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Risk Assessment of Marine Traffic Environment Using Unascertained Quantity

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***Abstract*—The risk of maritime traffic is an issue to express the uncertain information. In order to assess the risk of traffic environment at port, the theories and methods of unascertained mathematics were introduced. Considering the unascertained characteristics of traffic environment at port, the weight of risk system coefficients was determined and an unascertained quantitative model was established for evaluation of traffic environment on the basis of the information entropy theory. Then, it gets the corresponding rank and evaluation of the maritime risk, with the help of applying this model in 13 sections of two ports of China. Compared with traditional weight obtained method, the results show that the evaluation is reliable, and this unascertained measure is more propitious to resolve the evaluation of traffic risk in different ports by the same evaluation standard solely on the basis of objective data.**

***Keywords*—ship; traffic environment; unascertained measure; entropy; risk assessment**

I. INTRODUCTION

The traffic environment at port areas is an open and complex system, involving the factors in many aspects such as the society, economy, and natural environment etc. So the reasons initiated maritime risks are very complicated. While analyzing such tedious information, there will be unavoidably led to uncertainty of decision maker's subjective cognition to shipping environment, which is unascertained characteristic [3]. Therefore, the assessment on the port traffic risk is an issue, which is evaluated an unascertained system. At present, there are many methods used to assess traffic risk, such as Fuzzy Evaluation, Gray Analysis, DS Evident reasoning and Matter-element Analysis etc [1]. These methods have solved the uncertainty problems of known information, but it is hard to deal with the unascertained problem.

Risk assessment can be viewed as a process to deal with the uncertainty information. In addition to uncertain for objective conditions, the uncertain information also includes intension and experience of decision-makers. Therefore, different from random information, fuzzy information and gray information, the uncertainty of decision maker's subjective cognition is called unascertained [3], which results from insufficient evidence did not obtain true states and quantitative relation of information. As to unascertained information, we should deal it with the theory of unascertained mathematics [3,7] .

Thus, it is necessary to use the Unascertained Measurement to assess the port traffic risk to enable the quantitative analytical work of the maritime risk to be further improved.

This paper introduced an algorithm of Unascertained Measurement, considering the "uncertainty information" and "unascertained characteristic" in risk assessment of Traffic Environment at port, made a rational Confidence Degree Criteria and arranged in a series criterion, then established the unascertained model, finally, the method was applied on the base of data of specific port areas.

II. UNASCERTAINED MEASURE MODELS

The Unascertained Measure is one method of Uncertain Mathematics [3,6], mainly through setting up Confidence Degree Criteria to analyze the factors and confirm the degree of reliability of the coefficient factors. There are several important concepts in unascertained measure model(UMM), as the following introduced.

A. Single coefficient in UMM

Let: $X=\{x_1,x_2,\cdots,x_n\}$ represents evaluation objects set, which is also called the universe; there are m coefficients $I_1,I_2,\cdots,I_m$ of x_i ($x_i \in X$), that is, $I=\{I_1,I_2,\cdots,I_m\}$; x_{ij} is the observed value of object x_i under coefficient I_j ; $\mathrm{R}=\{R_1,R_2,\cdots,R_p\}$ is the evaluation space, where $R_k (1\le k\le p)$ is the k th evaluation grade, and $R_1<R_2<\ldots<R_k<\ldots<R_p$. The degree which x_{ij} shows x_i belong to the k th evaluation grade c_k is $u_{ijk}=u(x_{ij}\in R_k)$. Then u_{ijk} is a measurement result of the membership degree, that is, u_{ijk} satisfies:

$$\begin{cases} u_{ij1}=1, u_{ij2}=\cdots=u_{ijk}=0, & (x_{ij}\le a_{j1}) \\ u_{ijk}=1, u_{ij2}=\cdots=u_{ijk-1}=0, & (x_{ij}\ge a_{jk}) \\ u_{ijl}=\dfrac{a_{jl+1}-x_{ij}}{a_{jl+1}-a_{jl}}, u_{ijl+1}=\dfrac{x_{ij}-a_{jl}}{a_{jl+1}-a_{jl}}, & \\ u_{ijk}=0 \quad (k<l \,|\, k>l+1), & (a_{jl}\le x_{ij}\le a_{jl+1}) \end{cases} \quad \mathbf{(1)}$$

if $a_{j1} < a_{j2} < \cdots < a_{jk}$

and as a measurement it must satisfy the usual measurement ru les: "nonnegative-boundedness, additively and normalization", So the single coefficient unascertained matrix can obtain:

$$(u_{ijk})_{m\times K} = \begin{bmatrix} u_{i11} & u_{i1} & \cdots & u_{i1k} \\ u_{i21} & u_{i22} & \cdots & u_{i2k} \\ \cdots & \cdots & \cdots & \cdots \\ u_{im1} & u_{im2} & \cdots & u_{imk} \end{bmatrix} \tag{2}$$

B. Coefficient weights in UMM

Suppose w_{ij} is the relatively important intensity of indicator I_j compared with others. We call w_{ij} for the weight of coefficient I_j, and it must meet conditions:

$$w_j = (w_1, w_2, \cdots, w_m), 0 \le w_j \le 1, \\ \sum_{j=1}^{m} w_j = 1, j = 1, 2, \cdots, m \tag{3}$$

In the multi-coefficients synthetic evaluation measure, the determination of coefficient weight is very important, which will influence the appraised result directly. There are many methods to confirm weight as follows:

Option 1:The weights are often given by experts in advance according to their experiences, besides AHP method and Fuzzy Cluster Analysis method can also be used to decide the weights. But these above-mentioned methods all have too great subjective information[3,6], so it is easy to produce error in the risk assessment.

Option 2:According to the properties of the Attribute Theory, when the attribute value x_{ij} and evaluation criterion are confirmed, the corresponding weight of this attribute is also confirmed, therefore, it is not accurate to decide the weight by subjective information, and we should determine the weight basing on the actual measured value of each attribute. This paper applied the information entropy, obtained the peak value of attribute firstly, and then confirmed the attribute weight [7]:

$$V_{ij} = 1 + \frac{1}{\log_2 K} \sum_{k=1}^{K} \mu_{ijk} \log_2 \mu_{ijk} \\ w_{ij} = V_{ij} / \sum_{l=1}^{m} V_{il} \quad \text{j=1,2,3,…,m; i=1,2,3,…,n.} \tag{4}$$

Where K represents the number of evaluation rank, m denotes the number of entire coefficient attribute, and μ_{ijk} is the Single coefficient unascertained measure, V_{ij} describes importance degree of the coefficient attribute.

C. Multi-coefficients synthetic evaluation measure

If the single coefficient measure evaluation matrix of x_i and the coefficient Weights have been known, we can get the valuation vector of x_i using the following Eq.(5):

$$u_{ik} = u(x_i \in R_k) = \sum_{j=1}^{m} w_j u_{ijk}, \\ 1 \le i \le n, 1 \le k \le p, \\ 0 \le u_{ik} \le 1, \sum_{k=1}^{p} u_{ik} = 1 \tag{5}$$

D. Identification criterion

If $R_1 < R_2 < \ldots < R_k < \ldots < R_p$, we call $R = \{R_1, R_2, \cdots, R_p\}$, an ordered division on the evaluation space. When the division is ordered, the identification criterion of maximum membership degree is no more suitable, so we usually take the confidence degree as identification criterion. $\lambda (0.5 < \lambda \le 1)$ represents the confidence degree, it is usual adapted to 0.6 or 0.7.Let:

$$k_i = \min \left\{ k : \sum_{l=1}^{k} u_{il} \ge \lambda, 1 \le k \le p \right\} \tag{6}$$

Then, we can judge that x_i belongs to the k_i th evaluation rank R_{k_i}.

Finally, the ranking of assessment sample $u_i(R_i)$ is obtained, following the score criterion q_i:

$$q_i = \sum_{k=1}^{p} n_k \bullet u_{ik} \tag{7}$$

Where n_k is arithmetic progression.

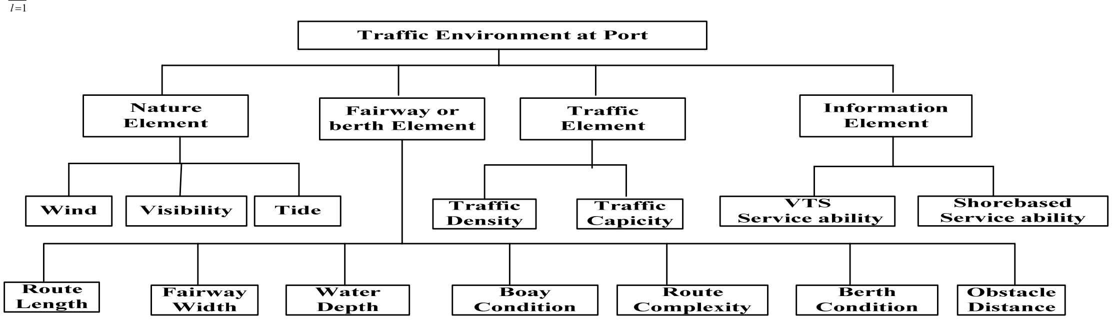

Figure 1. Elemental factors in traffic environment at port

III. RISK OF SYSTEM FORTRAFFIC ENVIRONMENT AT PORT

The port is the pivot of marine traffic, the departure, destination and transfer ground of ship, so it is easy to appear shipping traffic jam and even traffic accidents in the large density of the water areas. There are many factors (Figure.1) to contributing the port traffic accident; it can generally be divided into: Natural element, Fairway element, Traffic element and Information element. Combining multiple factors, this paper selected ten factors as coefficient to assess the traffic environment at port [1, 2], these factors are Wind & Visibility & Tide (I_1) , Water Depth （ I_2 ）, Buoy Condition (I_3), Route Length(I_4),Berth Condition(I_5), Route Complexity(I_6), Fairway Minimum Width(I_7), Minimum Distance to Obstacle (I_8), Traffic Density & Capacity(I_9), VTS Service ability& shore-based Service ability (I_{10}).

IV. CASE STUDY

According to the actual navigation conditions of Taizhou port and Jiaxing port, considering comprehensive factors of various fields and research of relevant experts and scholars, the paper established the criteria matrix (Table.1) of standard ship for environmental coefficient [2], which affects traffic safety in these water areas.

TABLE I. THE CRITERIA MATRIX FOR ENVIRONMENTAL COEFFICIENTS

Rank Index	Lower Risk R_1	Low Risk R_2	Middle Risk R_3	High Risk R_4	Higher Risk R_5
I_1	Very Weak	Weak	Middle	Strong	Very Strong
I_2	(0, 1/16]	(1/16, 1/12]	(1/12, 1/8]	(1/8, 1/4]	(1/4, ∞)
I_3	Complete	Less Complete	Middle	Incomplete	Very Incomplete
I_4	(0, 5]	(5, 10]	(10, 15]	(15, 20]	(20, ∞)
I_5	(0, 20]	(20, 40]	(40, 60]	(60, 90]	(90, 180)
I_6	(0, 1]	(1, 2]	(2, 3]	(3, 5]	(5, ∞)
I_7	(0,1/800]	(1/800,1/500]	(1/500,1/300]	(1/300,1/100]	(1/100,200)
I_8	(0,1/200]	(1/200,1/100]	(1/100,1/50]	(1/50,1/20]	(1/20,1)
I_9	(0,1/250]	(1/250,1/200]	(1/200,1/150]	(1/150,1/100]	(1/100,1/10)
I_{10}	Better	Good	Middle	Bad	Worse

TABLE II. THE TRAFFIC ENVIRONMENT COEFFICIENT DATUM FOR EACH SECTION OF PORT AREA

	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9	I_{10}
T1	VS	1/1.8	N	20.3	0	0	1/550	1/370	1/370	B
T2	S	1/1.6	C	21.7	8	1	1/550	1/190	1/140	G
T3	S	1/2.8	I	12.25	33	0	1/550	1/190	1/140	VB
T4	N	1/3.4	M	20	60	0	1/170	1/190	1/300	VB
T5	VS	1/14	I	20.5	78	1	1/1852	1/0	1/50	M
T6	W	1/12	C	33	0	1	1/384	1/740	1/∞	VB
T7	W	1/5	C	27.1	70	2	1/384	1/930	1/500	VB
T8	W	1/17	C	22	37	3	1/640	1/740	1/500	VB
J1	M	>12	C	17	0	1	∞	1	∞	G
J2	W	7.4/11	C	43	17-40	2	1	0	1/140	M
J3	VW	11.5/12	C	10	39	0	0.8	0	926	G
J4	S	11.5	C	12	90	0	1	0	0	B
J5	VW	2.7/7.1	C	14	90	0	0.1	0	200	B

Furthermore, the datum (Table.II) of Taizhou port(T1-T8) and Jiaxing port(J1-J5) are given based on field investigation. Furthermore, we investigate the weight of system elements in the form of Analytic Hierarchy Process(AHP). But we get the different weight coefficient.

A. *Calculation of single coefficient measure evaluation matrix*

Take the section T1 of Tai Zhou port for example, using the Eq. (1) & (2), we can got the single coefficient measure evaluation matrix: $\mathrm{T3}:(u_{1jk})_{10\times5}$ （Eq.（8））， the matrixes of other sections $(u_{ijk})_{10\times 5}$ (i=1,…,13) can also obtained in the same method.

$$
T3:(u_{1jk})_{10\times 5}=\begin{bmatrix}
0 & 0 & 0 & 0.75 & 0.25\\
0 & 0 & 0 & 0 & 1\\
0.25 & 0.75 & 0 & 0 & 0\\
0 & 0.275 & 0.725 & 0 & 0\\
0.35 & 0.65 & 0 & 0 & 0\\
1 & 0 & 0 & 0 & 0\\
0.2424 & 0.7576 & 0 & 0 & 0\\
0.9474 & 0.0526 & 0 & 0 & 0\\
0 & 0 & 0.5714 & 0.428 & 0\\
0 & 0 & 0 & 0 & 1
\end{bmatrix} \quad \textbf{(8)}
$$

B. Coefficient weight

Used the first option through AHP, each coefficient weight of Taizhou port(T1-T8) and Jiaxing port(J1-J5) can obtained as following[2,4]:

$$
w_{option1}\begin{cases}
w_1=\begin{pmatrix}0.157,0.025,0.048,0.022,0.090,\\ 0.048,0.090,0.155,0.154,0.025\end{pmatrix}(T1-T8)\\
w_2=\begin{pmatrix}0.101,0.056,0.157,0.187,0.140,\\ 0.020,0.187,0.056,0.101,0.042\end{pmatrix}(J1-J5)
\end{cases} \quad \textbf{(9)}
$$

This paper also used the Option 2 to achieve the coefficient weight matrix Eq.(10) based on the entropy of Eq. (8). Here it can be well known that each coefficient has a weight vector and the vector has been changed by the original data.

$$
w_{option2}=\begin{array}{c}\left[\begin{array}{cccccccccc}
0.1036 & 0.1036 & 0.1036 & 0.1036 & 0.1036 & 0.1036 & 0.0679 & 0.1036 & 0.1036 & 0.1036\\
0.1098 & 0.1098 & 0.1098 & 0.1098 & 0.1098 & 0.1098 & 0.0720 & 0.0958 & 0.0632 & 0.1098\\
0.1200 & 0.1200 & 0.1200 & 0.0761 & 0.0717 & 0.1200 & 0.0787 & 0.1046 & 0.0691 & 0.1200\\
0.1108 & 0.1108 & 0.1108 & 0.1108 & 0.0645 & 0.1108 & 0.0631 & 0.0966 & 0.1108 & 0.1108\\
0.1083 & 0.0623 & 0.1083 & 0.10833 & 0.0712 & 0.1083 & 0.1083 & 0.1083 & 0.1083 & 0.1083\\
0.1140 & 0.0689 & 0.1140 & 0.0652 & 0.1140 & 0.1140 & 0.0681 & 0.1140 & 0.1140 & 0.1140\\
0.1195 & 0.0741 & 0.1195 & 0.1195 & 0.0695 & 0.0680 & 0.0714 & 0.1195 & 0.1195 & 0.1195\\
0.1120 & 0.1120 & 0.1120 & 0.1120 & 0.0826 & 0.0677 & 0.0653 & 0.1120 & 0.1120 & 0.1120\\
\hline
0.1039 & 0.1039 & 0.1039 & 0.0645 & 0.1039 & 0.1039 & 0.1039 & 0.1039 & 0.1039 & 0.1039\\
0.1044 & 0.1044 & 0.1044 & 0.1044 & 0.1044 & 0.1044 & 0.1044 & 0.1044 & 0.0601 & 0.1044\\
0.1059 & 0.1059 & 0.1059 & 0.0603 & 0.0928 & 0.1059 & 0.1059 & 0.1059 & 0.1059 & 0.1059\\
0.1039 & 0.1039 & 0.1039 & 0.0645 & 0.1039 & 0.1039 & 0.1039 & 0.1039 & 0.1039 & 0.1039\\
0.1021 & 0.1021 & 0.1021 & 0.0814 & 0.1021 & 0.1021 & 0.1021 & 0.10213 & 0.1021 & 0.1021
\end{array}\right]\end{array}
\begin{array}{c}T1\\T2\\T3\\T4\\T5\\T6\\T7\\T8\\ \\J1\\J2\\J3\\J4\\J5\end{array} \quad \textbf{(10)}
$$

C. Results and Discussion

Then, multi-coefficients synthetic evaluation measure can be evaluated according to Eq.(5). The following is the matrix of U . (Eq. (11)and Eq.(12))

Eq.(11) is using the option 1 to obtain the weight of coefficients.

$$
U1=\begin{array}{c}\begin{array}{ccccc}R1 & R2 & R3 & R4 & R5\end{array}\\
\left[\begin{array}{ccccc}
0.431 & 0.051 & 0.207 & 0.000 & 0.311\\
0.438 & 0.060 & 0.036 & 0.247 & 0.220\\
0.263 & 0.253 & 0.095 & 0.150 & 0.240\\
0.313 & 0.005 & 0.293 & 0.057 & 0.332\\
0.252 & 0.027 & 0.017 & 0.271 & 0.433\\
0.570 & 0.213 & 0.103 & 0.000 & 0.114\\
0.358 & 0.178 & 0.130 & 0.094 & 0.239\\
0.499 & 0.209 & 0.045 & 0.023 & 0.224\\
0.416 & 0.104 & 0.123 & 0.045 & 0.312\\
0.313 & 0.209 & 0.139 & 0.026 & 0.313\\
0.428 & 0.224 & 0.030 & 0.000 & 0.318\\
0.416 & 0.019 & 0.045 & 0.208 & 0.312\\
0.408 & 0.008 & 0.073 & 0.102 & 0.408
\end{array}\right]\end{array}
\begin{array}{c}\\T1\\T2\\T3\\T4\\T5\\T6\\T7\\T8\\J1\\J2\\J3\\J4\\J5\end{array} \quad \textbf{(11)}
$$

Eq.(12) is using the option 2 to obtain the weight of coefficients.

$$
U2=\begin{array}{c}\begin{array}{ccccc}R1 & R2 & R3 & R4 & R5\end{array}\\
\left[\begin{array}{ccccc}
0.346 & 0.082 & 0.311 & 0.073 & 0.188\\
0.408 & 0.044 & 0.087 & 0.326 & 0.134\\
0.265 & 0.175 & 0.198 & 0.113 & 0.249\\
0.314 & 0.004 & 0.240 & 0.164 & 0.279\\
0.169 & 0.027 & 0.053 & 0.327 & 0.424\\
0.583 & 0.156 & 0.112 & 0.032 & 0.117\\
0.346 & 0.147 & 0.246 & 0.088 & 0.173\\
0.460 & 0.187 & 0.121 & 0.062 & 0.169\\
0.371 & 0.081 & 0.247 & 0.108 & 0.239\\
0.268 & 0.238 & 0.222 & 0.050 & 0.222\\
0.472 & 0.291 & 0.023 & 0.016 & 0.244\\
0.333 & 0.037 & 0.079 & 0.333 & 0.217\\
0.319 & 0.029 & 0.080 & 0.122 & 0.450
\end{array}\right]\end{array}
\begin{array}{c}\\T1\\T2\\T3\\T4\\T5\\T6\\T7\\T8\\J1\\J2\\J3\\J4\\J5\end{array} \quad \textbf{(12)}
$$

After getting the single coefficient measure evaluation matrixes and each coefficient weight, if we take the belief degree λ=0.6 , the risk assessment result is shown in Table.III. Take an example of T1, in the $U1$,

$$0.431(R_1)+0.051(R_2)+0.207(R_3)=0.689>\lambda=0.6$$

The risk rank of T1 is R_3 .

Comparing the computing value based on the Entropy, in the $U2$, $0.346(R_1)+0.082(R_2)+0.311(R_3)=0.739>\lambda=0.6$, The risk rank of T1 is also R_3 . The result is the same in spite of different weight vector.

TABLE III. THE RESULT OF PORT TRAFFIC RISK BASED ON UNASCERTAINED MEASURE

Result / Port area	*Option 1*			*Option 2*		
	Risk(R_i)	Confidence (k_i)	Rank	Risk(R_i)	Confidence (k_i)	Rank
T1	R_3	0.689	6	R_3	0.739	6
T2	R_4	0.780	3	R_4	0.866	3
T3	R_3	0.611	10	R_3	0.638	10
T4	R_4	0.668	5	R_4	0.721	5
T5	R_5	1.000	1	R_5	1.000	1
T6	R_2	0.783	11	R_2	0.739	12
T7	R_3	0.667	7	R_3	0.739	7
T8	R_2	0.708	12	R_2	0.648	13
J1	R_3	0.643	9	R_3	0.700	9
J2	R_3	0.661	8	R_3	0.728	8
J3	R_2	0.652	13	R_2	0.764	11
J4	R_4	0.688	4	R_4	0.783	4
J5	R_5	1.000	2	R_5	1.000	2

Certainty we can get a conclusion that there are small differences between the results which are obtained by two different weight determinate options. It is just the same risk rank of each section in Jiaxing port by the two options; however it has some differences in Taizhou port.

In Option 1 the coefficient weight is determined according to Delphi approach which is full of subjective information. But the option 2 can avoid the influence by entropy information which is calculated as to the original data. Hence, the subjective judgments of decision-maker are easy to get the assessment results which just use the objective data to be view as the resource of judgment.

Through the investigation, we could figure out that the result which gets from the option 2 is better to option 1, and which is more objective and reliable. It will unavoidably produce errors to the weight that just confirmed by experts' experiences, on the other hand, the entropy method can solve this problem smoothly and obtain more rational result readily [8,9,10].

V. CONCLUSION

The risk of maritime traffic is an issue to express the uncertain information. Uncertainty information includes random information, fuzzy information and uncompleted information. In this paper, assessment of uncompleted information in risk assessment is involved. The theories and methods of unascertained mathematics were introduced to compute the uncompleted risk information. Normally, the weight of risk system coefficients was determined by the use of Delphi which is full of subjective data[10]. In order to avoid the subjective judgments, the information entropy theory was hold out to assess the risk of traffic environment which can help to calculate the original data, not subjective judgment. It is certified that the result is better using the entropy. The results show that the evaluation is reliable, and this unascertained measure is more propitious to resolve the evaluation of traffic risk in different ports by the same evaluation standard solely on the basis of objective data. And the same time, this risk computing model of unascertained measure based on entropy can be viewed as a preliminary risk assessment approach[12,13].

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