Dynamic Assessment of Navigational Safety Risk of Ship Lock Project Based on Entropy Value Method and Markov Chain

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Abstract. Aiming at the characteristics of complex traffic environment and dynamic change of insecurity factors in the area of construction while navigating the ship lock project, a navigation safety risk assessment method based on the combination of entropy value method and Markov chain is proposed to assess the dynamic change of navigation safety status of the ship lock project. First of all, through expert consultation and reviewing specifications and other methods, the navigation safety risk factors of the ship lock project are sorted out and analysed, and a six-aspect safety assessment index system is established, including the intensity characteristics of the ship traffic flow, the speed characteristics of the traffic flow, the behavioural characteristics of the traffic flow, the indicators of the navigation conditions, and the indicators of the working conditions, etc., and the initial weight is determined by using the hierarchical analysis method. Then, the entropy value method is utilized to correct the initial weights and improve the objectivity and scientific of the weights of individual evaluation indicators. Secondly, based on Markov chain, the quantitative grading assessment model of navigation safety risk is established to carry out the dynamic assessment analysis of navigation safety risk. The selected case analysis shows that the results objectively reflect the risk level of the lock project and its dynamic changes, and gives suggestions for navigation safety control measures during the construction of the lock project, which verifies the practicality and effectiveness of the assessment method.

Keywords: Ship lock engineering; Entropy method; Markov chain; Navigation safety; Risk assessment

1 Introduction

Ship locks are usually constructed on dry land, which will have less impact on vessels traveling in the navigation channel. However, when the second-line locks are built

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next to the existing first-line locks, due to the close proximity of the second-line locks to the existing first-line locks, the construction work will seriously affect the safety of navigation of ships due to the occupation of space in the navigation channel and the change of the navigation environment. Therefore, it has become an important task to protect the normal navigation of the first-line locks and reduce the navigational risk of ships during the construction process [1]. However, due to the influence of construction, the navigation environment of ships is in dynamic change, how to effectively carry out the risk assessment of navigation safety is an important initiative to ensure the safe navigation of ships [2].

During the construction period of the project of building additional second-line locks, in addition to the accidents caused by the ships themselves, the risks to the navigation of the waterway due to the construction are more prominent [3]. Some scholars have conducted a lot of research on navigation safety risk assessment by using qualitative and quantitative methods from the aspects of the ship itself and the navigation environment of the waterway. Hu et al. [4] proposed a risk assessment model for ship navigation safety based on relative risk assessment and considered five factors including detailed information about the accident characteristics, which provided support for the pilotage safety assessment of ports. Christos et al. [5] extend the mitigate approach to capture situations in the risk assessment process to generate fine-grained and case-specific dynamic risk assessments. REN et al. [6] analysed the ship drifting law from the perspective of ship operation and marine traffic safety management for the safety impacts of the construction team ships navigating in the waters of wind power construction projects, and targeted safety measures were proposed. Tam et al. [7] et al. proposed a method for assessing the collision risk of surface vessels in close encounters, which can assess the risk of ship navigation for ship pilots when passing through dynamic obstacles. Bolbot et al. [8] integrated operational and functional hazard identification methods, while considering safety, security and network security hazards, and realized the safety assessment of inland vessel navigation in the design stage. Zhen et al. [9] proposed a regional ship collision risk assessment method that takes into account the intelligent monitoring and navigation of ship clustering density encountered by ship cluster. Liu et al. [10] analysed the safety of ship navigation in the inland waterway of Shanghai through the analysing the water transportation safety condition of Shanghai inland waterways, a comprehensive analysis was carried out from four aspects: live body, hardware, software and environment. In this paper, a multi-level fuzzy comprehensive evaluation method based on the AHP (Analytic Hierarchy Process) method is constructed, and a comprehensive assessment model of navigation safety risk in Shanghai inland waters is constructed to scientifically predict and analyse the future safe navigation of ships. Dai [11] establishes a visualized and intelligent dynamic pre-assessment system of maritime navigation risk to assess the maritime navigation risk under bad weather and puts forward safety measures in a targeted manner. Gan et al. [12] propose a risk assessment model based on the D-S evidence theory to assess the safety risk of cruise ship navigation on the inland waterways. Wang et al. [13] adopt a fuzzy cognitive mapping method to construct a systematic mapping relationship between ship navigation risk factors and safety levels in order to assess the effectiveness of ship navigation safety countermeasures. Huang et al. [14] quantitatively assessed the risk of ship grounding at port entrances and inland waterways using both the over-the-line method and the Monte Carlo method.

During the construction of construction projects, the impact of construction on the passage of the waterway and the impact of the passage of the waterway on the construction will inevitably result in a decline in the passage capacity of the waterway, which is in contradiction with the growing demand for navigation. Based on the safety risk analysis in navigable waters, targeted control strategies are proposed, such as Liu et al. [15] statistically analysed the main risk factors affecting the safety of ship navigation in complex waters, and using the N-K model, the probability of occurrence of multi-factor risk coupling affecting the safety of ship navigation in complex waters and the value of risk are calculated. Based on the results, strategies to improve the safety of ship navigation in complex waters are proposed. Yang et al. [16] quantified the effects of four flow indicators, namely, water surface slope, backflow, flow velocity, and water depth, on the safety of navigation by using a grey correlation analysis method, and the results showed that the construction of dams has a negative impact on the safety of ship navigation and affects the spatial distribution of navigation risk. Geng et al. [17] analysed the impact of different bridge pier spacing and Reynolds number on the safety of navigation by analysing the different risk factors. YU et al. [18] proposed a new Bayesian-based model for the current situation of the influence of offshore facilities on the safety of ship navigation to realize the assessment of the collision risk involving different navigational environments, and realize the protection of offshore facilities and the improvement of the safety of water transportation. Zhang et al [19]. used the avoidance behavior collision detection model to detect potential collision scenarios from AIS data and estimate collision probabilities in various routes related to a specific operating area. Xu et al. [20] built a Bayesian network model to predict the probability of ship distress in ice during escort operations along the Northern Sea Route. The model focuses on the first auxiliary ship and is based on expert inspiration. This method can fully predict the accident of the first auxiliary ship in the convoy operation.

Through the above analysis, it can be seen that the current research has established a quantitative method to study the safety of ship navigation from the perspective of ship navigation itself and the impact of offshore facilities construction projects on ship navigation, which provides reference and basis for the management of ship navigation safety and the management of ship safety during the construction projects. However, the current study still has certain deficiencies, such as the assessment of the risk state of ship navigation safety has not been analysed for the characteristics of the serious mutual influence between the construction work and ship navigation in the relatively narrow waters during the project of constructing additional second-line locks; at the same time, the dynamic assessment of the risk of ship navigation safety has not yet been carried out for the characteristics of the fast-changing environment in the construction of locks project. Therefore, to address the above deficiencies, based on the entropy value method and Markov chain theory, a dynamic assessment index system and assessment method for the navigational safety risk of the ship lock project when adding the second-line ship lock project were established.

2 Study on the Construction of the Indicator System

2.1 Analysis of Factors Affecting the Safety of Navigation while the Lock Project is under Construction

Compared with the new lock project, the safety situation of navigation is often exceptionally severe when building a second line of locks near the existing first line of locks. The risk mainly comes from the impact of construction operations on navigation and the risk of the ship's own navigation and other two aspects. First, due to the close proximity of the first-line locks and the second-line locks project, the temporary cofferdam of the second-line locks project, dredging of the approach channel, demolition of new bridges across the channel, construction of seepage control embankment and other sub-projects need to occupy part of the existing waterway, compression of the waterway space, change of the existing environment, the safety of navigation of the ship has a certain negative impact. Secondly, in the navigable waters, construction ships, engineering transportation ships, engineering traffic ships and other ships will interfere with the passage of the ship, affecting the normal driving of the ship. Thirdly, superimposed on the existing navigation risk of the ship itself, it leads to easy and high occurrence of ship collision and other accidents. Therefore, when constructing the assessment index system, it should be comprehensively analysed from the perspective of construction operations and ship navigation, and the main factors affecting navigation safety should be clearly identified.

Average Vessel Traffic.

The average ship flow rate indicates the average value of the number of ships passing through a certain water area or waterway over a period of time, which can be divided into annual, monthly and daily average ship flow rates; the average ship flow rate can reflect the busyness of the water area. The larger the value, the busier the waters are, and the higher the risk to ship navigation in the waters and the higher the regulatory requirements.

Vessel Traffic Density.

Traffic flow density indicates the number of ships per unit area of water at a certain time. Reacts to the dense degree of ships in the waters. At the same time also responds to the degree of congestion and the degree of danger of ship navigation in the waters. The size of the ship density and the number of ship accidents have a certain relationship.

Average Speed of Ships.

The average speed of vessel traffic flow in the waters can reflect the navigation of vessels in the waters, and when the overall speed of movement is greater, the risk of vessels is greater.

The Degree of Dispersion of Ship Speed Distribution.

Vessel speed distribution is very important for the safety of the waters of China and Australia. When the deviation of the speed distribution is getting bigger and bigger, and the difference in the speed of the ships in the waters is big, then the probability of the existence of catching up is also higher, and the risk of collision is also bigger.

Average Distance between Ships.

The average value of the instantaneous distance between ships at different moments in a period of time, the size of which reflects the size of the coefficient of safety in the waters, the smaller the average distance, the lower the coefficient of safety.

Cumulative Ship Track Channel Ratio.

The ratio of ship's width and fairway width, according to the fairway width and the degree of density can reflect the degree of congestion in the fairway and the high and low risk of navigation. At the same time, it can be measured due to the construction of the occupied channel, the ship navigation space compression situation.

Number of Ship Encounters.

In inland waterways, the number of ship collisions increases with the number of ship encounters. Therefore, the higher the number of ship encounters per unit of time, the higher the risk of collision.

Visibility Indicators.

Visibility refers to the maximum horizontal distance that can be seen by normal visual inspection, which is an important factor affecting the safe navigation of ships.

Channel Width Indicators.

The safety of ship navigation is directly affected by the width of the fairway. Ships navigating in narrow fairways are prone to shore suction, pushing and other conditions, which may lead to water traffic accidents such as ship collision, grounding and touching the shore, and also have an impact on the rate of ship encounters.

Indicators of Obstructions to Navigation.

Temporary cofferdams, seepage control bulkheads, etc. will encroach on part of the waterway and form obstacles to navigation. In the process of ship navigation, the ship-handling space will be affected by the surrounding obstacles, which will affect the safety of ship navigation, and the more obstacles there are and the closer they are to the fairway, the greater the impact.

Construction Cycle Indicator.

The longer the period of time that structures, construction machinery and ships occupy the waterway during construction, the greater the adverse impact on ship navigation and the higher the risk.

Indicators of the Content of Construction Work.

Due to the different processes, procedures, construction machinery and ships, the seriousness of the impact on the safety of ship navigation varies, and should be differentiated according to the content of the construction work.

Indicators of Construction Information.

When the lock project is under construction, the ship should be prompted through a variety of channels and methods that there is a construction area in the waterway ahead. The more comprehensive and timelier the information prompts are, the smaller the impact on the navigation safety of ships and the smaller the risk.

Construction Safety Protection Indicators.

When carrying out construction operations such as bridge demolition and reconstruction, cofferdam filling, etc., it is necessary to set up safety guards and collision avoidance facilities to prevent construction materials, etc., from falling onto passing ships.

Indicator of the number of Construction Vessels.

During the construction period, the greater the number of construction vessels and machinery, the greater the area of water occupied, and the greater the impact on the navigation safety of vessels.

2.2 Establishment of Indicators System

Based on the results of the analysis of the influencing factors affecting the safety of ship navigation from the perspective of construction operation and ship navigation in section 1.1, the navigation safety risk assessment index system of the lock project while navigating while constructing was constructed, including 5 first-level indexes and 15 second-level indexes, which was used to assess the safety status of navigation, as shown in Table 1. In the table, the three guideline level indicators, such as vessel traffic flow intensity characteristics, traffic flow speed characteristics, traffic behaviour characteristics, etc., are from the point of view of vessel navigation itself, focusing on the impact of the vessel's own traffic characteristics on the safety of passage. The navigational condition indicators and working condition indicators, on the other hand, start from the perspective of construction operations, focusing on the impact of construction operations on the navigational environment of ships, the impact of the stability of ship navigation and other factors.

Table 1. Indicator System for Traffic Safety Risk Assessment of Highway Reconstruction and Expansion Projects

Target level	Standardized layer	Indicator layer
Ship Lock Project While Navigable Construction Navigational Safety Risk Status A	Vessel Traffic Intensity Characteristics B_1	Average Vessel Traffic C_1
		Vessel Traffic Density C_2
	Traffic Flow Speed Characteristics B_2	Average Ship Speed C_3
		Dispersion of Ship Speed Distribution C_4
		Mean Voyage Intervals of Ships C_5
	Characterized By an Epidemic of Traffic B_3	Cumulative Ship Track Course Ratio C_6
		Number of Ship Encounters C_7
	Indicators of Navigational Conditions B_4	Increased Visibility C_8
		Channel Width C_9
		Obstruction C_{10}
	Working Condition Indicators B_5	Construction Period C_{11}
		Contents of Construction Work C_{12}
		Construction Information Alerts C_{13}
		Construction Safety Protection C_{14}
		Number of Construction Vessels C_{15}

3 Navigation Safety Risk Assessment Methodology

3.1 Assessment of Ideas

On the basis of the constructed evaluation index system, the hierarchical analysis method is used to determine the initial weights of each index; then the entropy value method is used to trim the initial weights of each index to improve the objectivity and scientific of each evaluation index; and then, the Markov chain is used to quantify the parameters of the navigational safety risk state in different time periods and conduct dynamic prediction analysis. The overall flow of this evaluation method is shown in Figure 1.

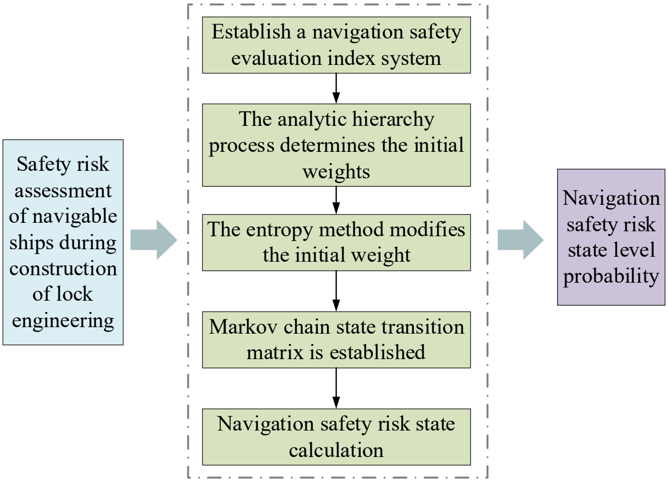

Fig. 1. Traffic safety risk assessment process of the lock project while navigable construction

3.2 Entropy Method

Analytic Hierarchy Process (AHP) can take a complex multi-objective decision-making problem as a system, decompose the objectives into multiple goals or criteria, and then into several levels of multiple indicators, and calculate the weight of each indicator through the fuzzy quantitative method of qualitative indicators. The data source is usually the score of the experts on the importance of each indicator. The initial weight value of each evaluation index can be obtained by using AHP. However, because the hierarchical analysis method is susceptible to the subjectivity of experts, it will result in greater uncertainty in the evaluation results. Therefore, in order to improve the objectivity and scientific of each evaluation index, the initial weights are further corrected and adjusted through the entropy value method.

The entropy value method is an objective assignment method, which determines the indicator weights according to the amount of information provided by the observation of each evaluation indicator. Assuming that there are m evaluation indicators and n evaluation objects, the original indicator data matrix $A=(a_{ij})_{m\times n}$ is constructed. The entropy value method calculates the entropy value of each indicator using information entropy according to the degree of change of each indicator. Then, the entropy value is used to correct the initial weight of each indicator, so as to obtain more objective indicator weights, the specific steps of the algorithm are as follows:

(1) Construct a judgment matrix A .

$$A=\begin{bmatrix} a_{11} & \cdots & a_{1m} \\ \vdots & \ddots & \vdots \\ a_{1n} & \cdots & a_{nm} \end{bmatrix} \tag{1}$$

(2) Normalize the judgment matrix to obtain the normalized matrix $B=(b_{ij})_{m\times n}$.

$$b_{ij}=\frac{\max(a_j)-a_{ij}}{\max(a_j)-\min(a_j)} \tag{2}$$

where $\max(a_j)$ and $\min(a_j)$ are the maximum and minimum values of the indicator value in the jth indicator, respectively.

(3) Calculate the weight of the *i*th evaluation object under the *j*th indicator for that indicator p_{ij} .

$$p_{ij}=\frac{b_{ij}}{\sum_{i=1}^{n} b_{ij}} \tag{3}$$

(4) Determine the entropy value of the *j*th evaluation indicator.

$$e_j=-\frac{1}{\ln n}\sum_{i=1}^{n} p_{ij}\ln(p_{ij}) \tag{4}$$

(5) Calculate the coefficient of variation of the *j*th evaluation indicator g_j . If the difference between the values of the indicator r_{ij} is greater, then the role of the indicator in the comprehensive evaluation is greater (the entropy value is smaller).

$$g_j=1-e_j \tag{5}$$

(6) Find the information entropy weight of the *j*th evaluation indicator v_j :

$$v_j=\frac{g_j}{\sum_{j=1}^{m} g_j} \tag{6}$$

(7) Combine the information entropy weights with the multiplier synthesis normalization method to derive the weights of each evaluation index.

$$\omega_j=\frac{v_j u_j}{\sum_{j=1}^{m} v_j u_j} \tag{7}$$

Where u_j is the initial weight of the first j indicator.

3.3 Markov Chain Theory

Markov chain mainly studies the change law of the state of the time series under the condition of time transfer. The main characteristic is that the state of the system at the moment $t+1$ is only related to the state at the moment t, and has nothing to do with the state before the moment t (no posteriority). In addition, the Markov chain also has the travers ability, that is, five rounds of the current moment of the system in what state, in the moment after T, the system state will tend to stabilize, independent of the current state.

Suppose $X(t)$ is a Markov chain, t is a time variable with positive integers, and the set of states of $X(t)$ is I. At any moment t there is a corresponding state i that satisfies the following relationship:

$$P_{ij} = P\left\{X(t_{n+1}) = j \middle| X(t_n) = i\right\} \tag{8}$$

where $i, j \in I, 0 \le P_{ij} \le 1$. P_{ij} is the one-step state transfer probability of the Markov chain $X(t)$ at the time of t.

If P is the matrix consisting of one-step state transfer probabilities P_{ij} in all states of the system, then the one-step state transfer probability matrix of the Markov chain is:

$$P=\begin{bmatrix} P_{11} & P_{12} & \cdots & P_{1M} \\ P_{21} & P_{21} & \cdots & P_{2M} \\ \vdots & \vdots & \cdots & \vdots \\ P_{M1} & P_{M2} & \cdots & P_{MM} \end{bmatrix} \tag{9}$$

There are properties by Markov chains:

$$X(t_{n+1}) = X(t_n) \times P \tag{10}$$

3.4 Entropy-Markov Risk Assessment Model for Navigation Safety

According to the assessment index system established in section 1.2, calculate the weights of the assessment indexes respectively, divide the safety risk level of the lock project while navigating and constructing, calculate the probability vector of the risk state at the corresponding time through the state level of each risk index in several time periods, then use Markov chain calculation to get the probability matrix for the transfer of the safety risk state, calculate the probability vector of the risk state in the future point of time, and evaluate the safety risk of the navigation state and predict the development trend of each risk indicator and the overall safety risk state of the system.

Calculation of Indicator Weights.

Using the methodology in Section 2.2, the hierarchical analysis and entropy value methods were combined to calculate the weight values of the indicators in Section 1.2, respectively.

Risk Classification.

In order to use Markov chain to assess the risk level of the navigation safety state assessment indicators to assess the overall state situation of the navigation safety risk, the risk level is divided into five levels of low risk, lower risk, medium risk, higher risk and high risk with reference to the safety risk classification standard, and is expressed as I, II, III, IV and V, respectively.

Determine a Vector of Risk State Probabilities for Known Points in Time.

At the time of t, the overall state of navigation safety risk is the probability value of each risk level, which constitutes the probability vector of the risk state Q, which is the key indicator for evaluating the risk state of navigation safety. There are n indicators in the established risk indicator system, assuming that there are s A indicators, m B indicators, f C indicators, k D indicators, l E indicators at the time of t, and if the weights of the corresponding indicators of each level are summed up, the probability value of the risk term level at the time of t can be obtained, then:

$$Q=(\sum_{i=1}^{s}\omega_i^{(t)},\sum_{i=s+1}^{s+m}\omega_i^{(t)},\sum_{i=s+m+1}^{s+m+f}\omega_i^{(t)},\sum_{i=s+m+f+1}^{s+m+f+k}\omega_i^{(t)},\sum_{i=s+m+f+k+1}^{n}\omega_i^{(t)}) \tag{11}$$

Determine the Average State Transfer Probability Matrix.

Due to the existence of dynamics and uncertainty, the risk level of each risk indicator will change over time. To calculate the risk state probability vector Q at a future point in time, and to assess the safety risk state of navigation at that moment, it is necessary to obtain the state transfer probability matrix. In fact, the state transfer probability matrix obtained at different points in time is not exactly the same, in order to reflect the overall transfer of the safety risk state, the average state transfer probability matrix is usually used to calculate and predict the risk state at future points in time.

If the risk indicator system changes the risk level of some indicators in the time period of $(t,t+1)$, and some of the indicators remain unchanged. Assuming that at t, there are s I indicators, and at $t+1$, among the original s indicators, s_1 indicators are still I indicators, s_2 indicators are changed to II indicators, s_3 indicators are changed to III indicators, s_4 indicators are changed to IV indicators, and s_5 indicators are changed to V indicators, the probability of s indicators shifting within the $(t,t+1)$ time slot is:

$$S=(V_{11},V_{12},V_{13},V_{14},V_{15})=\frac{(\sum_{i=1}^{s_1}\omega_i^{(t)},\sum_{i=s_1+1}^{s_1+s_2}\omega_i^{(t)},\sum_{i=s_1+s_2+1}^{s_1+s_2+s_3}\omega_i^{(t)},\sum_{i=s_1+s_2+s_3+1}^{s_1+s_2+s_3+s_4}\omega_i^{(t)},\sum_{i=s_1+s_2+s_3+s_4+1}^{s}\omega_i^{(t)})}{\alpha_s^{(t)}} \tag{12}$$

In the formula, $V_{11}+V_{12}+V_{13}+V_{14}+V_{15}=1$; $\alpha_s^{(t)}=\sum_{i=1}^{s}\omega_i^{(t)}$.

Similarly, the transfer probabilities of m II indicators, f III indicators, k IV indicators, and l V indicators in the time period $(t,t+1)$ are:

$$M=(V_{21},V_{22},V_{23},V_{24},V_{25})=\frac{(\sum_{i=1}^{m_1}\omega_i^{(t)},\sum_{i=m_1+1}^{m_1+m_2}\omega_i^{(t)},\sum_{i=m_1+m_2+1}^{m_1+m_2+m_3}\omega_i^{(t)},\sum_{i=m_1+m_2+m_3+1}^{m_1+m_2+m_3+m_4}\omega_i^{(t)},\sum_{i=m_1+m_2+m_3+m_4+1}^{m}\omega_i^{(t)})}{\alpha_m^{(t)}} \quad (13)$$

$$F=(V_{31},V_{32},V_{33},V_{34},V_{35})=\frac{(\sum_{i=1}^{f_1}\omega_i^{(t)},\sum_{i=f_1+1}^{f_1+f_2}\omega_i^{(t)},\sum_{i=f_1+f_2+1}^{f_1+f_2+f_3}\omega_i^{(t)},\sum_{i=f_1+f_2+f_3+1}^{f_1+f_2+f_3+f_4}\omega_i^{(t)},\sum_{i=f_1+f_2+f_3+f_4+1}^{f}\omega_i^{(t)})}{\alpha_f^{(t)}} \quad (14)$$

$$K=(V_{41},V_{42},V_{43},V_{44},V_{45})=\frac{(\sum_{i=1}^{k_1}\omega_i^{(t)},\sum_{i=k_1+1}^{k_1+k_2}\omega_i^{(t)},\sum_{i=k_1+k_2+1}^{k_1+k_2+k_3}\omega_i^{(t)},\sum_{i=k_1+k_2+k_3+1}^{k_1+k_2+k_3+k_4}\omega_i^{(t)},\sum_{i=k_1+k_2+k_3+k_4+1}^{k}\omega_i^{(t)})}{\alpha_k^{(t)}} \quad (15)$$

$$L=(V_{51},V_{52},V_{53},V_{54},V_{55})=\frac{(\sum_{i=1}^{l_1}\omega_i^{(t)},\sum_{i=l_1+1}^{l_1+l_2}\omega_i^{(t)},\sum_{i=l_1+l_2+1}^{l_1+l_2+l_3}\omega_i^{(t)},\sum_{i=s_1+l_2+l_3+1}^{l_1+l_2+l_3+l_4}\omega_i^{(t)},\sum_{i=l_1+l_2+l_3+l_4+1}^{l}\omega_i^{(t)})}{\alpha_l^{(t)}} \quad (16)$$

where $\alpha_m^{(t)}=\sum_{i=1}^{m}\omega_i^{(t)}$, $\alpha_f^{(t)}=\sum_{i=1}^{f}\omega_i^{(t)}$, $\alpha_k^{(t)}=\sum_{i=1}^{k}\omega_i^{(t)}$, $\alpha_l^{(t)}=\sum_{i=1}^{l}\omega_i^{(t)}$. As a result, the risk indicator system can be obtained by loading the probability transfer matrix V in the time period $(t,t+1)$:

$$V=\begin{bmatrix} V_{11} & V_{12} & V_{13} & V_{14} & V_{15} \\ V_{21} & V_{22} & V_{23} & V_{24} & V_{25} \\ V_{31} & V_{32} & V_{33} & V_{34} & V_{35} \\ V_{41} & V_{42} & V_{43} & V_{44} & V_{45} \\ V_{51} & V_{52} & V_{53} & V_{54} & V_{55} \end{bmatrix} \quad (17)$$

Within multiple phases, the probabilistic state transfer matrices are obtained separately for each time period and their arithmetic mean is calculated to obtain the average state transfer probability matrix for the total time period $\overline{V}$, which reflects the overall picture of the change in risk state during that time period.

Dynamic Assessment Analysis.

In order to assess the risk state of ship navigation, it is necessary to find the probability vector of the risk state of the system for the time period $Q^{(t)}$. According to the principle of maximum confidence, we can determine the risk level of the system whose risk state is at the maximum value of $q_1 \sim q_5$. If it is known that the probability vector of the risk state of the system at the time of t is $Q^{(t)}$ and the average state transfer probability matrix is $\overline{V}$, then the probability vector of the risk state at the time of $t+n$ can be obtained as $Q^{(t+n)}$:

$$Q^{(t+n)} = Q^{(t)} \times \overline{V}^{n} \tag{18}$$

At this point, the risk status of the project at future points in time can be assessed.

4 Example Analysis

4.1 Selection of Examples

Hangzhou-Ningbo Canal Xinba second-line locks project is arranged on the east side of the existing first-line locks, the centrelines distance between the two lines of lock chambers is 84m, the second line of locks on the head of the position of the first line of locks on the head of the downstream of the downstream shift of about 50m, staggered arrangement, the two lines of locks on the upper and lower approach channel independent separate arrangement. The total length of the main body of the lock is 370m, of which the length of the lock chamber is 306m, the length of the upper and lower gate head is 32m. the length of the upper and lower downstream approach channel is 502m and 518m respectively, and the effective scale of the lock chamber is 300m×25m×4.5m, and the width of the bottom is 58m. at the same time, the project also includes the alteration of three bridges, which are the gate head highway bridge, the bridge of the Maoshan Canal, and the bridge of the Wanan Bridge. In order to accurately grasp the risk status of navigation safety during the construction of the locks and predict the future development trend of the risk situation, it is necessary to assess the risk to ensure that low-risk and high-quality completion of the lock project construction tasks.

4.2 Calculation and Correction of Evaluation Indicator Weights

In the risk status assessment index system established in section 1.2, the degree of importance of each evaluation index is different. Therefore, various people such as experts in related fields, site managers and community members are invited to form a discussion group, and the results of the discussion are used as the basis for constructing the judgment matrix. First, the judgment matrix is constructed using the hierarchical analysis method, and the consistency test is carried out. After the consistency test is passed, the initial weights of the indicators are calculated. Then, based on the solving steps of entropy value method, after normalizing the sample data, the characteristic weight, information entropy value and letter entropy weight value of each index are calculated in turn. Finally, the multiplier synthesis normalization method is used to correct the initial weights, and the calculation results are shown in Table 2.

Table 2. Initial weight correction results

Norm	Initial Weight	Information Entropy Weights	Modification Weights
C_1	0.091	0.91	0.091
C_2	0.083	0.88	0.080
C_3	0.078	0.83	0.071
C_4	0.089	0.95	0.093
C_5	0.059	0.93	0.060
C_6	0.041	0.97	0.044
C_7	0.057	0.97	0.061
C_8	0.066	0.97	0.070
C_9	0.067	0.92	0.068
C_{10}	0.069	0.86	0.065
C_{11}	0.056	0.90	0.055
C_{12}	0.052	0.83	0.047
C_{13}	0.063	0.96	0.066
C_{14}	0.062	0.94	0.064
C_{15}	0.067	0.89	0.065
consistency test	CR=0.06<0.10	—	—

4.3 Risk Status Assessment

In different time periods, the risk level presented by the risk indicators is unstable. For this reason, a number of experts were invited to study the literature data and field analysis and judgment, to assess the risk level of the 15 risk indicators of the navigation safety risk state in six time periods during the construction period, and ultimately warned to get the risk level assessment table, as shown in Table 3.

Table 3. Risk level assessment table.

Norm	Weight	Time Period					
		1	2	3	4	5	6
C_1	0.091	II	I	II	III	II	I
C_2	0.080	I	II	II	II	I	I
C_3	0.071	III	I	III	I	II	I
C_4	0.093	II	I	IV	IV	V	I
C_5	0.060	III	I	I	III	III	III

C_6	0.044	III	III	II	II	III	II
C_7	0.061	III	I	II	II	I	I
C_8	0.070	I	V	V	IV	IV	II
C_9	0.068	I	III	III	III	I	III
C_{10}	0.065	II	II	II	I	I	II
C_{11}	0.055	II	II	II	II	II	II
C_{12}	0.047	III	II	I	IV	V	V
C_{13}	0.066	I	II	II	II	II	II
C_{14}	0.064	II	III	III	I	I	II
C_{15}	0.065	I	V	III	II	II	II

Based on the data in Table 3, the probability transfer matrix of the navigation safety risk state of the lock project can be obtained:

$$V_{1\to 2} = \begin{bmatrix} 0 & 0.40 & 0.20 & 0 & 0.40 \\ 0.40 & 0.40 & 0.20 & 0 & 0 \\ 0.60 & 0.20 & 0.20 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{19}$$

$$V_{2\to 3} = \begin{bmatrix} 0.20 & 0.40 & 0.20 & 0.20 & 0 \\ 0.20 & 0.80 & 0 & 0 & 0 \\ 0 & 0.33 & 0.33 & 0.34 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.50 & 0 & 0.50 \end{bmatrix} \tag{20}$$

$$V_{3\to 4} = \begin{bmatrix} 0 & 0 & 0.50 & 0.50 & 0 \\ 0.14 & 0.72 & 0.14 & 0 & 0 \\ 0.50 & 0.25 & 0.25 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix} \tag{21}$$

$$V_{4\to 5} = \begin{bmatrix} 0.67 & 0.33 & 0 & 0 & 0 \\ 0.33 & 0.50 & 0.17 & 0 & 0 \\ 0.33 & 0.33 & 0.33 & 0 & 0 \\ 0 & 0 & 0 & 0.33 & 0.67 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{22}$$

$$V_{5\to6} = \begin{bmatrix} 0.40 & 0.40 & 0.20 & 0 & 0 \\ 0.40 & 0.60 & 0 & 0 & 0 \\ 0 & 0.50 & 0.50 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0.50 & 0 & 0 & 0 & 0.50 \end{bmatrix} \tag{23}$$

The average state transfer matrix can be further derived as:

$$\overline{V} = \begin{bmatrix} 0.254 & 0.306 & 0.220 & 0.140 & 0.080 \\ 0.294 & 0.604 & 0.102 & 0 & 0 \\ 0.288 & 0.322 & 0.322 & 0.068 & 0 \\ 0 & 0.333 & 0 & 0.443 & 0.224 \\ 0.167 & 0 & 0.167 & 0.333 & 0.333 \end{bmatrix} \tag{24}$$

Assuming that time period 6 is the most recent time period in this navigation safety risk state assessment, the risk state vector for the next time period of the assessment can be predicted by using the average state probability transfer matrix $\overline{V}$ and the risk state vector of time period 6, combined with Equation (18). The risk state vector for time period 6 is $Q^{(6)} = (0.396, 0.428, 0.129, 0, 0.047)$. According to Equation (18), the risk state vector of the next time period is predicted to be assessed as. $Q^{(7)} = (0.271, 0.422, 0.18, 0.08, 0.047)$. According to the ergodicity of Markov chain, the vector of the risk state of this navigation safety tends to be stable in time period t and time period $t+1$, and the calculated steady state risk state vector is $Q^{7-w} = (0.239, 0.415, 0.157, 0.120, 0.069)$. According to the principle of maximum confidence, it is very likely that the risk state of the lock project will be at a lower risk in the next time period when the lock project is being constructed while navigation is in progress. Through the above analysis, it can be seen that the risk state of navigation safety of this lock project at this stage is in the risk state of the normative probability of lower risk, and higher risk and high-risk indicators are not prominent.

4.4 Discussion and Analysis

Analysis of the Optimization Effect of Entropy Value Method on Initial Index Weights.

As can be seen in Table 2, after the entropy value method to correct the initial weights of each indicator, the corrected weights of each indicator are obtained. In order to compare and analyse the effectiveness and scientific of the entropy value method for the correction of the indicator weights, the initial indicator weights calculated by the AHP method and the indicator weights corrected by the entropy value method are respectively brought into the Markov chain to obtain the predicted value of the risk state in time period 7. The steady state vector of risk state for time period 7 obtained by using the initial indicator weights calculated by the AHP method is $Q^{7\text{-AHP}} = (0.239, 0.413, 0.157, 0.121, 0.070)$. The steady state risk state vector obtained by using the modified indicator weights calculated by the entropy method is $Q^{7-w} = (0.239, 0.415, 0.157, 0.120, 0.069)$. From the two risk state vectors, it can be found that the risk state vector obtained from the weights of the indicators corrected by the entropy value method is more favourable for selecting the risk level according to the principle of maximum confidence. For example, the probability value of lower risk level is the largest in both $Q^{7\text{-AHP}}$ and Q^{7-w}, which are 0.413 and 0.415 respectively. However, the value of Q^{7-w} is more prominent than that of $Q^{7\text{-AHP}}$, which is more advantageous in determining the risk level by applying the maximum confidence principle.

Comparative Analysis of Risk Status Assessment.

In order to analyse the change of the navigation safety risk of this lock project and prove the feasibility of the method, the probability situation of the risk status in six time periods was calculated and compared with the predicted time period7 respectively. The calculation results are shown in Table 4 and Fig. 2. It can be seen from the data in the figure that the navigation safety risk status of the project is generally in lower risk and low risk. However, some time periods have the situation that the probability value of higher risk is prominent and the probability value of low risk is relatively reduced in lower risk, such as time period 3 and time period 4. Analysing time period 3 and time period 4 in combination with Table 3, it is found that mainly the indicators of the average speed of vessels C_3, the dispersion of the speed distribution of vessels C_4, the average sailing interval of vessels C_5, the visibility C_8, the width of the channel C_9, the content of the construction work C_{12}, the safety protection of the construction work C_{14}, and the number of the construction vessels C_{15} The safety risk level of the construction vessels is at III, IV and V levels. Among them, the influence of visibility indicators caused the risk level of vessel traffic flow speed characteristic indicators to increase, affecting the risk level of vessel navigation safety. During the period of time period 3 and time period 4, foggy weather occurred continuously in the navigable waters, and during the same period, the construction area of the bridge project was carried out, occupying part of the navigable waterway. Therefore, under the influence of the environment and the construction work content at the same time, the overall navigation safety risk state shows a trend toward high-risk state. However, with the improvement of the foggy weather in the navigable waterway and the completion of the construction work, the status of the lock's navigational safety risk has developed to a low-risk status. The above analysis shows that when carrying out construction operations, especially those that have a high impact on the risk of navigational safety, changes in the weather environment should be carefully analysed and forecasted. As far as possible, construction operations with greater impact on navigation safety risks should be scheduled in time periods when the weather is more seaworthy. In time period 7, compared with time period 6, the low risk and lower risk are weakened, indicating that there are some influencing factors have changed, and navigation safety control efforts and measures should be strengthened. The above analysis results show that the established entropy-Markov method can dynamically characterize the dynamic change of the safety risk of the lock project, which has a positive significance in guiding the safety control of the construction of the lock project while navigating, and proves the effectiveness and feasibility of the method.

Table 4. Probability of risk status for time periods 1 to 7

Time Frame	Risk Probability				
	I	II	III	IV	V
1	0.349	0.368	0.283	0	0
2	0.376	0.313	0.176	0	0.135
3	0.107	0.462	0.268	0.093	0.070
4	0.200	0.371	0.219	0.210	0
5	0.338	0.348	0.104	0.070	0.140
6	0.396	0.428	0.129	0	0.047
7	0.239	0.415	0.157	0.120	0.069

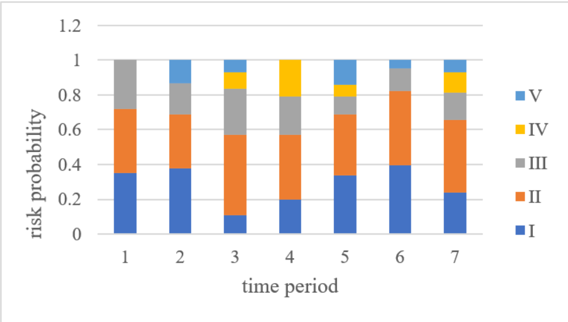

Fig. 2. Probability of risk status for time periods 1 to 7

5 Conclusion

This paper proposes a dynamic assessment method for the navigation safety risk state of the lock engineering while navigating and construction based on the combination of entropy value method and Markov chain, and the following conclusions are obtained:

(1) According to the current situation of the construction of ship locks while navigating, from the perspective of ship navigation and the impact of the construction on ship navigation, a navigation safety risk assessment index system consisting of 5 first-level indexes and 15 second-level indexes has been constructed for the construction of ship locks while navigating, which comprehensively covers all aspects affecting the risk assessment of navigation safety.

(2) On the basis of analysing the shortcomings of the AHP method, the method of using the entropy value method to correct the initial weights of the indicators obtained by the AHP method is proposed in order to reduce the subjectivity of the initial weights and improve the accuracy and objectivity of the weights.

(3) On the basis of analysing the characteristics of the dynamic change of the navigation safety risk state over time during the construction of the lock project while navigating, the entropy-Markov chain navigation safety risk assessment model was established by using the Markov chain theory combined with the entropy value method. The model realizes the dynamic quantitative grading assessment and dynamic prediction of the navigational safety risk state when the lock project is under construction while navigating. The feasibility and scientific of the method are verified through the selected cases, which objectively reflect the change of the grade of the navigation safety risk status, analyse the influence of the assessment indexes on the navigation safety risk status, and give suggestions on the navigation safety control measures during the construction of the ship lock project.

It is worth highlighting that the index system and evaluation method proposed in this study have only been validated in a single ship lock project. To enhance the universality and scientific rigor of the index system and evaluation method, future research will involve the incorporation of other relevant lock engineering projects for further investigation and analysis. By expanding the scope of study to encompass a wider range of projects, the applicability and robustness of the proposed index system and evaluation method can be thoroughly evaluated and validated. This broader approach will contribute to the overall improvement and refinement of the assessment framework for lock engineering projects.

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