AIS DATA ANALYSIS FOR REALISTIC SHIP TRAFFIC SIMULATION MODEL

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Abstract: AIS (Automatic Identification System) data provide valuable input data for the development of simulation models to prevent shipping accidents. This paper reports on the detailed analysis of AIS data for that purpose. This analysis is focused on restricted waterways to support inland waterway simulations, comparing the differences between a narrow waterway in the Netherlands (narrow waterway in the Port of Rotterdam) and a wide one in China (wide waterway of Yangtze River). Statistical distributions can be used to characterize position, speed, heading and interval times for different types and sizes of ships. It was found that the distributions between narrow and wide waterways differ significantly.

Key words: ship traffic; traffic simulation; AIS; probabilistic risk model

1. INTRODUCTION

This work was inspired by the increasing number of collisions between ships and bridges in busy waterways of China and elsewhere. The subject was addressed earlier by Lucjan in 2009. When ship traffic intensifies, like in the Yangtze River, bridges and other objects are at increased threat of the collisions from ships. To estimate the risk, the probability of the collisions can be estimated through simulation following this work.

Previously, analytical methods were used to calculate the probability of collisions, such as AASHTO model (2004). However, these models lack in the detailed description of the movements of the ships. In recent years, simulation models have been developed to describe the dynamic movement of ships in all kinds of situations (Goerlandt, 2011, Statheros, 2008, and Montewka, 2011). Alternatively, dynamic ship movement can be simulated with manned ship-handling simulators (e.g. the Mermaid 500 at MARIN), but it requires experts to operate it and the equipment is expensive (Benedict, 2009). The cheaper option is to simulate ship movements that are based on Fuzzy Mathematics Methods (Zalewski, 2010), Bayesian Networks (Ying, 2007) and Neural Networks (Łaącki, 2009). However, these methods are still dependent on expert decision or human intervention.

As opposed to expert opinions, this work is based on actual behavior of ships and their crews from historical data of the AIS (Automatic Identification System) database. The historical information can be used to calibrate a simulation model based on multi-agent simulation and artificial force field theory. In order to make that possible, the first step is studying AIS data to unveil the characteristics of real-live ship movement.

2. AIS DATA ANALYSIS

The AIS database contains a huge amount of ship tracks with status of ships (dimension, position, speed, and heading etc.). After interpretation of those ship tracks, we can derive information of ship traffic behavior that is characterized by the mean values and statistical distribution of position, speed, heading and interval times for different types and sizes of ships. The ultimate goal of the analysis is building a realistic simulation for (inland) waterways, which can be used for safety assessment of the waterway. We also expect a realistic ship traffic simulation can be further applied for design of approach channel and solving bottle neck problems of busy waterways.

A realistic simulation of ship behavior should be internationally applicable. In this sense, the model evolved from a specific area should be applicable in other places of the world. Possible similarities and differences of ship behavior resulting from many influences should be identified, which include local regulation, behavior of officers on watch, and characteristics of the waterway.

In order to find those similarities and differences, two typical busy waterways which are different in many aspects are analyzed. Those two waterways are a channel of the Port of Rotterdam in the Netherlands and a main passage of Yangtze River in China. There are many differences between those waterways. First, the part of navigable channel of the Port of Rotterdam is about 200m wide, and the part of navigable main passage in China is 890m wide, which is constrained by the main span of Su-Tong Bridge. Second, the channel of Port of Rotterdam has traffic in both directions without separation scheme. However, the main passage in China is divided into 4 traffic lanes, with two in each direction and a separation zone in between. Third, the local regulation is different, which results in different ship behavior. Besides those differences, we can also find some similarities. First, those two waterways are very busy, where we expect large numbers of ship passages every day. Second, there are various ship types and a wide range of dimensions of ships sailing in both waterways. Third, the water currents in both waterways are influenced by tide and river discharge. As a result, there is inflowing current and outflowing current.

A realistic simulation of ship behavior should be applied into both cases, which should be able to reflect all those differences and similarities of ship behavior in both waterways of the Netherlands and China. There are two steps in studying the AIS data, we analyze the refined information derived from AIS data, and then we compare the similarities and differences in both cases.

3. RESULTS FOR THE NETHERLANDS

In this case, a nearly straight waterway in the Port of Rotterdam is chosen. The Maassluis waterway is selected, which is 1 mile upstream and downstream of coordinates (+51° 54' 13.77", +4° 16' 19.07"), also see Fig. 1. The Dutch Maritime Research Institute MARIN provided the data and was kind enough to allow the use of their software "Show Route" for the data analysis.

The software "Show Route" at MARIN is able to transfer the raw AIS data into a database with detailed dataset of status of ships. Then we draw crossing lines at regular intervals perpendicular to the waterway in "Show Route", to which the AIS information is transferred. Then, we divide the data into ship classes and examine the data on each crossing line. In the end, we produce graphs for statistical analysis for comparison.

3.1 Spatial distribution perpendicular to the water flow

Fig. 2 shows spatial distribution of ships that was extracted from the AIS database. The x-axis is the non-dimensional lateral distance from the center of waterway, and the y-axis gives the fraction of ship numbers. We can find that most of the ships were navigating on the right side of the waterway. And most of the traffic prefers to stay closer to the centerline rather than to the bank. Further, one can find that the normal distribution fits the data very well.

3.2 Speed distribution of ships

Different ships will maneuver with a different speed, as we can see from Fig. 3 with the distribution of speed for the ship traffic on the crossing line 1, which is located at the left boundary of the "place of interest" shown in Fig. 1. A normal distribution function can be fitted to the speed data. The speed of ships is varied in a range from 5 kn to 17 kn, with a mean of 11.8 kn and a standard deviation of 1.6 kn. However, there is few ships navigating with a speed less than 5kn or larger than 15kn. This means most of ships could not navigate at a full speed.

A ship will navigate with a safe speed in the waterway. Especially in the busy channel, the OOW (Officer on Watch) should be able to decide an economic speed which guarantees the safety of the ship. So, the ship speed is determined by many factors, such as experience of OOW, characteristics of OOW, ship position, ship condition, ship dimensions, ship type, characteristics of the waterway, encountering situation, and environment. As a result, each ship will sail with its own speed which is required by good seamanship, and which results in the large variation of speeds.

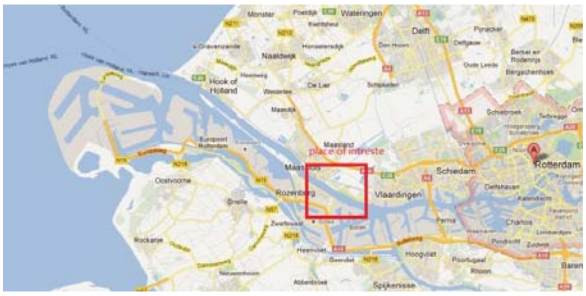

Fig.1 Maassluis waterway

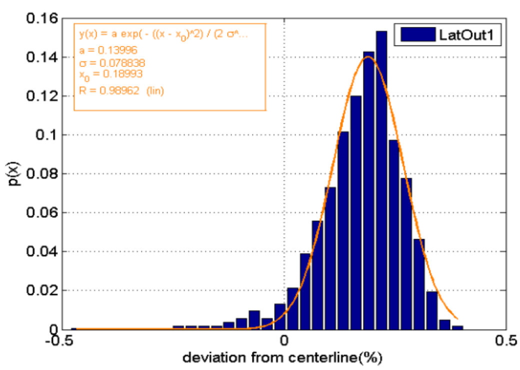

Fig.2 Ship spatial Distribution (Outgoing containerships less than 5100t, 2110 passages)

3.3 Course distribution of the ships

As is shown in Fig. 4, the headings do not vary much in the data, which is a normal distribution with mean of 302.3 degrees and standard deviation of 1.2 degrees. This means that the heading of the ships does not change much when they are sailing in the channel. There are reasons for this phenomenon. First, the location of the case study is a straight channel where the ships do not need to change their course during navigation. Second, the channel we studied is narrow (about 200m wide), and there is no room to change course significantly. Third, the only reason for changing course is encountering situation, and with the limitation on the scale of the waterway, the ships opt for speed change to make safe maneuver to avoid collision, as we can see the speed variation of ships in Fig. 3.

3.4 Time interval between two ships

In the previous description of the statistical analysis of the AIS data, position, speed, and heading were presented. Those statistical data were related to the status of individual ships. However, the time interval between the passages of two ships is a measure for traffic density in the studied area. If the time intervals are large, we can expect the volume of traffic to be small. On the contrary, if the time intervals are small, we can expect there is dense ship traffic.

In the AIS data base, we can derive the arrival time of every ship, and we record it as [t_1, t_2 … t_n]. Then we calculate the time interval between two times. Afterwards, the analysis of the 3 months AIS data shows that the time intervals fit well with a lognormal distribution, see Fig. 5. The lognormal formula is a function of μ and σ:

$$F(x) = f(x \mid \mu, \sigma) \quad (1)$$

In order to see how well we use the lognormal distribution to describe the time intervals, with the help of function "lognrnd (mu, sigma)" in Matlab, we generated 100000 lognormal random numbers with the same function using the same interval on the x axis. Then we derived the red line which fits well with the bar diagram.

With this statistical analysis, we can find the traffic load in the different locations of studied area, and we can simulate traffic density by generating ships using the formula.

Tab. 1 Container ship classification

Class number	Class 1	Class 2	Class 3	Class 4	Class 5
GT	<5100	5100-12000	12000-20000	20000-38000	>=38000

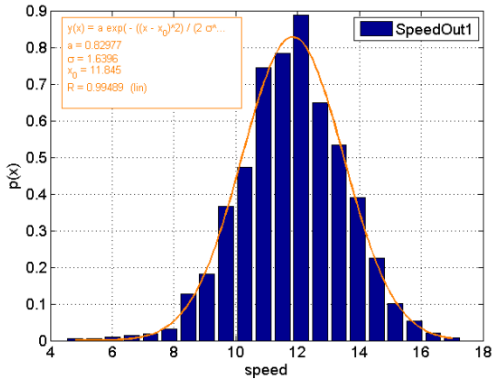

Fig.3 Speed distribution of ships (Outgoing containerships less than 5100t, 2110 passages)

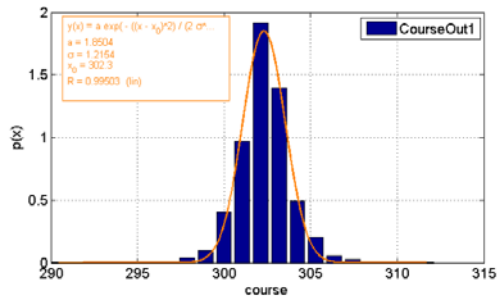

Fig.4 Course distribution of the ships (Outgoing containerships less than 5100t, 2110 passages)

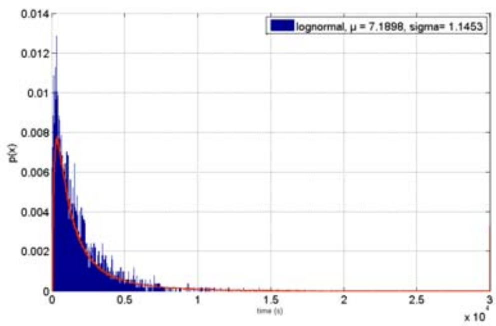

Fig.5 Distribution of time intervals (1828 passages)

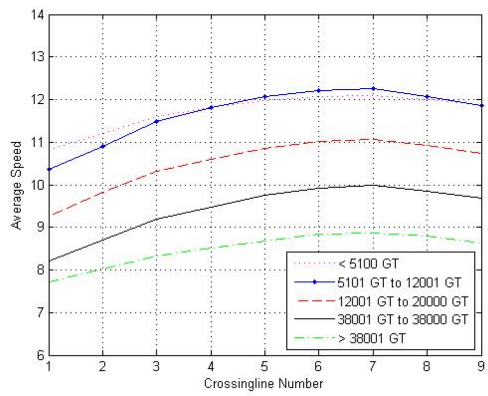

Fig.6 Average Speed of Incoming Container Ships

3.5 Average Speed in the waterway

Compared to the relative stable position and course, the speed is constantly changing in the waterway. Taking incoming container ships as example, we categorize these into 5 groups according to gross tonnage, and we calculate the averaged speed in each group of ships on each crossing line. The details of the classification can be found in Table 1.

As can be seen in the Fig. 6, the average speed for ships in different groups is very different, which can vary from 8kn to 12 kn. We can see that the larger ships take passage with smaller speed, and the ships intend to increase speed in the channel. But the speed decreases before the river bend. We can still find from the graph that the largest ships steer with a speed less than 9kn, and the speed doesn't change much.

4. RESULTS FOR MAIN PASSAGE OF SU-TONG BRIDGE AREA IN CHINA

In this case, a nearly straight waterway close to the Su-Tong Bridge is chosen. The Su-Tong Bridge is located in Nantong city of Jiangsu Province, China, 108 kilometers to the mouth of Yangtze River. The river crossing perpendicular to the river flow is 8146m wide and the main waterway passes under the Su-Tong Bridge, which has a span of 1088m wide and is 62m in height. In order to keep the ships clear off the bridge, the navigable waterway clearance is designed as 890m, which is then separated into 4 traffic lanes and a 100m wide separation zone. It was designed to fulfill the navigational needs for 50,000t container ships and 48,000t convoys. The characteristics of the waterway and the bridge are shown in Fig. 7.

China MSA (Maritime Safety Administration of the People's Republic of China) provided the AIS data for the case study and was kind enough to provide other related information such as positions of navigational aids.

Fig. 8 shows that the ship traffic under the Su-tong Bridge is quite busy. The ships are within 500m range of each other. So it is an interesting case with dense ship traffic. Relevant local ordinances include the following. According to the separation scheme of Jiangsu Waterway, the two "suggested waterways" are 200m wide traffic lanes (if available), which are separated from the "deep-waterway" by navigational aids on both sides. The "deep-water way" is specifically navigable for "very large ships" and "large ships", the "suggested waterways" are specific for "small ships". According to the local regulations, "very large ships" are the ships (or convoys) which have a fresh water draught more than 9.7m or length more than 205m, or ships (convoys) with maximum height above water which is close to the span clearance of the bridge and overhead power cables, or ships (convoys) with restricted maneuverability. And "large ships" are the ships (convoys), which have a fresh water draught between 4.5m and 9.7m or length between 50m and 205m in the regulation. "Small ships", also defined in the regulations, are the ships (fleet) with dimensions smaller than the "very large ships" and "large ships". An important ordinance factor is that overtaking is not allowed in the waterway near the bridge area.

4.1 Spatial distribution perpendicular to the water flow

Fig. 9 shows the AIS data of the ship positions under the main span. The x-axis is the non-dimensional lateral distance from the center of waterway, and the y-axis gives the fraction of ship numbers. As shown in the figure, there are 4 clusters of ship traffic, which is a result of separation scheme. The two clusters in the middle are positions of "large ships", and the two clusters on the sides are positions of "small ships". In the four clusters, the two on the right side are positions of incoming ships. Similarly, the two clusters on the left side are positions of outgoing ships. The histogram shows that the ship traffic conforms to the separation scheme as a whole. And there are more ships in the center of each lane compared to the sides, this is because many "small ships" are not equipped with AIS, and we cannot take them into account.

Fig.7 Characteristics of the waterway and the bridge

Fig.8 pictures of Su-Tong Bridge

4.2 Speed distribution of ships

The speeds of ships are very different in the waterway. Sea-going ships have a larger speed than the inland ships. The speed of ships depends on all varying circumstances on the water but that is hard to detect in these compound data sets. On the whole, the speed of ships fits well to a normal distribution, ranging from 3 knots to about 18 knots, with a mean of 8.68 kn, see Fig. 10.

4.3 Course distribution of the ships

The course is distributed with a variance of 30 degrees in both sides, which is different from the Rotterdam case with 10 degrees of variance. This means that the ships have more freedom for maneuvering, and they divert much more than the ships in Rotterdam, see Fig. 11.

4.4 Time interval between two ships

The time interval between ships conforms to lognormal distribution based on one day AIS data (426 ship passages) records, see Fig. 12. We count the number of ships in intervals of 15 seconds, and finally get the graph with bars. The x axis is the time interval (s), and the y axis is the number of ships divided by total ship numbers (426) in every 15 seconds. And with regression, we get mean and standard deviation of the log-normal distribution, in which μ is 5.0 and σ is 0.9.

4.5 Average Speed in the waterway

In Fig. 13, the average speed of incoming ships and outgoing ships is shown. The x-axis is the crossing line numbers, which is from 1 to 14. The y-axis stands for the average speed of the ships. The crossing lines are drawn perpendicular to the parallel of latitude, at 1000m distance from one another. On a whole, the outgoing ships have a larger speed and are showing little speed change. On the other hand, the incoming ships navigate slower, and show larger speed change, especially between crossing line 1 to crossing line 7. The collected AIS data lack information on ship type and tonnage, so we cannot classify the data in different ship types and sizes.

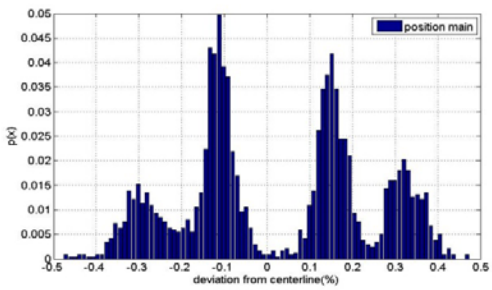

Fig.9 Distribution under the Main Span (Incoming and Outgoing Ships with 2372 passages)

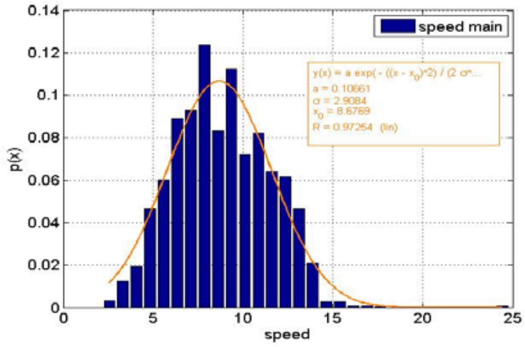

Fig.10 Speed Distribution (Incoming and Outgoing Ships with 2370 passages)

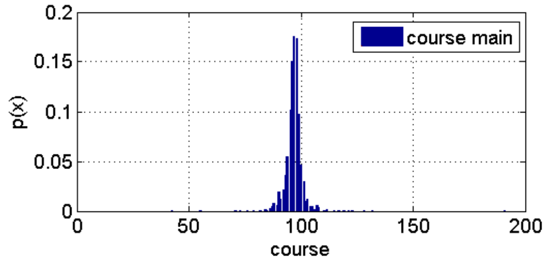

Fig.11 Course distribution (Incoming Ships with 1197 passages)

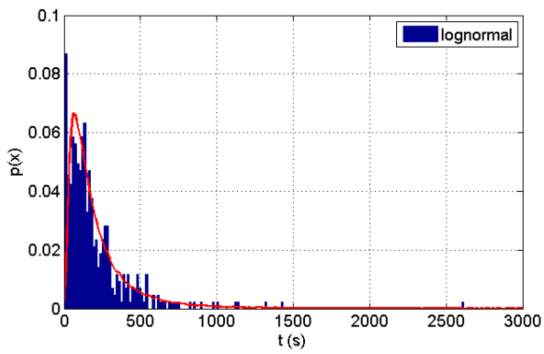

Fig.12 Distribution of time intervals (426 passages)

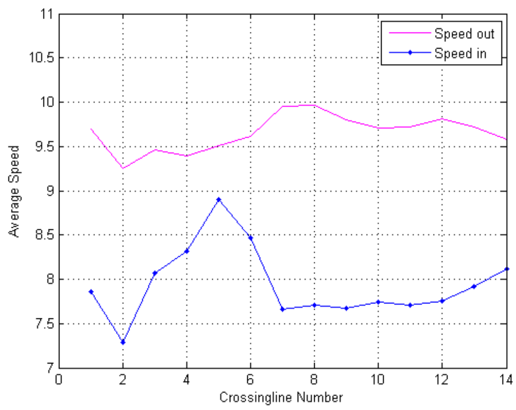

Fig.13 Average Speed of ships on Incoming Direction

5. RESULTS

The AIS data have provided a lot of information for analysis. From the graphs, we can see similarities and differences in ship traffic characteristics when comparing the Dutch case and the Chinese case.

On the one hand, there are similarities in both cases. The ship positions, speed, course, and time intervals conform to certain distributions, which can be used to describe the ship traffic. The normal distribution fit the ship position with mean and standard distribution, the same happens with course of ships and ship speed at certain position of the waterway. The time intervals between two consecutive ships also are tested to conform to the lognormal distribution. With the distributions, we can treat the PDF (Probability Density Function) as input of the ship traffic simulation later on. We can also treat the PDF as verification for the result of the ship traffic simulation to see whether the simulation is realistic or not.

On the other hand, there are several differences comparing the details between the cases of the Netherlands and China. First, in ship spatial distribution of the Rotterdam case, there are ships which deviate from the normal position to the other side of the waterway. However, the incoming and outgoing ships under the Su-Tong Bridge do not deviate from their own space, which is the result of separation scheme. Second, the speeds of the ships in Rotterdam are relatively higher than the same under the Su-Tong Bridge. One of the reasons is that overtaking is not allowed in the waterway of the Su-Tong Bridge, which forces the ships navigate with a lower speed. Another reason is that the traffic in Yangtze is denser. Third, the room for the ships to change course is different. The course variation of ships in Rotterdam is only 10 degrees. However, the course of the ships can be different within 30 degrees. The reason is that the navigational width of the waterway is larger compared to Rotterdam. Fourth, the time intervals between two consecutive ships are smaller in the China case, which is because the volume of ship traffic is much larger. Last but not least, the speed change throughout the waterway is different. The speed change depends on the ship types, the characteristics of the waterway, and different regulations. So, the reason for speed change is very complicated.

6. CONCLUSION AND DISCUSSION

This research presents AIS data analysis to get better knowledge about the ship traffic in the waterway, which is also a basis for a realistic ship traffic simulation later on for maritime risk or other maritime related purposes. Some dynamic values (position, speed, course, time interval) of ship AIS information are selected, and the values are presented in a statistical way to describe the characteristics of the ship traffic. In the end, the characteristics of ship traffic in both the Netherlands and China are compared to show the similarities and differences. This is valuable to understand the relevant parameters.

The data analysis at this stage only concerns the direct information. There is other indirect information beyond this analysis that is also important to describe the ship traffic, including ship interaction, human factor, and ship response to navigational environment. For the ship interaction part, it refers to head-on situation, overtaking situation, ship avoidance of objects and grounding, and avoidance behavior of crossing section. Those interactions are individual behavior as a result of human factor and regulations, which will be further investigated in the next stage.

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