Study on the effectiveness of navigation safety measures for Nanjing Yangtze River Bridge

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Abstract. Combined with navigation safety measures such as navigation mark adjustment, synchronous flash distribution, and real ship test adopted by Nanjing Yangtze River Bridge, theoretical analysis methods and data analysis are used to determine the safety evaluation risk index system, and an unascertained measure evaluation model based on entropy weight is constructed. Through the comparison of the effectiveness of the security measures analyzed by the questionnaire, the effectiveness of the bridge safety guarantee measures was evaluated; further suggestions on the optimization of relevant safety protection measures were proposed. The research results are of great significance for maintaining the safety of the bridge, the navigation order of the waters in the bridge area, protecting the navigation resources of the bridge area, and ensuring the navigation safety of the ship.

1 Introduction

Bridges play an irreplaceable role in promoting economic and social development. However, in the event of a bridge safety incident, the consequences will be unimaginable. Nowadays, more and more bridges are built in the same jurisdiction. It is especially important to carry out the necessary safety guarantees for the safety of the bridge and how to properly solve the problem of water traffic safety in the bridge section. Safety evaluation of the safety measures implemented by the bridge is carried out, and corresponding countermeasures are proposed in time. Through the analysis and evaluation of effectiveness, we can better understand and master the effectiveness of the safety and security measures implemented by the bridge, and provide scientific decision-making basis for the maritime management department to improve the navigation environment and traffic safety of the bridge section and the navigation management and control. And reference, thus having a certain practical value [1].

2 Brief Introduction to Safety Measures for Navigation in Bridge Area

In order to ensure the safety of the bridge, the water management department has adopted the following navigation safety guarantee measures, as shown in Table 1 below.

Table 1. Bridge navigation safety protection measures list

Measure	Effect
Adjusting the navigation area of the bridge area	Guide the ship's driver to accurately identify the navigation bridge hole and reduce the drift of the ship. As shown in Figure 1
Navigation bridge hole setting buoy synchronous flash	The navigation mark of the bridge area is more obvious, and the ship driver can correctly follow the navigation mark to guide the safe navigation through the bridge area. As shown in Figure 2
Lighting the navigation bridge hole	Solved the problem that the crew "can't see clearly and unclear" about the bridge hole. As shown in Figure 3.
Intelligent early warning monitoring	Improve the safe navigation ability of ships at night and effectively prevent ships from entering the non-navigate waters
Carry out the 6-hole real ship test of the bridge	Through the actual ship test data, the ship's navigation characteristics are analyzed, the navigation sign setting is optimized, the ship navigation method is simulated and simulated, navigation suggestions are provided, and the bridge navigation safety is guaranteed.

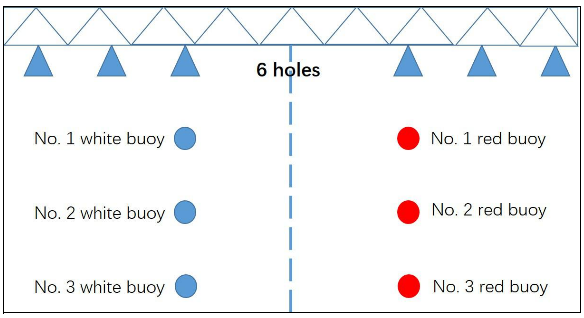

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Figure 1. Schematic diagram of the adjustment scheme for the navigation mark hole navigation mark

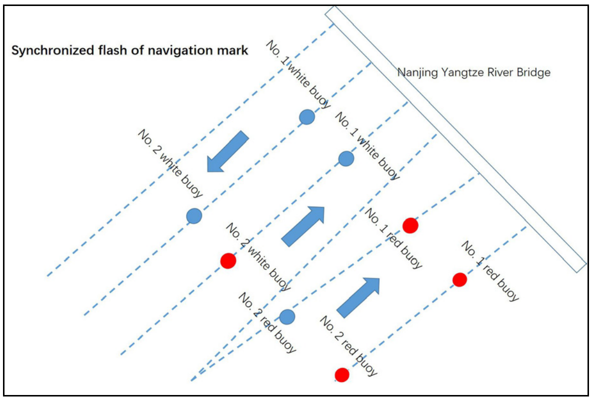

Figure 2. Schematic diagram of synchronous flash distribution scheme.

Figure 3. Schematic diagram of the distribution scheme of the navigation bridge hole lighting.

3 Safety Benefit Evaluation of Bridge Safety Protection Measures

3.1. Safety Benefit Evaluation of Bridge Segment

Establish a safety assessment risk indicator system for this jurisdiction, including people, ships, bridges, environment, and management, with a total of 26 secondary evaluation indicators. The expert judgment method is used to construct the comparative judgment matrix of the evaluation index. The brainstorming method is used to determine the membership degree of each index. Finally, the center of gravity method is used to defuzzify and obtain the comprehensive evaluation score of each index [2]. Five fuzzy comments were expressed for the safety benefits, and finally the effectiveness of the bridge safety guarantee measures was judged.

3.2. Unascertained measure evaluation model based on entropy weight

3.2.1 Single indicator not determined calculation

The calculation of the single-index unascertained measure matrix uses the method of constructing the unascertained measure function, and is determined by the expert scoring method. According to the characteristics of the specific problem to be solved and the severity of the state change, the undetermined measure function can be connected by different curves such as a straight line and a quadratic curve [3]. Among them, the linear unascertained measure function is currently the most widely used. Its calculation formula is as follows:

$$\mu(x \in c_{k+1}) = \frac{-x}{a_i+1} + \frac{a_{i+1}}{a_{i+1}-a_i} a_i < x < a_{i+1} \tag{1}$$

$$\mu(x \in c_{k+1}) = x > a_{i+1} \tag{2}$$

Among them, a_i is the classification standard of each indicator, and C_k is the evaluation level. From the calculation formula (1) (2), it can be concluded that the observation value x_i of the index I_j with respect to the index x_{ij} causes the object to be in the single-index unsure degree matrix of each evaluation level C_k as follows:

$$\left(u_{ijk}\right)_{m\times k} = \begin{bmatrix} u_{i12} & u_{i12} & \cdots & u_{i1k} \\ u_{i21} & u_{i22} & \cdots & u_{i2k} \\ \cdots & \cdots & \cdots & \cdots \\ u_{im1} & u_{im2} & \cdots & u_{imk} \end{bmatrix} \tag{3}$$

$$i = 1,2,\cdots,n; j = 1,2,\cdots m; k = 1,2,\cdots K$$

3.2.2. Entropy weight method weight calculation

Entropy is a measure of the uncertainty of the state of the system. The index weight assignment method based on entropy weight is a combination of quantitative and qualitative methods, which expresses and processes human subjective judgments in quantitative form [4]. Calculate the measure value of the evaluation index according to the corresponding membership function to construct $(\mu_{i1}, \mu_{i2}, L\ , \mu_{il})$, The entropy is now:

$$H = -\frac{1}{\log_{10} k} \sum_{k=1}^{k} u_{ijk} \log_{10} u_{ijk} \tag{4}$$

$$v_{ij} = 1 + \frac{1}{\log_{10} k} \sum_{k=1}^{k} u_{ijk} \log_{10} u_{ijk} \tag{5}$$

Obviously, $0 \leqslant u_{ijk} \leqslant 1$ let:

$$w_{ij} = v_{ij} / \sum_{j=1}^{m} v_{ij} \tag{6}$$

The weight $w_i = \left(w_{i1}, w_{i2}, \cdots, w_{im}\right)^T$ is used as the weight vector of the attribute set U, that is, its entropy weight. Where H is the entropy value of the evaluation index; v_{ij} is the proportion of the j-th evaluation object in the i-th indicator.

3.2.3 Multi-indicator comprehensive measure calculation

According to the single-index unascertained degree u_{ijk} and the index weight vector ω ,the unascertained degree vector x_{ij} of the evaluation object can be calculated, and the calculation formula is as follows:

$$u_{ik} = \sum_{j=1}^{m} w_j u_{ijk} (i = 1,2,\cdots n; k = 1,2,\cdots K) \quad (7)$$

Then we call the vector $u_i = (u_{i1}, u_{i2}, \cdots u_{ik})$, T is a multi-indicator synthesis Measure vector.

3.2.4. Confidence recognition

Because the evaluation grades are ordered, it is not possible to adopt the maximum membership recognition criterion for the out-of-order division, and instead use the confidence recognition criterion. Pre-set the confidence threshold λ , then:

$$k = \min_{k}(k : \sum_{k=1}^{K} uik \geqslant \lambda,\ 1 \leqslant k \leqslant K) \quad (8)$$

From this formula, it is judged that the object x_i belongs to the k_0 -th evaluation level and the confidence is higher than λ .

3.3. Establishment of evaluation index system

According to the regulations of the ship's alignment system, combined with the natural environment and navigation environment of the waters of the bridge area, comprehensive consideration of various factors affecting the establishment of water efficiency indicators of the bridge area, and selection of ships, environment and management [5] as evaluation Indicators; as shown in Table 2.

Table 2. Bridge area water area safety risk assessment index

Primary evaluation factor	Secondary evaluation factor	
Ship factor	Improvement effect of dangerous goods ship accident	
	Ship sailing freely to improve the effect	
	Improve the effect of crossing the traffic lane	
	Improved navigational safety index	
envirnmental factor	Natural environment (impact effect)	Wind direction
		Flow rate
		Visibility
	Traffic environment (impact effect)	water depth
		Navigation aid sign
		Obstruction
		traffic flow
Management factor	Bridge area water safety protection facilities	
	First aid to improve the effect	

The effective grades of each evaluation index are divided into five levels: no effect, some effects, general effects, large effects, and large functions. They are represented by C1-C5, and the evaluation criteria corresponding to each level are shown in Table 3.

Table 3. Bridge area water area safety risk assessment index

Not working at all	Some role	General role	Greater effect	Great effect
(0,60)	[60,70)	[70,80)	[80,90)	[90,10)

3.4. Determine evaluation indicator weights

The score of the evaluation is given to each indicator by the expert. The evaluation scores of the evaluation factors were counted, and the statistical results are shown in Table 4

Table 4. Bridge area water area safety risk assessment index

Primary factor	Secondary factor	Survey results				
		C1	C2	C3	C4	C5
Ship	Improvement effect of dangerous goods ship accident	0	0	0	14	66
	Ship sailing freely to improve the effect	0	0	0	12	68
	Improve the effect of crossing the traffic lane	0	0	0	14	66
	Improved navigational safety index	0	8	10	16	46
Envirn-mental	Natural environment (impact effect)	0	0	0	8	72
	Traffic environment (impact effect)	0	0	4	10	66
Manage-ment	Bridge area water safety protection facilities	0	0	4	14	62
	First aid to improve the effect	0	0	6	10	64

The fuzzy evaluation is obtained by using the single index measure calculation method to determine the membership degree of the index, and the entropy weight of the second evaluation factor is calculated. The membership function is constructed as follows: membership degree = factor to get the corresponding questionnaire valid questionnaire/total effective questionnaire.

The measure values of the respective evaluation indexes can be calculated according to the constructed membership function, and the calculation results are shown in Table 5 below.

Table 5. Indicator value vector

Measure vector				
C1	C2	C3	C4	C5
0	0	0	0.175	0.825
0	0	0	0.150	0.850
0	0	0	0.175	0.825
0	0.100	0.125	0.200	0.575
0	0	0	0.100	0.900
0	0	0.050	0.125	0.825
0	0	0.050	0.175	0.775
0	0	0.075	0.125	0.800

According to the entropy weight calculation formula (4) described above, the calculated values of the entropy weights of each evaluation index can be obtained as follows:

$$H_{V11}=-\frac{1}{\lg 5}(0+0+0+0.175*0.0825)=0.288$$

In the same way, the calculation is:
H_{V12}=0263,H_{V13}=0.288,H_{V14}=702,H_{V21}=0.202;
H_{V31}=405,H_{V3}2=393;
therefore,H_{V1}=(0.288,0.263,0.288,0.702),
H_{V2}=(0.202,0.353),H_{V3}=(0.405,0.393);
According to formula (5), it can be calculated:
V_{U1}=(0.712,0.737,0.712，0.298);In the same way,
V_{U2}=（0.798,0.647）;V_U3=（0.595,0.607）;
Calculate the entropy weight of each indicator according to formula (6):
w_{U1}=（0.289,0.300,0.289,0.121）
In summary, the calculation results of the entropy weight of each of the secondary indicators and the primary indicators are shown in Table 6.

Table 6. Index entropy weight calculation result

Primary factor	Weights	Secondary evaluation factor	Weights
Ship	0.300	Improvement effect of dangerous goods ship accident	0.289
		Ship sailing freely to improve the effect	0.300
		Improve the effect of crossing the traffic lane	0.289
		Improved navigational safety index	0.121
envirnmental factor	0.380	Natural environment	0.5522
		Traffic environment	0.448
Management factor	0.320	Bridge area water safety protection facilities	0.495
		First aid to improve the effect	0.505

3.4. Bridge safety evaluation

3.4.1 Single indicator unascertained degree calculation

The evaluation results were processed by the mean value analysis method to obtain the scores of the respective indexes, as shown in Table 7.

Table 7. Effectiveness evaluation indicator score

Primary evaluation factor	Secondary evaluation factor		Score
Ship factor	Improvement effect of dangerous goods ship accident		93.25
	Ship sailing freely to improve the effect		93.50
	Improve the effect of crossing the traffic lane		93.25
	Improved navigational safety index		87.5
envirnmental factor	Natural environment	Wind direction	94.00
		Flow rate	
		Visibility	
		water depth	
	Traffic environment	Navigation aid sign	92.75
		Obstruction	
		traffic flow	
		Wind direction	
Management factor	Bridge area water safety protection facilities		92.25
	First aid to improve the effect		92.25

From the definition of the single-index measure function, an image of the single-index unascertained function of each index risk assessment can be obtained, as shown in Figure 4.

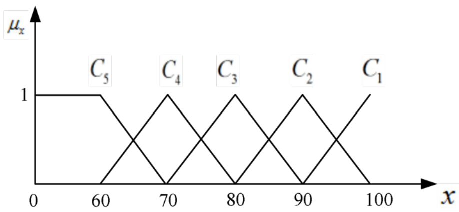

Figure 4. The unascertained measure function

The values of the indicators in Table 7 are respectively taken into the single-index measure function, and the single-index evaluation matrix for the safety and effectiveness evaluation of the safeguard measures is calculated [6].
Taking the "improvement effect of dangerous goods ship accident" in the ship factor as an example, according to the score value of Table 7, Figure 5 and formula (1). (2) and the "normality" of the unascertained measure, it can be concluded that The single-index measure vector that separates the opposite traffic flow to reduce the effect on the situation is (0 0 0 0.675 0.325). The same method can be used to find the unascertained measure of other indicators.

According to the calculation, the unascertained measure evaluation matrix of the ship safety factor for safety and safety measures is:

$$\mu_{15}=\begin{bmatrix}0&0&0&0.675&0.325\\0&0&0&0.650&0.350\\0&0&0&0.675&0.325\\0&0&0.25&0.750&0\end{bmatrix}$$

The unascertained measure evaluation matrix for environmental factors is:

$$\mu_{25}=\begin{bmatrix}0&0&0&0.600&0.400\\0&0&0&0.725&0.275\end{bmatrix}$$

The unascertained measure evaluation matrix for management factors is:

$$\mu_{35}=\begin{bmatrix}0&0&0&0.675&0.325\\0&0&0&0.675&0.325\end{bmatrix}$$

3.4.2 Multi-indicator unascertained degree calculationcalculation

The single indicator measure vector of the ship factor in the safety effectiveness assessment of the bridge navigation safety measures is:

$$\mu_{11}=\omega_1\times\mu_{15} \tag{8}$$

$$=(0.289\ \ 0.300\ \ 0.289\ \ 0.121)\times\begin{bmatrix}0&0&0&0.675&0.325\\0&0&0&0.650&0.350\\0&0&0&0.675&0.325\\0&0&0.25&0.750&0\end{bmatrix}$$

$$=(0\ \ 0\ \ 0.302\ \ 0.3759\ \ 0.2929)$$

By repeating the above calculations in the same way, the single-index unascertained measure vectors of the ship, environment and management factors in the safety and effectiveness assessment of the bridge navigation safety measures can be obtained as follows:

$$\mu_{22}=(0\ \ 0\ \ 0\ \ 0.6560\ \ 0.3440)$$

$$\mu_{33}=(0\ \ 0\ \ 0\ \ 0.6750\ \ 0.3250)$$

Therefore, a new unascertained matrix " μ " can be constructed. According to formula (7), the multi-indicator unascertained comprehensive measure "" μ " " for the safety and effectiveness evaluation of the bridge navigation safety measures can be calculated.

$$\mu=\omega\times\mu_1 \tag{9}$$

$$=(0.300\ \ 0.380\ \ 0.320)\times\begin{bmatrix}0&0&0.0302&0.6759&0.2929\\0&0&0&0.6560&0.3440\\0&0&0&0.6750&0.3250\end{bmatrix}$$

$$=(0\ \ 0\ \ 0.0091\ \ 0.6681\ \ 0.3226)$$

3.4.3 Bridge safety assessment conclusion

According to the comprehensive measure calculated above, using the formula (7) to identify the multi-indicator comprehensive measure of the safety and effectiveness assessment of the bridge safety guarantee measures [7], the following conclusions can be drawn:

a. k_0=1, at this time there is 0.6681 for maximum integration and greater than 0.66. If it is taken λ=0.66, there is k_0=1, $0.6681>\lambda$, that is, the safety effectiveness evaluation level of the bridge navigation safety measure belongs to the " Great effect" level, and the confidence level is not less than 66%.

b. k_0=2, at this time there is 0.6681+0.3226=0.9907.

If it is taken λ=0.99, there is k_0=1, $0.9907>\lambda$, that is, the safety effectiveness evaluation level of the bridge navigation safety protection measure belongs to the "Greater effect" level, and the confidence level is not less than 99%.

4 Research conclusions and prospects

This paper takes the various security measures adopted by the Nanjing Yangtze River Bridge as the research object, and uses theoretical analysis methods and questionnaire survey data to evaluate the implementation effectiveness of the bridge navigation safety guarantee measures for the navigation environment of the bridge area of the Nanjing Yangtze River Bridge, and analyze the Nanjing Yangtze River. The safety benefits brought by the bridge in terms of ensuring the safety of the navigation of the ship, the smooth flow of the channel [8], and the construction of the port are finally evaluated to evaluate the effectiveness of the safety measures for the navigation of the bridge; further recommendations for the optimization of relevant safety measures are proposed.

The research results are of great significance for maintaining the safety of other bridges, the navigation order of ships in the bridge area, protecting the navigation resources of the bridge area, and ensuring the navigation safety of the ships. It is of great significance to the development of the Yangtze River trunk shipping and the sustainable development of the port water transport economy. At the same time, it can provide suggestions for maritime affairs and related departments, which has certain practical significance for improving the safety of the bridge.

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