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Risk Assessment of Operation Safety in Seaports Using Man-Machine-Environment-Management Multiple Safety Indices

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Abstract

In this paper, It is study that the safety evaluation of the entry and exit of hazardous chemical ships. At first, the risky factors of the entry and exit of dangerous chemicals are identified and screened. It has been determined that the risk assessment set of the entry and exit risk of hazardous chemical ships. Then, the established evaluation set is used to construct the evaluation system for the entry and exit of hazardous chemicals. The analytic hierarchy process based on multiple expert groups decision-making is applied. The criteria and indicators affecting safe entry and exit are compared, which determine the weight of each factor and the total order of levels. The Fuzzy Comprehensive Evaluation was established, and the risk of entering and leaving the port of Yang Shan Deepwater Port was evaluated by using this model. The Suggestions for the safe entry and exit of hazardous chemical ships are put forward, which can provide reference for the safety management of the entry and exit of hazardous chemical ships.

Keywords

Seaport; Safety Evaluation; Multiple Safety Indices; Man-Machine-Environment-Management; Fuzzy comprehensive evaluation method.

1. INTRODUCTION

Maritime Safety Evaluation Technology (MSET) is the technical basis for realizing maritime scientific pre-control. By evaluating the past lessons (post-mortem evaluation) of specific things (organizations, activities, processes, systems), the current security situation and evolution trend (in-process evaluation), the future possible security situation and major risks (pre-evaluation) Make a qualitative/quantitative statement of safety/risk degree, and give the evaluated direct, management, and essential improvement and pre-control measures.

In order to pre-control maritime affairs and ensure maritime safety, MSET should be competent for the following tasks: evaluation of people, machines, environment, and management in a broad and narrow sense; design, manufacture, inspection and evaluation of ships and marine products; and safety management of companies and ships Audit; port state monitoring; voyage risk assessment of companies and captains, risk assessment of officers on duty; pilot's assessment of pilot safety; port authorities, flag state governments, and Port State Control (PSC) organizations Evaluation etc. The research on MSET should pay attention to the universality and particularity of its content, methods, rules, procedures, mathematical tools [1]. Risk analysis in seaports plays an increasingly important role in ensuring port operation reliability, maritime transportation safety and supply chain distribution resilience [2]. The International Maritime Organization [3, 4] (IMO) promoted Formal Safety Assessment (FSA) as

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a framework for risk assessment and management. Moreover, all risk is advised to be controlled under ALARP (As Low as Reasonably Practicable) principle [5].

Formal Safety Assessment (FSA) is the premier scientific method that is currently being used for the analysis of maritime safety and for the formulation of related regulatory policy. FSA is an improved transplantation of onshore industrial safety assessment methods, which is conducive to enriching and widely serving marine safety assessments, but needs to be developed and improved in accordance with the goals of MSET. Under the guideline of FSA, various risk assessments have been carried out in the field of maritime safety management [6-8]. However, Merrick and Van Dorp [9] and Goerlandt [11] criticized the imprecise risk measurement caused by subjective judgments and the uncertainty of risk during the procedure of performing FSA.

In order to evaluate of safety, many efforts have been made in different engineering fields. Fault tree and event tree analysis were widely applied in the field of accident investigation. Liu [12] combined fault tree and quantitative analysis methods to obtain a more comprehensive view of accident and its possibilities to occur. In process industry, event tree method was applied to identify the accident propagation paths and the most dangerous equipment in order to analyze the domino scenarios which have severe consequences of accident. The safety level of land use planning can then be improved [13]. Probabilistic Risk Assessment (PRA) methods are also extensively used in the field of safety management and risk analysis [14-16]. With the rapid development of information and computer technology, big data theory and advanced techniques were also introduced to study the mechanism of safety and accident. Martín [17] applied data mining technique to study the relationships between road conditions and crash accidents to improve road safety. Verma [18] utilized association rule mining to identify safety patterns in steel plant.

MSET in terms of port operation safety is also developing rapidly. Moua [19] proposes a framework of safety indexes to evaluate the risk level in busy ports according to the accident severity, fatality rate and special indicators of maritime transportation. To facilitate maritime safety management with satisfactory efficiency and efficacy. Alyami H [20] develops an advanced Failure Mode and Effects Analysis (FMEA) approach through incorporating Fuzzy Rule-Based Bayesian Networks (FRBN) to evaluate the criticality of the Hazardous Events (HEs) in a container terminal. The rational use of the Degrees of Belief (DoB) in a fuzzy rule base (FRB) facilitates the implementation of the new method in Container Terminal Risk Evaluation (CTRE) in practice. Mokhtari K [21] uses fuzzy set theory (FST) to describe and evaluate the associated risk factors within the Ports and Terminals Operations and Management (PTOM). An Evidential Reasoning (ER) approach is employed to synthesise the information produced. These processes constitute a decision support framework that will be used to conduct port-to-port risk evaluations or to assess a whole port’s and terminal’s overall risk level in order to facilitate continuous improvement strategies. Vidmar P [22] presents the methodology applying different approaches, probabilistic, deterministic and qualitative to present deeper understanding and relations governing the cruise in port transport risks. Jo B [23] development of a cloud computing-based pier type port structure stability evaluation platform is presented. Experiments making use of the platform were conducted, which demonstrated the good performance of the platform and the convenience of monitoring the harbor structure. Xue J [24] study mainly focuses on the concept of human-like maneuvering for autonomous ships. Based on experimental data of experienced seafarers and using a simulation platform under the scenario of the Shanghai Waigaoqiao wharf, an inference model utilizing grey and fuzzy theories is proposed. The proposed model combined with expert linguistic terms in order to select the ship maneuvering decision making main influencing factors from multi-source influencing factors (in overall and separated categories of natural environment, ship motion, force parameters, draft, and position), and to study the decision-making prioritization for maritime traffic safety for specific ship maneuvering scenarios. This method can prioritize the main

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factors which affect maneuvering decisions as well as guide an autonomous ship assisted or automatic maneuvering evaluation system for the research of human-like maneuvering behavior. This study provides a new perspective on the identification of main ship maneuvering decision-making influencing factors in theory and in practice. It can be utilized for better decision-making concerning maritime traffic safety of autonomous ship maneuvering, which in turn makes shipping safer and promote the application and spreading of autonomous ships.

Research on the safety evaluation model method has been in progress. In fact, as early as 1985, operations researcher Thomas L Saaty published The Analytic Hierarchy Process. Provides an overview of Analytic Hierarchy Process (AHP), which is a systematic procedure for representing the elements of any problem hierarchically. It organizes the basic rationality by breaking down a problem into its smaller constituent parts and then guides decision makers through a series of pair-wise comparison judgments to express the relative strength or intensity of impact of the elements in the hierarchy. These judgments are then translated to numbers. The AHP includes procedures and principles used to synthesize the many judgments to derive priorities among criteria and subsequently for alternative solutions. It is useful to note that the numbers thus obtained are ratio scale estimates and correspond to so-called hard numbers. Problem solving is a process of setting priorities in steps. One step decides on the most important elements of a problem, another on how best to repair, replace, test, and evaluate the elements, and another on how to implement the solution and measure performance.

This paper selects the main evaluation indicators (man factors, machine factors, environmental factors and management factors) using the Delphi method (DM) method to initially select Multiple Safety Indicators (MSI), and then conduct sensitivity analysis to obtain the final Multiple Safety Indicators (MSI). The proposed framework is shown in Figure 1. First, a Multiple Safety Index (MSI) is established based on four aspects: Man-Machine-Environmental-Management (MMEM). Secondly, the Delphi method (DM) is used to conduct a sensitivity analysis on the preliminarily established Multiple Safety Index (MSI) to obtain the final Multiple Safety Index. In addition, the MSI weight is determined by the AHP method, and then the fuzzy comprehensive evaluation method (FCE) is used to make decisions and evaluate the safety of the object.

This article uses this method to conduct safety analysis and risk assessment of dangerous chemical ships entering and leaving the port in Yangshan Deepwater Port, to test the applicability of this method, and use it as a theoretical guide for the safety evaluation method based on Man-Machine-Environmental-Management Multiple Safety Indicators (MMEMMSI) method.

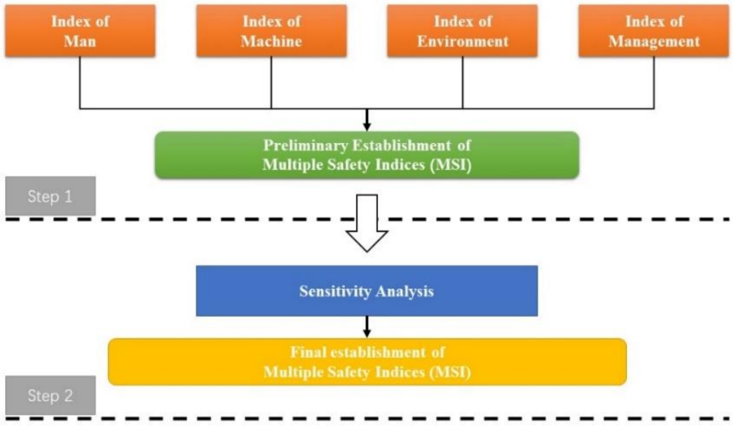

Figure 1. Proposal framework for multiple safety indicators (MSI)

2. THE ESTABLISHMENT OF MULTIPLE SAFETY INDICES (MSI)

The safety of dangerous chemical ships entering and leaving the port is affected by many factors, so it is very important to establish an evaluation index system.

The first is scientific. In order to reflect the safety of dangerous chemical ships entering and leaving the port, the selected evaluation index system should be considered under the guidance of comprehensive science and technology. Secondly, it is practical. The selected evaluation index system should be improved, with clear levels, simple methods, and practical value and promotion value. Finally, it must have strong operability, and the selected evaluation index system should be operable, clear and easy to understand.

According to these principles, based on the MMEM model, the evaluation index system for hazardous chemical ships entering and leaving the port is divided into four categories, namely, human factors, machine factors, environmental factors, and management factors.

There are many safety evaluation factors that affect the entry and exit of hazardous chemical ships, and the composition of these indicators is also relatively complex. It is necessary to screen on the initially selected indicator system to exclude those indicators with higher relevance. Therefore, it will not affect hazardous chemicals. Under the premise of the basic evaluation system for ships entering and leaving the port, the Delphi method (DM) and the group decision method are used to screen the evaluation indicators, and the final multiple safety evaluation indicator system is shown in Figure 2.

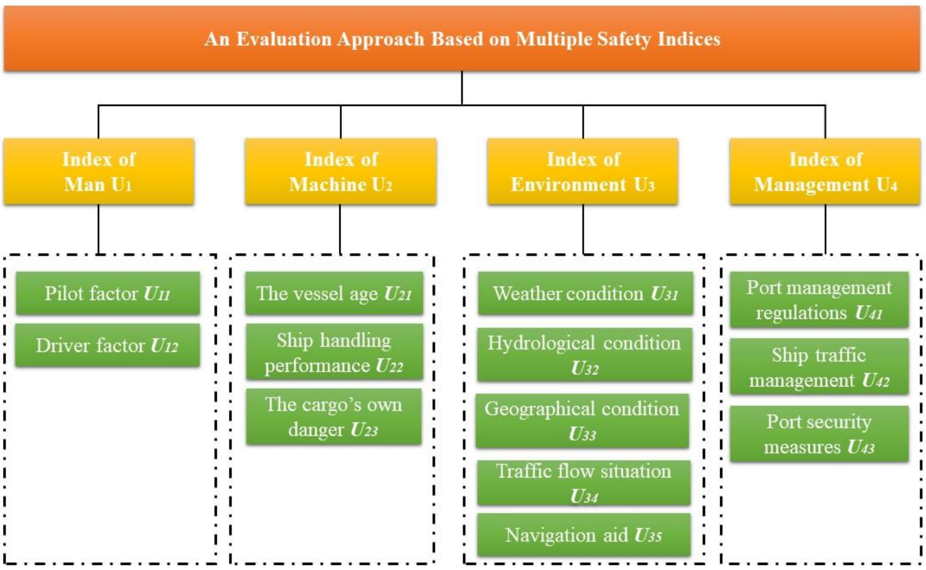

Figure 2. Multiple Safety Indices (MSI)

3. THE PORTS OPERATION INTEGRATED FUZZY EVALUATION MODEL

Fuzzy Evaluation Model is a quantitative mathematic approach making a comprehensive evaluation for a kind of fuzzy phenomenon which influenced by many complicated factors. When some indices are fuzzy and there is need to classify the degree of importance of these indices, then Fuzzy Evaluation Model can be used to get weights and orders of these indices.

3.1. Establishment of the Index Set and Review Set

Suppose that m main factors are set to reflect the port operation safety assessment objects in this article, and defined by u1, u2, u3,..., um, so they can be expressed as U = {u1, u2, u3,..., um}. For each of the factors, it can be divided into several levels or given a certain evaluation. If there

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are n division levels defined by v1, v2, v3,..., vn, the evaluation level can be expressed as V = {v1, v2, v3,..., vn}, where n is the number of evaluation levels, called For the factor evaluation set.

3.2. The Determination of MSI Weight

The steps to use the analytic hierarchy process to determine the weight of each indicator are as follows:

(1) Construct a judgment matrix

An element Ak in the structure model is related to the n elements B={$B1$, $B2$... Bn} in the structure model. Use Bij to represent the mutual importance of the elements under the structure of Ak, which constitutes a judgment matrix between elements. It is shown in Table 1.

Table 1. Judgment matrix

Ak	B1	B2	...	Bj	...	Bn
B1	b11	b12	...	b1j	...	b1n
B2	b21	b22	...		...	b2n
⋮	⋮	⋮	⋮	⋮	⋮	⋮
Bi	bi1	bi2	...	bij	...	bin
⋮	⋮	⋮	⋮	⋮	⋮	⋮
Bn	bn1	bn2	...	bnj	...	bnn

Experts use the 1-9 scale method to compare the importance of influencing factors at the same level. The scale is divided into 9 levels, with 1, 2, 3, 4, 5, 6, 7, 8, 9 means that 1, 3, 5, 7, and 9 respectively mean equally important, slightly important, more important, very important, and absolutely important. As shown in Table 2.

Table 2. Quantitative scale

Bi/Bj	equal	Slightly important	Obviously important	Strongly important	Extremely important
bij	1	3	5	7	9

If the relative importance of the two factors to be judged is between the two, Bij can be selected as 2, 4, 6, 8; and the reciprocal is the result of the opposite importance of the two factors.

Among them $b_{ij} = \frac{B_i}{B_j}$, indicates the judgment value of the relative importance of factor Bi to factor Bj for the element bij. The larger the value, the more important Bi is relative to Bj. The element on the diagonal of the matrix is 1, which means that the importance of each element relative to itself is 1.

(2) Use and integral to solve the judgment matrix

Get the relative weight of the compared elements under the element Ak-that is, the level single order:

Add the resulting matrix according to the rows:

$$w_i = \sum_{j=1}^{N} \frac{b_{ij}}{N} \tag{1}$$

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Get the vector:

$$\overline{\mathrm{w}} = [\mathrm{w}_1, \mathrm{w}_2, \cdots, \mathrm{w}_\mathrm{N}]^\mathrm{T}, \mathrm{i} = 1,2, \cdots, \mathrm{N} \quad (2)$$

The calculated column vector W is normalized to obtain the sorting weight vector of each compared element under a single criterion.

Here you can also normalize Ak, and then find the feature vector W.

(3) Check the consistency of the judgment matrix

Calculate the largest characteristic root of the matrix Ak:

$$\lambda_{max} = \sum_{i=1}^{N} \frac{(Aw_i)_i}{nw_1}, i = 1,2, \cdots, N \quad (3)$$

Consistency index:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (4)$$

Inspection factor:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \quad (5)$$

CI is an index to judge the consistency of the matrix. The smaller the CI, the higher the consistency of the matrix. When CI=0, the judgment matrix is completely consistent.

It is unlikely that the judgment matrix has complete consistency, and then there will be a certain deviation in the eigenvector of the judgment matrix. In order to ensure the rationalization of the analysis conclusion, the consistency of the judgment matrix must be checked to determine whether it can be accepted or not, and the judgment matrix is revised again. Introduce the average random consistency index RI. See Table 3 for specific values.

Table 3. Average random consistency index

Matrix order	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Usually, the judgment matrix of 1st and 2nd order is completely the same, then RI=0. When n≥3, CR≤0.1 and CI is less than one-tenth of the consistency index RI, we think it is acceptable; otherwise, when CR>0.1, the error is unacceptable, and the judgment matrix needs to be adjusted to achieve Acceptable standards.

3.3. Make Decisions

First, calculate the fuzzy matrix for R to obtain the membership vector of the criterion layer index Uk to the evaluation set Bk

B=WR= ($B1$, $B2$, $B3$…,Bi)

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$$R = \begin{bmatrix} B_1 \\ \vdots \\ B_i \end{bmatrix} = \begin{bmatrix} b_{11} & \cdots & b_{1n} \\ \vdots & \ddots & \vdots \\ b_{i1} & \cdots & b_{in} \end{bmatrix} \tag{6}$$

$$B = W \cdot R = W(w1, w2, \dots, wi) \cdot \begin{pmatrix} B_1 \\ \vdots \\ B_i \end{pmatrix} = (b_1, b_2, \cdots, b_n) \tag{7}$$

When $\sum_{i=1}^{n} b_{j\neq 1}$, Normalize.

The evaluation model for the entry and exit of hazardous chemical ships is:

$$B = W \times R = W \times \begin{pmatrix} B_1 \\ B_2 \\ \vdots \\ B_i \end{pmatrix} = W \times \begin{pmatrix} W_1 \times R_1 \\ W_2 \times R_2 \\ \vdots \\ W_i \times R_i \end{pmatrix} \tag{8}$$

The fuzzy comprehensive evaluation model is:

$$B = W \times R = (B_1, B_2, \cdots, B_n) \tag{9}$$

Finally, according to the principle of maximum membership, the evaluation of the largest corresponding evaluation set among $B1$, $B2$,..., Bn is the evaluation result.

4. CASE STUDY

Shanghai Yangshan Deepwater Port is located in the eastern part of Hangzhou Bay and Qiqu archipelago, on the west side of Shengsi. It is composed of two island chains in the north and south, which mainly for small and large Yangshan Islands and surrounding waters around the island reef. Yangshan Deepwater Port Area has a quay length of about 6.2Km. Its location is 30° 38' 06N/122° 03.' 29E. The north of Yangshan Port is connected to the south mouth of Lingang by the Donghai Bridge (32.5Km), about 48.5 nautical miles from Yangshan Port south to Ningbo Port, Zhejiang. The east side is directly connected to the outer sea through the waters of Huang Ze Yang. The climate in the port area is a north subtropical marine monsoon climate, with a southerly wind in summer and a northerly wind in winter.

4.1. Determine the Index Set U and Comment Set V

Index set U, The evaluation set established in this article: V = {$v1$, $v2$, $v3$, $v4$, $v5$} = {very good, good, better, average, poor}

The scores are very good, good, good, average, and poor, which are 90, 80, 70, 60, 50 respectively. Where j = (1, 2, 3, 4, 5).

4.2. Membership Function

The membership function is:

$$u_{vj}(u_i) = \begin{cases} 1 & u_i \geq 90 \\ \frac{u_i - 80}{10} & 80 \leq u_i < 90 \\ 0 & u_i < 80 \end{cases} \tag{10}$$

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$$u_{vj}(u_i) = \begin{cases} \frac{u_i - 70}{10} & 70 \le u_i < 80 \\ \frac{90 - u_i}{10} & 80 \le u_i < 90 \\ 0 & u_i < 70, u_i \ge 90 \end{cases} \tag{11}$$

$$u_{vj}(u_i) = \begin{cases} \frac{u_i - 60}{10} & 60 \le u_i < 70 \\ \frac{80 - u_i}{10} & 70 \le u_i < 80 \\ 0 & u_i < 60, u_i \ge 80 \end{cases} \tag{12}$$

$$u_{vj}(u_i) = \begin{cases} \frac{u_i - 50}{10} & 50 \le u_i < 60 \\ \frac{70 - u_i}{10} & 60 \le u_i < 70 \\ 0 & u_i < 50, u_i \ge 70 \end{cases} \tag{13}$$

$$u_{vj}(u_i) = \begin{cases} 0 & u_i \ge 60 \\ \frac{60 - u_i}{10} & 50 \le u_i < 60 \\ 1 & u_i < 50 \end{cases} \tag{14}$$

4.3. The Determination of MSI Weight

In this paper, the method of weighted arithmetical average and product normalization of each expert judgment matrix is selected. The aggregate judgment matrix of each expert judgment matrix is calculated by arithmetical average and product normalization of each expert judgment matrix, and then the ranking weight of the assembled matrix is calculated. See Appendix 1 for the original data.

The assembled judgment matrix --- the safe entry and exit of chemical vessels

Consistency inspection coefficient: 0.0302; weight for "safe entry and exit of chemical vessels": 1.000

Table 4. Judgment matrix--- the safe entry and exit of chemical vessels

	Index of Man U1	Index of Machine U2	Index of Environment U3	Index of Management U4	Wi
Index of Man U1	1	5/2	3	2	0.4273
Index of Machine U2	2/5	1	1	1/3	0.1312
Index of Environment U3	1/3	1	1	1/3	0.1253
Index of Management U4	1/2	3	3	1	0.3162

The assembled judgment matrix --- Index of Man U1

Consistency ratio: 0.0000; weight for "chemical vessels entering and leaving port safely": 0.4273

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Table 5. Judgment matrix--- Index of Man U1

	Pilot factor U11	Driver factor U12	Wi
Pilot factor U11	1	1/1.29	0.4365
Driver factor U12	1.29	1	0.5635

The assembled judgment matrix --- Index of Machine U2

Consistency ratio: 0.0707; weight on "chemical vessels entering and leaving port safely": 0.1312

Table 6. Judgment matrix--- Index of Machine U2

	The vessel age U21	Ship handling performance U22	The cargo's own danger U23	Wi
The vessel age U21	1	2/9	1/3	0.1172
Ship handling performance U22	9/2	1	3	0.6144
The cargo's own danger U23	3	1/3	1	0.2684

The assembled judgment matrix --- Index of Environment U3

Consistency ratio: 0.0374; weight for "safe entry and exit of chemical vessels": 0.1253

Table 7. Judgment matrix--- Index of Environment U3

	Weather condition U31	Hydrological condition U32	Geographical condition U33	Traffic flow situation U34	Navigation aid U35	Wi
Weather condition U31	1	1.3	1	0.82	1.3	0.2010
Hydrological condition U32	1/1.3	1	1/3	1/2	1/1.15	0.1251
Geographical condition U33	1	3	1	3	3	0.3581
Traffic flow situation U34	1/0.82	2	1/3	1	1.3	0.1889
Navigation aid U35	1/1.3	1/1.15	1/3	1/1.3	1	0.1269

The assembled judgment matrix --- Index of Management U4

Consistency ratio: 0.0004; weight for "chemical vessels entering and leaving port safely": 0.3162

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Table 8. Judgment matrix--- Index of Management U4

	Port management regulations U41	Ship traffic management U42	Port security measures U43	Wi
Port management regulations U41	1	1.22	1.15	0.3729
Ship traffic management U42	1/1.22	1	1	0.3105
Port security measures U43	1/1.15	1	1	0.3166

4.4. Fuzzy Synthetic

According to the scoring results of 10 experts in the industry, the membership of each indicator is calculated. Expert evaluation results are shown in the appendix 2.

Membership of Pilot factor U11 (0.78, 0.22, 0, 0, 0)

Membership of Driver factor U12 (0.75, 0.22, 0.03, 0, 0)

Membership of The vessel age U21 (0.61, 0.28, 0.09, 0.02, 0)

Membership of Ship handling performance U22 (0.77, 0.21, 0.02, 0, 0)

Membership of The cargo's own danger U23 (0.66, 0.30, 0.04, 0, 0)

Membership of Weather condition U31 (0.61, 0.24, 0.14, 0.01, 0)

Membership of Hydrological condition U32 (0.59,0.29,0.10,0.02,0)

Membership of Geographical condition U33 (0.71,0.27,0.02,0,0)

Membership of Traffic flow situation U34 (0.31,0.38,0.24,0.07,0)

Membership of Navigation aid U35 (0.69,0.30,0.01,0,0)

Membership of Port management regulations U41 (0.69,0.27,0.04,0,0)

Membership of Ship traffic management U42 (0.72,0.22,0.06,0,0)

Membership of Port security measures U43 (0.86,0.14,0,0,0)

The judgement matrix of Indexes of Man U1 $R_1 = \begin{bmatrix} 0.78 & 0.22 & 0 & 0 & 0 \\ 0.75 & 0.22 & 0.03 & 0 & 0 \end{bmatrix}$

The judgement matrix of Indexes of Machine U2 $R_2 = \begin{bmatrix} 0.61 & 0.28 & 0.09 & 0.02 & 0 \\ 0.77 & 0.21 & 0.02 & 0 & 0 \\ 0.66 & 0.30 & 0.04 & 0 & 0 \end{bmatrix}$

The judgement matrix of Indexes of Environment U3 $R_3 = \begin{bmatrix} 0.61 & 0.24 & 0.14 & 0.01 & 0 \\ 0.59 & 0.29 & 0.10 & 0.02 & 0 \\ 0.71 & 0.27 & 0.02 & 0 & 0 \\ 0.31 & 0.38 & 0.24 & 0.07 & 0 \\ 0.69 & 0.30 & 0.01 & 0 & 0 \end{bmatrix}$

The judgement matrix of Indexes of Management U4 $R_4 = \begin{bmatrix} 0.69 & 0.27 & 0.04 & 0 & 0 \\ 0.72 & 0.22 & 0.06 & 0 & 0 \\ 0.86 & 0.14 & 0 & 0 & 0 \end{bmatrix}$

4.5. Decision Making

$$\mathrm{B}_1 = \mathrm{W}_1\mathrm{R}_1 = (0.4365 \quad 0.5635)\begin{bmatrix} 0.78 & 0.22 & 0 & 0 & 0 \\ 0.75 & 0.22 & 0.03 & 0 & 0 \end{bmatrix} = (0.7631 \quad 0.2200 \quad 0.0169 \quad 0 \quad 0) \tag{15}$$

$$B_2 = W_2R_2 = (0.1172 \quad 0.6144 \quad 0.2684)\begin{bmatrix} 0.61 & 0.28 & 0.09 & 0.02 & 0 \\ 0.77 & 0.21 & 0.02 & 0 & 0 \\ 0.66 & 0.30 & 0.04 & 0 & 0 \end{bmatrix} = (0.7217 \quad 0.2424 \quad 0.0336 \quad 0.0023 \quad 0) \tag{16}$$

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$$B_3 = W_3R_3 = (0.2010 \quad 0.1251 \quad 0.3581 \quad 0.1889 \quad 0.1269)\begin{bmatrix}0.61 & 0.24 & 0.14 & 0.01 & 0\\0.59 & 0.29 & 0.10 & 0.02 & 0\\0.71 & 0.27 & 0.02 & 0 & 0\\0.31 & 0.38 & 0.24 & 0.07 & 0\\0.69 & 0.30 & 0.01 & 0 & 0\end{bmatrix} = (0.5968 \quad 0.2911 \quad 0.0944 \quad 0.0177 \quad 0) \tag{17}$$

$$B_4 = W_4R_4 = (0.3729 \quad 0.3105 \quad 0.3166)\begin{bmatrix}0.69 & 0.27 & 0.04 & 0 & 0\\0.72 & 0.22 & 0.06 & 0 & 0\\0.86 & 0.14 & 0 & 0 & 0\end{bmatrix} = (0.7531 \quad 0.2133 \quad 0.0336 \quad 0 \quad 0) \tag{18}$$

$$R = \begin{bmatrix}B_1\\B_2\\B_3\\B_4\end{bmatrix} = \begin{bmatrix}0.7631 & 0.2200 & 0.0169 & 0 & 0\\0.7217 & 0.2424 & 0.0336 & 0.0023 & 0\\0.5968 & 0.2911 & 0.0944 & 0.0177 & 0\\0.7531 & 0.2133 & 0.0336 & 0 & 0\end{bmatrix} \tag{19}$$

$$B = WR = (0.4273 \quad 0.1312 \quad 0.1253 \quad 0.3162)\begin{bmatrix}0.7631 & 0.2200 & 0.0169 & 0 & 0\\0.7217 & 0.2424 & 0.0336 & 0.0023 & 0\\0.5968 & 0.2911 & 0.0944 & 0.0177 & 0\\0.7531 & 0.2133 & 0.0336 & 0 & 0\end{bmatrix} = (0.7337 \quad 0.2297 \quad 0.0341 \quad 0.0025 \quad 0) \tag{20}$$

Using the evaluation model obtained by AHP, combined with the scores of experts, evaluate the entry and exit of dangerous chemical ships in Yangshan Port. The risk of safe entry and exit of Yangshan port chemical ships is 73.37%, which may be “no risk”, 22.97% may be “low risk”, 3.41% may be medium risk, and 0.25% may be high risk. Judging by the principle of maximum subordination, the risk level of dangerous chemical ships entering and leaving the port at Yangshan Port is between “no risk” and “low risk”. Generally speaking, the entry and exit of dangerous chemical ships at Yangshan Deepwater Port is very safe.

5. DISCUSSION

The main work of this paper is to provide a new solution to the unresolved problems in the port operation security risk assessment. The evaluation method proposed in this paper based on multiple safety indicators, to a certain extent, truly and effectively reflects the risk assessment of hazardous chemicals entering and leaving the port. The case shows that the Shanghai Yangshan Deepwater Port hazardous chemical ships entering and leaving the port are very safe. This kind of safety evaluation method can be used to evaluate the safety risk assessment of port operations. This article starts from the four aspects of human, machine, environment, and management, establishes four first-level indicators, and establishes a total of 13 sub-indices under them. They constitute an evaluation system for multiple safety indicators. The judgment matrix results in the case show that human The weights of, machine, environment, and pipe are 0.4273, 0.1312, 0.1253, and 0.362, respectively, indicating that the higher factors affecting the entry and exit of dangerous chemical ships in Shanghai Yangshan Deepwater Port are human factors and management factors, while machine factors and environmental factors are more important. low. The purpose of this article is to provide good guidance for the analysis and assessment of port operational safety risks. For different ports, starting from the four aspects of man-machine environmental management, the evaluation system of multiple safety evaluation indicators established is different. Limited to the 13 sub-indicators described in this article, the weight of the indicator is not limited to the points scored by experts. Having more accurate information will help the accuracy of the evaluation results.

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6. CONCLUSIONS

This paper presents a practical and scientific evaluation method based on the safe operation of ports. In this method, we regard human-machine-loop-tube as an important factor. The weights are determined by the expert scoring method. Compared with the relevant literature, this is a contribution to the port safety operation evaluation system. In addition, our research advantages are as follows:

(1) Compared with the traditional evaluation index system, the proposed multiple safety index (MSI) covers the index factors of man-machine-loop-tube. First, the initial structure of multiple security factors (MSI) is selected using the Delphi method. Secondly, the sensitivity of the port operation safety evaluation index was analyzed and the final MSI was selected by using the total average acceptability. The results show that the proposed evaluation index system is an excellent tool for port safety evaluation. Multiple safety index (MSI) has sample structure, easy to operate and strong practicability. The meaning of MSI is clear and value is easy to obtain. This method can not only be applied to the safety evaluation of ports, but also has applicability in other safety fields.

(2) On the basis of the traditional fuzzy comprehensive evaluation (FCE) method, this study can also extend the FCE model based on the combination of subjective weight and objective weight. There are some differences from the traditional FCE method. In the proposed method, the weight of the risk index is derived from the comprehensive weight (subjective weight and objective weight together). Therefore, the proposed method can more reasonably describe the decision-making process and reflect the decision-making opinions and Suggestions of the expert group as well as the objective conditions for the safe operation of the port. Combined with the subjective method (AHP method) and the objective method (entropy method) to determine the comprehensive weight, the port security can be evaluated.

(3) The structure of MSI was strictly verified and the comprehensive weight was determined according to the method proposed in this paper. The results show that it is very safe for hazardous chemicals ships to enter and leave the port at Shanghaishan deepwater port.

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APPENDIX

Appendix 1

The weighted arithmetic average of the original expert judgment matrix calculates the assembled total judgment matrix

Judgment matrix after assembly---safe entry and exit of chemical ships

Consistency ratio: 0.0836; weight for "safe entry and exit of chemical ships": 1.0000

Table 9. Judgment matrix--- safe entry and exit of chemical ships

safe entry and exit of chemical ships	Index of Man	Index of Machine	Index of Environment	Index of Management	Wi
Index of Man	1	2.5	3	2	0.419
Index of Machine	0.4167	1	1.25	0.3333	0.1392
Index of Machine	0.3333	1.25	1	0.3333	0.1304
Index of Management	0.5	3	3	1	0.3114

The assembled judgment matrix---Index of Man

Consistency ratio: 0.0000; weight for "safe entry and exit of chemical ships": 0.4190

Table 10. Judgment matrix--- Index of Man

Index of Man	Pilot factor	Driver factor	Wi
Pilot factor	1	2.6667	0.5559
Driver factor	1.6	1	0.4441

The assembled judgment matrix---Index of Machine

Consistency ratio: 0.0569; weight for “safe entry and exit of chemical ships”: 0.1392

Table 11. Judgment matrix--- Index of Machine

Index of Machine	The vessel age	Ship handling performance	The cargo’s own danger	Wi
The vessel age	1	0.225	0.3333	0.113
Ship handling performance	4.5	1	3	0.6211
The cargo’s own danger	3	0.3333	1	0.2659

The assembled judgment matrix ---Index of Environment

Consistency ratio: 0.5463; weight for "safe entry and exit of chemical ships": 0.1304

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Table 12. Judgment matrix--- Index of Environment

Index of Environment	Weather condition	Hydrological condition	Geographical condition	Traffic flow situation	Navigation aid	Wi
Weather condition	1	2.6667	1.6667	1.1667	2.6667	0.2475
Hydrological condition	1.6	1	0.3333	0.5	2.1667	0.1311
Geographical condition	1.6667	3	1	3	3	0.2914
Traffic flow situation	1.75	2	0.3333	1	2.6667	0.1769
Navigation aid	1.6	1.625	0.3333	1.6	1	0.1532

The assembled judgment matrix --- Index of Management

Consistency ratio: 1.0190; weight for "chemical vessels entering and leaving port safely": 0.0864

Table 13. Judgment matrix--- Index of Management

	Port management regulations U41	Ship traffic management U42	Port security measures U43	Wi
Port management regulations U41	1	1.75	2.1667	0.3441
Ship traffic management U42	1.1667	1	2.125	0.3048
Port security measures U43	1.625	2.125	1	0.3511

Appendix 2

Experts scoring tables

Expert / Index	1	2	3	4	5	6	7	8	9	10
Pilot factor	93	90	88	94	87	92	86	85	93	82
Driver factor	92	88	92	91	77	85	88	89	85	91
The vessel age	90	92	86	84	93	88	79	95	68	83
Ship handling performance	87	94	93	91	90	94	86	78	85	89
The cargo’s own danger	83	82	90	88	92	84	76	89	91	90
Weather condition	92	88	92	84	91	85	84	93	75	69
Hydrological condition	88	78	91	83	88	91	90	68	92	80
Geographical condition	91	93	88	86	90	78	92	82	85	91
Traffic flow situation	84	83	76	66	90	79	86	74	67	88
Navigation aid	82	79	95	93	89	85	91	83	91	90
Port management regulations	82	92	93	88	83	88	92	90	88	76
Ship traffic management	74	89	84	93	87	92	86	90	90	86
Port security measures	96	92	92	90	89	92	87	83	89	88