Visualization of Ship Collision Risk in the Inland Bridge Waterway Based on the Maritime Traffic Simulation

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Abstract. The collision risk is increasing in inland bridge waterways given that the restrictive waterway and many of obstructions. It is crucial for seafarers and supervisors to identify the high-risk areas in a bridge waterway. This paper takes the Wuhan Bridge Waterway in the Yangtze River as a case. In accordance with the maritime traffic simulation, the potential collision frequency and its distribution are obtained in order to evaluate the risk in different areas of the case waterway. The nautical routes with respect to the ships passing the waterway and ferryboats crossing over the waterway are then modeled. A collision detecting method is proposed to obtain the collision information extracted from the simulation data. This collision information is visualized in order to illustrate the collision risk in each area. The high risk sites can be illustrated by the proposed method in order to assist the maritime supervisors in paying pointed attentions to the identified sensitive areas.

1. Introduction

It is worth noting that the Yangtze River is the longest and busiest waterway around the world with exceeding over 2,800 km. In addition, there are more than 80 bridges in total constructed or being constructed over the Yangtze River up to now. The highest density section in terms of bridge is Wuhan section of the river with 6 ones being in use. Those bridges, to some extent, degrade the nautical environment and increase the maritime risk. The identification of high risk areas and the corresponding risk degree becomes more important for the seafarers and supervisors in order to assure the safety of the inland bridge waterway of interest. Since the state of maritime traffic is hard to be mathematically modeled, maritime traffic simulation is a suitable method to identify and evaluate ship collision risk [1].

Jason R. W. M. et al. [2] established a traffic simulation model for ship traffic in San Francisco Bay. The model can evaluate the change of the number of ship’s encounter, the degree of congestion of the channel and the safety risk of the ship's navigation. Floris Goerlandt et al. [3] presented a micro-simulation model of the ship traffic flow based on the ship collision detection algorithm in order to predict the number of ship collision accidents and the time and place of the accidents. Kazuhiko Hasegawa et al. [4] developed an intelligent maritime traffic simulator. In the simulator collision avoidance decision of the ships is realized by the expert system and the fuzzy inference rules and the simulator can evaluate the traffic status of the ships under any sea area, channel and complex traffic...
conditions. Watanabe S. et al. [5] extended the marine ship traffic simulation system of the literature [4] and developed the river traffic simulator. The simulation model is used to evaluate the safety and efficiency of the inland water ship traffic.

From the review of literatures, it can be concluded that: (1) maritime simulation is an efficient way for the maritime risk evaluation; (2) many researches about the maritime risk are in open water or an entire river. Actually, the nautical environment and navigation rules of the Yangtze River are significantly differing from other areas. A number of specific characteristics of the inland bridge waterway should be taken into account for the maritime traffic simulation aiming at collision risk evaluation.

2. The case waterway - Wuhan section of the Yangtze river

In this work, the Wuhan section of the Yangtze River is taken as a case for the collision risk investigation. The basic information of this section is introduced firstly, followed by the analysis of the nautical rules.

Wuhan city is located at the middle of the Yangtze River. In the about 30 km section of the Yangtze River crossing the urban area, six bridges constructed from the 1950s are spanning over the river. More attention should be specifically drawn among the Yingwuzhou Bridge, the First Yangtze River Bridge and the Second Yangtze River Bridge. As shown in Fig. 1, these three bridges are much closed to each other, while three crossover lines are in operation: (1) Hanyangmen ferry dock - Jijiazui ferry dock, (2) Zhonghualu ferry dock - Wuhanguan ferry dock and, (3) Yueliangwan ferry dock - Wangjiaxiang ferry dock.

Among these three bridges, the most senior First Yangtze River Bridge has the narrowest opening for navigation. There are only 120 metres between each two adjacent piers leading to a 100-metres-width waterway navigable. As for the Second Yangtze River Bridge, the main opening with 400 metres width is available for both upstream and downstream ships. As for the Yingwuzhou Yangtze River Bridge, the northern opening is 850 metres width.

![Figure 1. Bridges and crossover lines in Wuhan section of the Yangtze River.](image-url)
In order to assure the safety of the maritime traffics and bridges, an especial navigation waterway is delimited by the Yangtze River Maritime Safety Administration (MSA) for each bridge. This kind of bridge waterway is from a downstream boundary to an upstream boundary, while the downstream boundary is 1,000 meters away from the bridge and the upstream boundary is 1,500 meters away from the bridge. Overtaking is forbidden in this each 2,500-meters-long bridge waterway. The bridge waterway therefore evolves into a kind of bottleneck for the river transportation.

Furthermore, three ferry crossover lines are all in the area between the First Yangtze River Bridge and the Second Yangtze River Bridge as shown in Fig. 1. It is more likely to generate a very catastrophic accident once any one ferryboat is involved.

The waterway from the upstream boundary of the Yingwuzhou Yangtze River Bridge to the downstream boundary of the Second Yangtze River Bridge is chosen for the simulation study. The object waterway includes three bridges and three crossover lines. The maritime traffic data of the object area is collected for the maritime traffic simulation in order to investigate the collision risk characteristics.

3. Modelling method
This study consists of the maritime traffic simulation modelling and collision risk calculation modelling.

3.1. Framework of the Modelling
The framework of the modelling is illustrated in Fig. 2.

![Figure 2. Main steps of the modeling.](image)

Firstly, Monte Carlo Methods are used to simulate the maritime traffic in the area of interest [6]. The historical data in terms of the ship traffic is collected to analyze traffic characteristics, namely the distributions of ship type, size, speed, arrival time and trajectory. The characterized parameters will be the inputs of the simulation.

Secondly, the maritime traffic can be simulated based on the random variables generated by Monte Carlo Methods. In order to focus on the collision characteristics, each ship is set as being in free navigation following its own upstream/downstream channel.

Thirdly, the generated simulation data can be used to calculate the collision risk based on a collision risk calculation model.

Fourthly, the necessary information (collision time, positions and distance when collision and, essential ship information) will be recorded for use if any collision risk is detected by the collision risk calculation model.

Finally, the collision risk can be characterized and analyzed.

3.2. Maritime Traffic Simulation Modelling
The maritime traffic simulation model is based on free-navigation ships. In the case waterway as shown in Fig. 1, there are totally eight routes for ships. In this work, the route for upstream merchant ships is defined as Route 1, while the other one for downstream merchant ships is defined as Route 2.
In the simulation, each crossover line varies from northern to southern. Therefore, the routes for ferryboats are defined as:

Route 3: from Hanyangmen ferry dock to Jijiazui ferry dock; Route 4: from Jijiazui ferry dock to Hanyangmen ferry dock; Route 5: from Zonghualu ferry dock to Wuhanguan ferry dock; Route 6: from Wuhanguan ferry dock to Zonghualu ferry dock; Route 7: from Yueliangwan ferry dock to Wangjiaxiang ferry dock; Route 8: from Wangjiaxiang ferry dock to Yueliangwan ferry dock.

Relevant simulation information in terms of the ship length, ship width, position (latitude and longitude), time and speed will all be stored into the simulation database for future processes.

3.3. Ship collision modelling

A collision model should be proposed to detect whether a two-ship collision is occurred based on the stored simulation data. The ship domain theory is used for the collision risk study. The collision between two simulated ships can be calculated based on their own ship domains. If there is overlap between the domains of two approaching ships, a collision in the simulation can be identified. The involved ship is referred as collision candidate in this work.

The concept of ship domain theory was initially presented by Fujii and Tanaka (1977) when the maritime traffic capacity was investigated in the sea water near Japan [7]. An elliptical domain centred by the ship was created when the ship was in restrictive water, as shown in Fig. 3.

Since the inland bridge waterway is considered as a kind of restrictive water, the elliptical domain is adopted in this work. It means that the ship domain in the inland waterway is considered as an ellipse centred by the ship. The major axis is on the centre line of the ship. It should be pointed out that the ship domain is not the destination of this work. Therefore, the ship domain in this work defined by the semi-major axis $a$ and the semi-minor axis $b$ is set as (1):

$$
\begin{align*}
    a &= 1.5l \\
    b &= 1.5w
\end{align*}
$$

Where, $l$ is the length of ship and $w$ is the width of ship.

In an approaching with both ship $A$ and ship $B$ involved, set the length of ship $A$ as $l_1$, the width of ship $A$ as $w_1$ and the position of ship $A$ as $(x_1, y_1)$. Meanwhile, set the length of ship $B$ as $l_2$, the width of ship $B$ as $w_2$ and the position of ship $B$ as $(x_2, y_2)$. Note that the unit of length in the simulation is metre.

The distance $d$ between the approaching ships can be calculated using (2):
\[
d = 6371004 \times \arccos[\sin x_1 \sin x_2 + \cos x_1 \cos x_2 \cos(y_1 - y_2)]
\]  

(2)

Suppose ship A is the own ship, then the relative course \( \theta_1 \) of ship B can be calculated by (3):

\[
\theta_1 = \begin{cases} 
\arcsin \frac{x_2 - x_1}{y_2 - y_1} & x_1 \leq x_2, y_1 \leq y_2 \\
2\pi + \arcsin \frac{x_2 - x_1}{y_2 - y_1} & x_2 < x_1, y_1 < y_2 \\
\pi + \arcsin \frac{x_2 - x_1}{y_2 - y_1} & y_2 < y_1 \\
\pi/2 & x_1 < x_2, y_1 = y_2 \\
3\pi/2 & x_2 < x_1, y_1 = y_2 
\end{cases}
\]  

(3)

Suppose the Course over Ground (COG) is \( \gamma_1 \), then the intercept \( d_1 \) in the domain of ship A can be obtained by (4):

\[
d_1 = \sqrt{(b_1 \sin(\theta_1 - \gamma_1))^2 + (a_1 \cos(\theta_1 - \gamma_1))^2}
\]  

(4)

In a same way, suppose ship B is the own ship, then the relative course \( \theta_2 \) of ship A can be obtained by (3). Suppose the COG of ship B is \( \gamma_2 \), then the intercept \( d_2 \) in the domain of ship B can also be obtained as (5):

\[
d_2 = \sqrt{(b_2 \sin(\theta_2 - \gamma_2))^2 + (a_2 \cos(\theta_2 - \gamma_2))^2}
\]  

(5)

In this work, a simulated collision is occurred when domains of two ships are touched. It means that, as shown in Fig. 3, the collision condition is the distance \( d \) of two ships as (6):

\[
d \leq d_1 + d_2
\]  

(6)

The collision model can be used to investigate the collision risk. There exist eight routes in the case waterway. Therefore, two situations should be taken into account:

(1) A collision between two merchant ships. The investigated waterway is separated as Route 1 and Route 2, for upstream and downstream ships respectively. It means that there is no effect in terms of ship heading, between an upstream ship and a downstream ship. Consequently the collision between two merchant ships can only happen in the same route. The proposed collision model can be used to detect the collision situation in the simulation. If the distance between two ships follows equation (6), a collision situation will be recorded by the position and time information of ships, as well as the values of \( d, d_1 \) and \( d_2 \).

(2) A collision between a merchant ship and a ferryboat. The crossing encounter situation is able to be formed between a merchant ship and a ferryboat. Each simulated maritime traffic upstream/downstream flow and each simulated ferryboat traffic flow should be tested according to equations (1) to (6), in order to investigate the collision between a merchant ship and a ferryboat.
4. Visualisation of the collision risk

The visualization of simulated collision candidates can directly show the risk distribution in different areas of the investigated bridge waterway based on the above simulation model and collision model. The visualization in this work is based on the inland Electronic Navigational Chart (ENC). As shown in Fig. 4, the investigated inland bridge waterway is split into a number of 125 metres × 125 metres grids. The number of collision candidates in each grid can then be obtained to indicate the risk degree by colour.

![Image](image_url)

**Figure 4.** Visualization of the collision risk.

The numbers of collision candidates in those grids are in the range [0,350]. The Fig. 4(a) shows the distribution of collisions caused by two merchant ships in Routes 1 and 2, while the Fig. 4(b) shows the distribution of collisions caused by a merchant ship and a ferryboat.

It can be seen in the Fig. 4(a) that the number of deep-colour grids for upstream ships are more than those of downstream ships, which is in accordance with the fact that the Average of collision number (ACN) of Route 1 is larger than the ACN of Route 2. In particular, colors of the grids near the First Yangtze River Bridge and the Second Yangtze River Bridge are significant deep as their numbers of collision candidates are larger than 250. This is due to the fact that the navigational-hole-breadths of these two bridges are narrower than that of the Yingwuzhou Yangtze River Bridge, while the Speed over Ground (SOG) of upstream ships are less than the SOG of downstream ships. As for Route 2, colors of the grids near the First Yangtze River Bridge and the Second Yangtze River Bridge are not as deep as that of the grids of Route 1. The collision candidates are relatively less because of the wider navigational-holes and the faster ship speed.

It can also be seen in the Fig. 4(b) that while one of the ferryboat routes (Routes from 3 to 8) is crossing with the merchant vessel routes (Routes 1 and 2), the deep-colour-grids in Route 1 are more concentrative than the ones in Route 2.

The deep-color-grids in Fig. 4 denote higher risk grids. Ships should keep prudent in those areas. In addition, more attention should be paid to these areas by the maritime supervisors in order to ensure the safety of maritime operations.

5. Conclusion

This paper proposes the ship traffic flow simulation and the ship collision model. The models can determine the status of ship collision, such as time, place and dangerous degree, and add up potential
collision frequency. Then the distribution of frequency can be visualized so we can intuitively see ship collision risk in different parts of the channel. The risk identification and assessment method proposed in this paper is helpful for maritime supervision departments to improve their supervision ability. They can add CCTV, radar and other equipment in these high-risk areas and strengthen the supervision of passing ships.

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