipe and jet is fluence according to the air out of the jet in the cabins, and the results can be judged directly too; the other four parameters take the function of state evaluation as evaluation models, their state grade distribution curve functions are shown in Figure 1 - Figure 4. Evaluation results are: the A-system is intact, the state is great; B-a slight deterioration, the system need to be strengthening monitoring; C- part of the system damaged, needs item repairs; D- needs overhaul repairs.

According to the evaluation model of above parameters, combined with field testing we can get the assessment conclusions of the parameters , that is the subject degree of the parameters to the status level A, B, C, D, as well as the evaluation uncertainty U of each parameter , as shown in Table III:Construct DS-AHP decision making output model, calculate the reliability function value $Bel(\{a_i\})$ and the plausibility function value $Pls(\{a_i\})$ of the programs by using the simplified progress of the convex function model, the achieved test values express the accredit range of the fire extinguishing system state to four states A, B, C, D. State A: $[0.034,0.437]$, state B: $[0.526,0.872]$, State C: $[0.204,0.643]$, status D: $[0.006,0.653]$, take the lower limit of trustfulness, in state B, the minimum confidence is 0.526, much larger than for other trustfulness state evaluations, for which we can assess the current state of fire extinguishing system, draw the best state level determination is B.

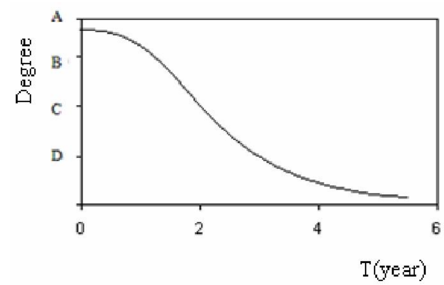

Figure 1. State degree distributing of 1301 storage time

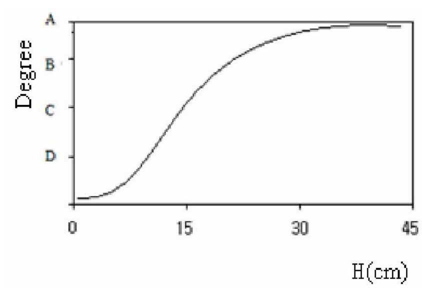

Figure 2. Degree distributing of 1301 storage height

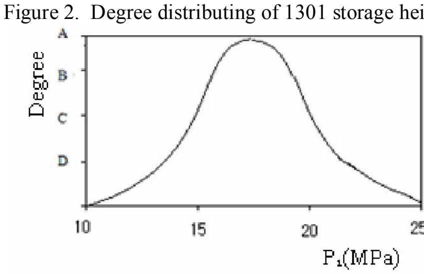

Figure 3. State degree distributing of pipe high pressure

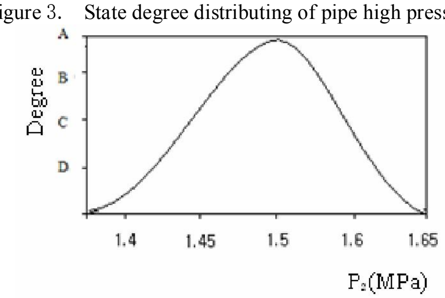

Figure 4. State degree distributing of pipe middling pressure

Compared with the running time, failure rate and other parameters of the fire-fighting system, the conclusions derived from the test data in line with the actual fire fighting operation status, which indicates reasonable of the established evaluation model to the fire extinguishing system.

TABLE III. THE EVALUATION CONCLUSION OF THE PARAMETER

	J	C	T	H	P1	P2
A	0	0	0.002	0	0	0.002
B	0.368	0.092	0.721	0.141	0.404	0.779
C	0.314	0.721	0.169	0.698	0.330	0
D	0	0	0	0	0.002	0
U	0.318	0.187	0.108	0.161	0.264	0.219

V. CONCLUSIONS

AHP is a common method of Multi-attribute decision-making process, as for the characteristics of uncertainty and multilevel to the ship fire fighting system's state assessment process, we introduced the DS-AHP decision making method. Aim at the lackness of decision-making model, we analyse the decision making characteristics of state assessment, calculate optimally to the property synthesis process by the use of convex function theory, the example illustrates the computation of the optimal calculation is less than the traditional AHP and the DS-AHP, the fusion of different parameters's assessment results is more intuitive and scientific. Finally, apply the optimization model to the state assessment of ship fire extinguishing systems, application of this optimization model can evaluate the status accurately.

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