Safety Level Analysis of Waterway Traffic Based on Trend Test in the Yangtze River

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Abstract. In order to improve the safety of waterway traffic in the Yangtze River, comprehensively integrate the current status of waterway traffic safety at home and abroad. Analogy and MK trend analysis methods are used to analyze the current status and development trend of safety level of waterway traffic in the Yangtze River. The results show that there are significant differences in F-N indicators for waterway traffic safety in different countries. The U.S. has an outstanding ability to respond quickly to accidents, and can maintain a low level of F-N indicators even with a large number of accidents. The safety level of waterway traffic in the Yangtze River is relatively low. In particular, there is still a big gap of the rescue capability between China and developed countries. The safety level of water traffic on the Yangtze River is constantly improving, and the changing trend of waterway traffic safety level shows a more significant growth.

1. Introduction

With the rapid development of society and economy, the number and tonnage of ships has increased rapidly with the development of shipping [1]. At the same time, problems such as congested routes, low standardization of ships, and ship aging have become increasingly serious, and the navigation environment is becoming more and more complex [2-4]. The risk of waterway traffic safety is also on the rise. From 2010 to 2019, there were a total of 2,339 general and above waterway traffic accidents of transportation ships nationwide, with 2,416 people dead or missing, 1,205 shipwrecks and direct economic losses of 3.189 billion Yuan. The four indicators of national waterway traffic accidents have declined year by year, and the safety of waterway traffic is basically stable. However, hidden dangers and risks still exist, serious accidents still occur from time to time, and the safety production situation of waterway traffic is still very severe. Therefore, there is an urgent need to strengthen the prevention and management of waterway traffic safety risks, and improve waterway traffic safety governance capabilities. This has important practical significance for the construction of a safe, convenient, smooth, efficient, green and intelligent modern comprehensive transportation system.

Through the analysis of related accidents and the current status of waterway traffic safety risk management, it can be found that the current risk assessment and management technology in the field of water transportation has developed to a certain extent, but a more specific water transportation safety level assessment system has not yet been formed [5-8]. Taking the Yangtze River as an example, this study puts forward the level of waterway traffic safety in the Yangtze River by analysing the statistical data of waterway traffic safety accidents in recent years. And on this basis, explore the development trend of waterway traffic safety at home and abroad, and provide theoretical foundation and scientific support for waterway traffic safety risk prevention, control and management.
2. M-K trend analysis method

The non-parametric Mann-Kendall test method is used to detect the long-term trend and sudden change of waterway traffic accidents in the Yangtze River. The Mann-Kendall test method was originally proposed by Mann and Kendall [9]. In time series trend analysis, the Mann-Kendall test does not require the sample to follow a certain distribution, nor is it affected by a few outliers. In the Mann-Kendall test, the null hypothesis $H_0$ is time series data, $(X_1, X_2, ..., X_n)$ is a sample of n independent and random variables with the same distribution, the alternative hypothesis $H_1$ is a two-sided test. For all $i, j < n$ and $i \neq j$, the distributions of $X_i$ and $X_j$ are not the same. Define the test statistic $S$:

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i-1} \text{sign}(X_i - X_j)$$  \hspace{1cm} (1)

Among them, $\text{sign}()$ is a symbolic function. When $X_i - X_j$ is less than, equal to or greater than zero, $\text{sign}(X_i - X_j)$ is -1, 0, or 1, respectively. $S$ is a normal distribution, its mean is 0, and the variance $\text{VAR}(S) = n(n-1)(2n+5)/18$. When the M-K statistic formula $S$ is greater than, equal to, and less than 0, they are:

$$Z = \begin{cases} 
\frac{S - 1}{\sqrt{\frac{n(n-1)(2n+5)}{18}}} \\
\frac{S + 1}{\sqrt{\frac{n(n-1)(2n+5)}{18}}} 
\end{cases}$$  \hspace{1cm} (2)

In the two-side trend test, for a given confidence level $\alpha$, if $|Z| \geq Z_1 - \alpha / 2$, the null hypothesis $H_0$ is unacceptable. Even at the confidence level $\alpha$, there is a significant upward or downward trend in time series data. A positive value of $Z$ indicates an increasing trend, and a negative value indicates a decreasing trend. When the absolute value of $Z$ is greater than or equal to 2.32, 1.64, and 1.28, it means that it has passed the significance test of 99%, 95%, and 90%, respectively.

When the Mann-Kendall test is further used to test sequence mutations, the test statistic is different from the above $Z$, by constructing a sequence:

$$S = \sum_{i=1}^{k} \sum_{j=1}^{i-1} a_{ij}$$  \hspace{1cm} (3)

Where, $a_{ij} = \begin{cases} 
1 & X_i > X_j \\
0 & X_i < X_j 
\end{cases}$, $1 \leq j \leq i$

Define statistical variables:

$$UF_k = \frac{[S_k - E(S_k)]}{\sqrt{\text{Var}(S_k)}} \hspace{1cm} (k = 1, 2, ..., n)$$  \hspace{1cm} (4)

Where, $E(S_k) = \frac{k(k+1)}{4}; \text{Var}(S_k) = k(k-1)(2k+5)/72$
$U_{F_k}$ is a standard normal distribution, given a significance level $\alpha$, if $|U_{F_k}| > U_{\alpha/2}$, it indicates that there is a significant trend change in the sequence. Arrange the time series $x$ in reverse order, and then calculate according to the above formula, while using:

$$
\begin{align*}
UB_k &= -U_{F_k} \\
&= n + 1 - k
\end{align*}
$$

By analyzing the statistical sequence $U_{F_k}$ and $U_{B_k}$, the trend change of sequence $x$ can be further analyzed. The time of mutation can be clarified and the region of mutation can be pointed out. If the value of $U_{F_k}$ is greater than 0, it indicates that the sequence is on an upward trend; if it is less than 0, it indicates that the sequence is on a downward trend. When they exceed the critical line, it indicates a significant upward or downward trend. If the two curves of $U_{F_k}$ and $U_{B_k}$ intersect, and the intersection point is between the critical lines, then the moment corresponding to the intersection point is the moment when the mutation starts.

3. Safety level analysis
The agency responsible for water traffic safety in Canada is the Transportation Safety Committee (TSB), which is specifically responsible for Canadian waterway traffic safety management and data statistics. In 2018, TSB reported 282 maritime accidents, up from the 279 reported in 2017. In the past 10 years, the proportion of shipping accidents (relative to shipboard accidents) remained constant at 83%. As shown in Figure 1, the total number of deaths in water traffic accidents was 20 in 2018, of which 14 were caused by 8 transportation accidents, and the remaining 6 were caused by 6 accidents on board. This is an increase from the 11 deaths reported in 2017 and exceeds the average annual death toll of 16 in 2008-2017.

Figure 1. The number of waterway traffic accidents and deaths in Canada from 2008 to 2018.

The agency responsible for waterway traffic safety in the United States is the Maritime Administration of the Department of Transportation. The Maritime Administration promotes the use of waterway transportation and its seamless integration with other parts of the transportation system, and enhances the survivability of American merchant ships. In 2018, there were 2,628 water traffic accidents in the United States, which was higher than the 2,830 in 2017, but lower than the 10-year average of 4,507 (2008-2017). Although the number of waterway traffic accidents in the United States is large, its water rescue force is relatively strong, with excellent emergency rescue capability, and the casualties caused by waterway traffic accidents are less. As shown in Figure 2, in the past ten years, the average annual death toll was 35, and the average annual injury was 148. Among them, a total of 21 people died in water accidents in 2018, and 108 people were injured, both of which were lower
than in 2017 and also lower than the average value of the past ten years, indicating that the overall waterway traffic safety situation is improving.

Figure 2. The number of waterway traffic accidents and deaths in the United States from 2008 to 2018.

The agency responsible for waterway traffic safety in Japan is the Transport Safety Committee of the Ministry of Land and Transport. It is mainly responsible for preventing accidents and reducing the hazards caused by accidents, and protecting people's life safety while improving the safety awareness of transportation. In 2018, there were a total of 830 waterway traffic accidents, which was higher than the 764 accidents in 2017, but lower than the 10-year (2008-2017) average of 930 accidents. It can be seen from the changing trend of the death toll from waterway traffic accidents in the past ten years (Figure 3) that the average annual death toll in the past ten years is 149. Among them, 146 people died in water accidents in 2018, which is lower than the average value of the past ten years.

Figure 3. The number of waterway traffic accidents and deaths in Japan from 2008 to 2019.

In 2019, there were a total of 121 waterway traffic safety incidents in the Yangtze River, which was lower than the 142 incidents in 2018 and also lower than the average of 275 incidents in the past eight years. It can be seen from the changing trend of the number of deaths from water distress in the past ten years (Figure 4) that the average annual death toll in the past ten years is 114. Among them, 22 people died in 2019 due to water distress, which is far below the average of the past ten years.
Based on the existing data of waterway traffic accidents in China and abroad, the F-N indicator is used to reflect the level of water traffic safety, where the F-N indicator is the ratio of the number of deaths in the accidents to the number of accidents. Since the statistics of domestic waterway traffic accidents are only divided into four types: general accidents, minor accidents, major accidents and particularly major accidents, in order to accurately reflect the safety level of waterway traffic in the Yangtze River, the ratio of the number of deaths to the number of water distresses is used to express the waterway traffic safety status. Comparing foreign waterway traffic safety levels, it can be found that the average F-N index of the Yangtze River from 2012 to 2019 is 0.43, which is much higher than 0.008 in the United States, 0.052 in Canada and 0.179 in Japan. It shows that the waterway traffic safety level of the Yangtze River is relatively low compared with the developed countries, especially in the water search and rescue capacity. There is still a large gap between China and developed countries. Among them, the shipwreck of the Oriental Star in 2015 was a catastrophic incident, which caused 442 deaths. Even if the impact of the Oriental Star shipwreck is removed, the average value of the F-N index for the remaining 7 years has reached 0.27, which is still far behind the developed countries.

4. Trend of waterway traffic safety

Through the trend test of waterway traffic accidents in the Yangtze River from 2009 to 2019, the result of the standard normal system variable Z is -1.0733. It shows that the number of waterway traffic accidents in the Yangtze River has shown a significant downward trend in the past decade, and the level of waterway traffic safety has gradually improved. In addition, it can be seen from Figure 5 that the value of the UF curve is below the zero line, indicating that the number of accidents has shown a significant downward trend in the past ten years. Moreover, the intersection of the UF curve and the UB curve between 2010 and 2011 indicates that a sudden change occurred between 2010 and 2011, and the downward trend has changed more significantly, which means the safety level of waterway traffic in the Yangtze River has been significantly improved.
5. Conclusion

There are big differences in the level of water traffic safety in various countries, and the U.S. ranks among the top in the world for water emergency rescue capabilities. The safety of waterway traffic is constantly improving in the Yangtze River, especially after 2010. However, compared with developed countries, there is still a big gap, especially in terms of waterway traffic accident rescue capabilities, and there is still much room for improvement.

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