Key Factors Analysis of Arctic Navigation Security Based on Fuzzy AHP

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Abstract: Due to the complexity and vulnerability of Arctic waters, mass of security risks inevitably arise for ship navigation in the Arctic. In the perspective of security, an Arctic navigation security system with 4 levels and 24 evaluation indexes is developed in the present study. The fuzzy AHP based on trapezoidal fuzzy number is adopted, and expert weights are taken into account in the evaluation, so as to scientifically evaluate the weight of each index. According to the Pareto principle, the key factors are identified. The results of this study can provide reference for improving the arctic navigation security level.

1. Introduction

With the global warming, the Arctic sea ice area continues to hit a new low, which not only makes it possible to explore abundant energy resources in the Arctic region, but also benefits to open up a golden channel connecting the three continents of Asia, Europe and America. However, the unique geographical location and special environmental conditions of the Arctic give it unique strategic advantages and economic value, also bring a lot of security risks. Therefore, in the process of developing and utilizing the Arctic shipping routes, there is a direct and realistic demand for the navigation security in the Arctic, such as navigation data, port terminal status, environmental protection, ship and navigation conditions, etc. The proposal to jointly build the Polar Silk Road and promote sustainable development of the Arctic region highlights the current dilemma of opportunities and challenges. In this context, China should give full play to its advantages in scientific research, capital, and infrastructure construction; strengthen cooperation with relevant countries, especially coastal countries, and work together to build a unified Arctic navigation security system. According to the characteristics of Arctic navigation, it is also necessary to invest a large amount of human and material resources in order to achieve breakthroughs in Gordian technique as early as possible. Most of the existing studies have discussed the establishment of Arctic navigation security system from a qualitative point of view, there is a lack of systematic and hierarchical quantitative study. Therefore, in this study, based on the analysis of the existing studies and experts' suggestions, an Arctic navigation security evaluation system is developed, in which F-AHP is applied to get the weight of each index and the key factors effecting Arctic security are also identified. Finally, potential security measures are proposed for further improving Arctic navigation security capabilities and promoting the development of Arctic shipping industry.

2. Establishment of evaluation system

Arctic navigation security refers to a series of public goods and services provided by the government and related organizations to deal with the safety issues associated with the Arctic navigation activities, such as navigation safety, ship and crew safety, and ecological environment protection, etc.

In order to ensure the scientificity and rationality of the system, indexes are selected based on the principles of systematisms, comprehensiveness and operability, and Delphi method is applied to invite experts to put forward suggestions for improvement. According to the hierarchical structure of the analytic hierarchy process (AHP) [1], an evaluation framework of Arctic navigation security system with 4 levels and 24 indexes is finally established, as shown in Fig. 1.

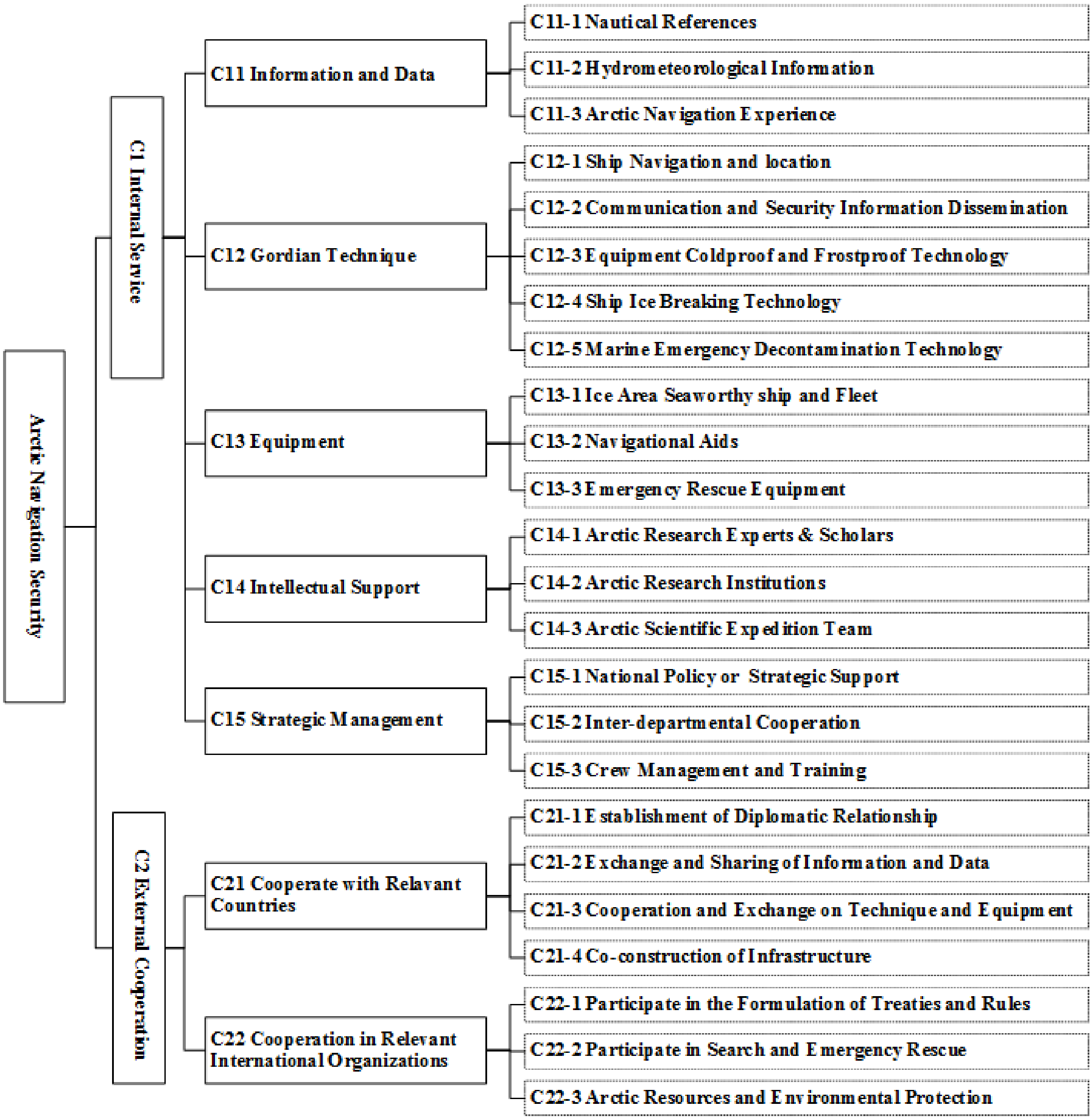

Figure 1. Arctic navigation security evaluation framework

3. Key factors identification

3.1 F-AHP

As a systematic analysis method, AHP has been widely used in various fields since 1970s. However, the multi-attribute decision analysis based on conventional AHP paid less attention to the fuzziness of expert's judgment, which is critical for risk evaluation. In fact, there are several of vague statements to describe the importance degree of each index and the preference opinions of experts. Therefore, the development of AHP in the fuzzy environment is necessary. In the present study, with the introduction of trapezoidal fuzzy number [2], the analysis framework of F-AHP is established, in which the linguistic expressions of experts corresponds to trapezoidal fuzzy numbers.

Let the domain R , if $\mu_N(x): R \to 0,1$ exist, then $\mu_N(x)$ is generally called the membership function of N , which is expressed as:

$$\mu_N(x) = \begin{cases} \dfrac{x}{a_2 - a_1} - \dfrac{a_1}{a_2 - a_1}, & x \in [a_1, a_2] \\ 1 & x \in [a_2, a_3] \\ \dfrac{a_4}{a_4 - a_3} - \dfrac{x}{a_4 - a_3}, & x \in [a_3, a_4] \\ 0 & otherwise \end{cases} \tag{1}$$

Where $a_1 \le a_2 \le a_3 \le a_4$, the trapezoidal fuzzy number is expressed as $N(a_1, a_2, a_3, a_4)$.

Based on the judgment of experts, the steps of system hierarchy analysis using trapezoidal fuzzy numbers are as follows:

Calculation of the degree of similarity. $S_{uv}(\tilde{E}_u, \tilde{E}_v)$ is defined as the degree of agreement for different opinions between each pair of experts. Suppose $\tilde{E}_u$ and $\tilde{E}_v$ are represented as two triangular fuzzy numbers ($u \neq v$), then,

$$S_{uv}(\tilde{E}_u, \tilde{E}_v) = 1 - \frac{1}{J} \sum_{i=1}^{J} |a_i - b_i| \quad i = 1, 2, 3 \tag{2}$$

Where J is the number of fuzzy set members, $J = 4$ for standard trapezoidal fuzzy numbers.

(2) Calculation for the Average of Agreement (AA) degree for each expert viewpoint.

$$AA(E_u) = \frac{1}{U - 1} \sum_{u \neq v, v=1}^{U} S_{uv}(\tilde{E}_u, \tilde{E}_v) \tag{3}$$

Where U is the total number of experts.

(3) Calculation for the Relative Agreement (RA) degree between two kinds of experts. The value of $RA(E_u)$ can be obtained by,

$$RA(E_u) = \frac{AA(E_u)}{\sum_{u=1}^{U} AA(E_u)} \tag{4}$$

(4) Estimation of the Consensus Coefficient (CC) for each expert. The value of $CC(E_u)$ for the u^{th} expert can be obtained by,

$$CC(E_u) = \beta * P(E_u) + (1 - \beta) * RA(E_u) \tag{5}$$

Where the coefficient $\beta (0 \le \beta \le 1)$ is introduced to represent the importance of $P(E_u)$ over $RA(E_u)$. $\beta = 0.5$ Is considered to be optimal value [3].

(5) Calculation for the aggregated results of the experts' viewpoints. The aggregated results denoted by $\widetilde{R}_A$ can be computed by,

$$\widetilde{R}_A = CC\left(E_1\right) \otimes \widetilde{E}_1 \oplus CC\left(E_2\right) \otimes \widetilde{E}_2 \oplus \cdots \oplus CC\left(E_U\right) \otimes \widetilde{E}_U \tag{6}$$

(6) Defuzzification of the aggregated results. The method of Center of Area (CoA) extended by Nguyen H T et al. [4] is widely used for the defuzzification operation, which is expressed as,

$$AV = \int \mu_M(x)xdx \Big/ \int \mu_M(x)dx \tag{7}$$

Where AV (Aggregated value) represents the defuzzification result, and $\mu_M(x)$ indicates the aggregated membership functions. Therefore, the fuzzy numbers of the aggregated results, denoted as $\widetilde{R}_A\left(c_1, c_2, c_3, c_4\right)$ for fuzzy trapezoidal numbers, can be defuzzificated by (5) and (6), respectively.

(7) Standardizing the indexes at each level and calculation of the integration weights. Suppose there are n indexes in the K layer, and standardizing the indexes is expressed as,

$$SV = \frac{AV_i}{\sum_{i=1}^{n} AV_i} \quad i = 1, 2, \cdots n \tag{8}$$

Where SV (Standardized value) represents the defuzzification result.

And the IV (Integrated value) means that, for the index weight of the K layer, the Standardized value should multiply the corresponding index weight of the $K-1$ layer.

3.2 Calculation of expert credibility

Five experts are invited to give their opinions on the evaluation of Arctic navigation security system. The credibility of experts is evaluated by considering their professional position, working experience, and education level and qualification certificate [5]. The detailed information is shown in Table 1.

Table 1. Criteria for determining the expert weight

Expert	Professional position	Working experiences	Education level	Certificate rank	Weight
E1	Engineer (3)	≥30 (5)	Master (4)	Senior Captain (5)	0.224
E2	Engineer (3)	20-29 (4)	Master (4)	Chief Officer (3)	0.184
E3	Senior academic (5)	20-29 (4)	Ph.D. (5)	Senior Chief Engineer (5)	0.25
E4	Junior academic (4)	10-19 (3)	Master (4)	Captain (4)	0.197
E5	Engineer (3)	6-9 (2)	Bachelor (3)	2nd Engineer (3)	0.145

3.3 Weight assignment of evaluation system

Five experts are invited to compare the indexes at each level by questionnaires. The linguistic expressions and their corresponding fuzzy numbers can be found in Gupta S et al. [6]. The F-AHP algorithm is implemented by MATLAB, and the weight for each index is obtained, as shown in Table 2.

Table 2. Weight assignment of evaluation system

Index	*AV*	*SV*	*IV*	Index	*AV*	*SV*	*IV*
C1	0.8105	0.5	/	C13-1	0.6430	0.0427	0.0031
C2	0.8105	0.5	/	C13-2	0.7250	0.0482	0.0035
C11	0.6430	0.1546	0.0773	C13-3	0.6430	0.0427	0.0031
C12	0.8105	0.1948	0.0974	C14-1	0.6979	0.0464	0.0033
C13	0.5970	0.1435	0.0717	C14-2	0.6686	0.0444	0.0031
C14	0.5889	0.1416	0.0708	C14-3	0.8105	0.0539	0.0038
C15	0.3930	0.0945	0.0472	C15-1	0.6430	0.0427	0.0020
C21	0.5390	0.1296	0.0648	C15-2	0.5390	0.0358	0.0017
C22	0.5889	0.1416	0.0708	C15-3	0.7250	0.0482	0.0023
C11-1	0.7405	0.0492	0.0038	C21-1	0.4869	0.0324	0.0021
C11-2	0.6720	0.0447	0.0035	C21-2	0.3389	0.0225	0.0015
C11-3	0.6512	0.0433	0.0033	C21-3	0.6430	0.0427	0.0028
C12-1	0.7770	0.0516	0.0050	C21-4	0.5390	0.0358	0.0023
C12-2	0.8105	0.0539	0.0052	C22-1	0.3930	0.0261	0.0018
C12-3	0.7770	0.0516	0.0050	C22-2	0.2530	0.0168	0.0012
C12-4	0.6430	0.0427	0.0042	C22-3	0.7250	0.0482	0.0034
C12-5	0.5000	0.0332	0.0032				

3.4 Identification of key factors

The Pareto principle stipulates that the most important of any group of things is only a small part, about 20%, and the remaining, although majority, are secondary [7]. According to this principle, the integrated value of indexes is converted into the form of cumulative percentage, as shown in Fig. 2. The key factors of the top 20% are: communication and security information dissemination (C12-2), ship navigation and location (C12-1), equipment cold proof and frostproof technology (C12-3).

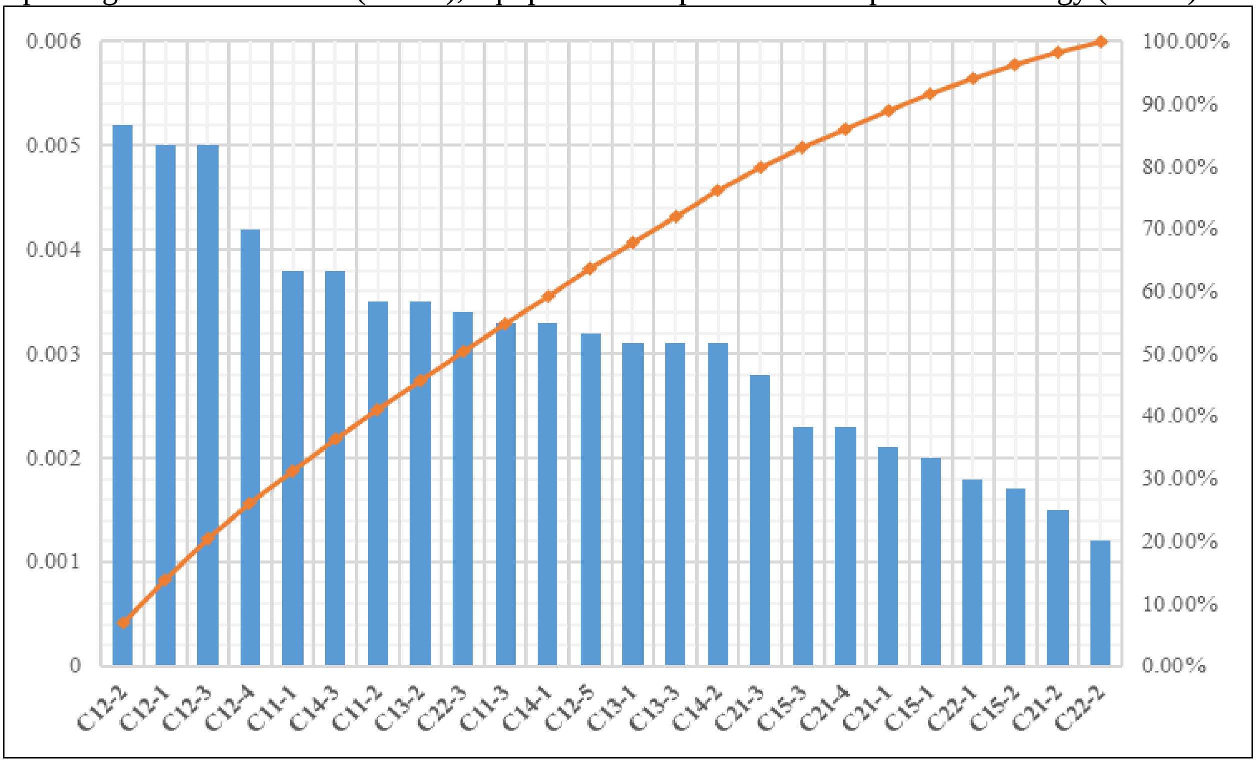

Figure 2. Key factors in the Pareto diagram

4. Conclusion

In the present study, considering the ambiguity of expert judgment, F-AHP model is established to identify the key factors for the Arctic navigation security. The results show that communication and security information dissemination technology, ship navigation and location technology, equipment cold proof and frost proof technology are key factors of the Arctic navigation security system. Therefore, it is necessary to take some measures to strengthen security, such as tracking the technical development of navigation satellite system and trying to apply it to Arctic navigation security; launching professional projects for the development of Arctic navigation security technology, and raise it to the institutional level to effectively strengthen the design and development of technology and equipment; developing e-Navigation demonstration projects, under the guidance of standards and norms formulated by international organizations such as International Maritime Organization (IMO), International Hydrographic Organization (IHO) and The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), etc.

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