AIS DATA BASED VESSEL SPEED, COURSE AND PATH ANALYSIS IN THE BOTLEK AREA IN THE PORT OF ROTTERDAM

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Abstract: Maritime traffic safety and port capacity is increasingly important nowadays. Due to the fast development of vessel traffic in ports and waterways, a lot of attention has been paid to maritime traffic safety and port capacity. Many simulation models have been used to predict traffic safety and port capacity in ports and waterways. However, maritime traffic models only consider few aspects, as the influences of human behavior and external factors have not been included regarding maritime traffic safety. To investigate the vessel behavior and external influencing factors, an analysis has been performed based on Automatic Identification System (AIS) data under various external conditions. The study area includes a junction and a slight bend with high maritime traffic density within the port of Rotterdam, the Netherlands. Vessels are classified in different categories based on their type and gross tonnage. Equidistant cross-sections approximately perpendicular to the navigation direction are used for investigation of vessel behavior, including speed, course and path for each vessel category. The influences of external factors (wind, visibility and current) on vessel behavior are identified by comparing with unhindered vessel behavior. In the analysis, specific thresholds are set to select external conditions and eliminate the influence of encounters. The analysis of unhindered vessel behavior for each vessel category provides insight into vessel behavior. The results revealed that the wind has influence on vessel path, the visibility can affect vessel speed and path, and the current can influence vessel speed. Analysis results can be used as input for the development of new maritime traffic model, as well as for its verification and validation.

Key words: AIS, data analysis, unhindered vessel behavior, external factors

1. INTRODUCTION

Maritime traffic is getting more important nowadays since international shipping is carrying around 90% of world trade with more than 50,000 merchant vessels as indicated in Dolivo (2007). With the fast development of maritime traffic, the balance between maritime traffic safety and capacity tends to get jeopardized: when the utilization of waterways increases, usually the safety decreases. Maritime traffic safety is a big issue, in particular in port areas, because of possibly serious consequences of maritime traffic accidents, such as personnel and property losses, traffic congestion and environmental influences both in the water and in the surroundings.

Some maritime traffic models have been developed to investigate this complex system consisting of various elements, such as hydrodynamics, vessel interactions, external factors and human factors. Currently, maritime traffic models are only developed for open seas and not applicable in constrained waterways such as ports. Researchers have established mathematical models considering the hydrodynamics of vessels and/or the influence of external factors on vessel behavior as in Sutulo and Moreira (2002) and Sarioz and Narli (2003), others investigated the models calculating the maritime traffic safety index, such as Pedersen (1995), Fowler and Sørgård (2000), Degre and Glansdorp (2004). However, external factors which could potentially affect maritime traffic safety were only considered as probability parameters in these models. It is still not clear that how external factors affect vessel behavior. Hence, a new maritime traffic model is required to describe the relationships between individual vessel behavior, influence of external factors and maritime traffic safety.

In this study, the data analysis has been performed at the Maritime Research Institute, Netherlands (MARIN, one of the leading institutes for hydrodynamic research and maritime technology). The research area is Botlek area in the port of Rotterdam (the Netherlands). The Botlek area is an ideal area to do this research since it comprises a waterway including a bend and a junction with high traffic density. It offers enough data for the analysis of different vessel categories to identify influences of different factors including wind, visibility and current, as well as navigation direction and waterway geometry.

All the data used in this paper was collected from the Automatic Identification System (AIS) in MARIN. AIS is an onboard autonomous and continuous broadcast system transmitting vessel data between nearby vessels and shore stations on the VHF maritime mobile band (see Bailey and Ellis (2008)). By the end of 2004, the AIS system had to be installed on:

- all ships of 300 gross tonnage and more, engaged on international voyages;
- cargo ships of 500 gross tonnage and more not engaged on international voyages;
- all passenger ships irrespective of size.

AIS has proven itself as a useful tool to investigate maritime traffic, such as Ristic and Scala (2008), Aarsaether and Moan (2009), Mou and van der Tak (2010). Combined with data on wind, visibility and current, AIS data including vessel speed, course, position, etc. can be used to investigate influences of external factors on vessel behavior. We analyzed historical AIS data (from January 2009 to April 2011) in the Botlek area at MARIN.

As a basis of the new maritime traffic model, this data analysis aims to identify unhindered vessel behavior, which is single vessel behavior without encounters and strong external influences, and influences of external factors (wind, visibility and current) on vessel behavior. The AIS data analysis set-up is given in the next section. Then the unhindered vessel behavior for each vessel category based on vessel type and size is investigated. The influence of external factors (wind, visibility and current) on vessel behavior is analyzed by comparing with unhindered vessel behavior. Finally, further recommendations are given.

2. AIS DATA ANALYSIS SET-UP

Different types of data are recorded in AIS system, including static data (Maritime Mobile Service Identity (MMSI) number, type of vessel, length, beam, etc.), dynamic data (vessel position, time instant, speed, course, etc.), voyage related information (draught, cargo, destination, etc.) and short safety messages (see Bailey and Ellis (2008)). The dynamic information, which is automatically updated from the ship sensors to AIS system, includes most of the data for vessel behavior, such as vessel speed, course and position. In this paper, this dynamic information is used as input for our analysis.

The AIS data come from ship borne machines which are used by different bridge teams on different vessels. Although the accuracy of AIS data has been improved in recent years, AIS data are not reliable in many cases as shown in Harati-Mokhtari and Wall (2007). However, the incorrect information appears mostly in static aspects, such as length and beam, which are not included in the data analysis.

To analysis AIS data, it is important to know the time interval of AIS signals. In the research area, most vessels navigate with a speed of 0-14 knots (1 knot = 1.852 km/h = 0.514 m/s), while they send AIS messages with an interval of 10 seconds. When vessels sail with larger speeds of 14-23 knots, they send AIS messages every 6 seconds (see Eriksen and Hoye (2006)). Then, a smart way should be proposed to extract and compare speed, course and path between different tracks. In this paper, we use cross-sections, which will be illustrated in the next section, to compare vessel behavior of different vessel tracks.

In the remainder of the paper, we will investigate the unhindered vessel behavior and the influences of external factors on vessel behavior including parameters of vessel speed, course and path. To structure our analysis, we have set up the following research questions about unhindered vessel behavior and influence of external factors for each vessel category:

Question 1: Which factors influence the speed of an unhindered vessel?

Question 2: Which factors influence the course of an unhindered vessel?

Question 3: Which factors influence the path of an unhindered vessel?

Question 4: Does wind influence vessel speed, course and path?

Question 5: Does visibility influence vessel speed, course and path?

Question 6: Does current influence vessel speed, course and path?

3. DATA ANALYSIS METHODOLOGY

In this data analysis research, some thresholds are set to select external conditions and eliminate the influence of encounters. Unhindered vessel behavior is investigated by eliminating influences of external factors and encounters using the thresholds mentioned above. Then, we investigate the influence of external factors by adding these elements to the vessel behavior with opposite thresholds individually. For example, wind is set as less than 8 m/s in unhindered vessel behavior; the opposite selection (larger than 8 m/s) is chosen when we investigate influences of wind on vessel behavior. This way, we compare vessel behavior under non ideal conditions with unhindered vessel behavior to identify the influence of external factors.

Since AIS data are signal based data corresponding to all points on each vessel track, cross-sections are used to extract vessel behavior from raw AIS data in ShowRoute, which is dedicated software developed by MARIN used for investigation of AIS data. For each vessel track, linear interpolation is used on cross-sections based on the first point after the cross-section and the last point before the cross-section.

The time period from January 2009 to April 2011 is selected for AIS data analysis. This way, we have more than two years of the most recent data. In addition, more vessels have installed AIS in the research area compared to previous years. Although we aimed to obtain more data, the data set depends on the size of the Access file, which should be less than 2G and will get slower when the file gets larger.

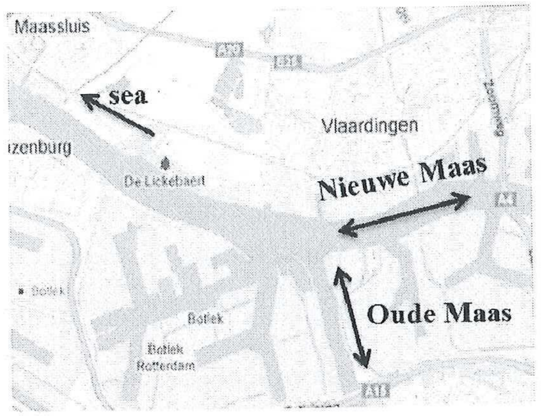


Fig. 1 Research area

The research area is shown in Fig. 1. The Nieuwe Maas, flowing east to west, connects the older port basins of the Waalhaven and Eemhaven with the sea. The Oude Maas joins the Nieuwe Maas from the south and forms the main connection for vessel traffic to the hinterland. We distinguish in the analysis the following four main vessel flows:

- Sea-Nieuwe Maas.
- Nieuwe Maas-Sea.
- Sea-Oude Maas.
- Oude Maas-Sea.

There are many vessel types in the research area, such as container vessels, tankers and General Dry Cargo vessels (GDC). Different types of vessels may have different unhindered vessel behavior since they have different sensitivity to danger and different maneuverability. The influence of vessel types on vessel behavior is investigated in this paper.

To some extent, vessel size determines vessel's maneuverability. For example, compared to larger vessels, smaller vessels have larger freedom in restricted waterways. This implies that the vessel size is expected to affect the vessel's behavior as well. As a key index of vessel size, the gross tonnage (GT) has been used to classify vessels in different categories.

It should be noted here that there are many berths in this area which could result in special maneuvering and vessel berthing paths. Although berthing vessels show particular behaviors, this data analysis mainly investigated sailing behavior without berthing. In this research, berthing behavior is thus filtered from the data set by the boundary defined in ShowRoute.

For the five vessel types (Container, GDC, Dredger, RoRo and Tanker) with the largest occurrence in the AIS data, vessels are classified into several categories based on their size distribution. The criterion for this classification is to classify vessels with expected similar behavior in the same group. For each vessel type, size categories are chosen in such a way that in every data set approximately the same amount of data points is available. Here, we set 3,000 data amount as the minimum required to distinguish a separate category. Container vessels have five categories because they have the largest amount of AIS data and enough data for each category. GDC vessels are classified into four categories. Dredger, RoRo and Tanker vessels are divided into three categories because less data for these vessels are available.

Cross-sections are proposed to investigate vessel behavior based on AIS data in this research. As we can see in Fig. 2 and Fig. 3, 69 cross-sections for navigation directions Sea-Nieuwe Maas and Nieuwe Maas-Sea, and 68 cross-sections for navigation directions of Sea-Oude Maas and Oude Maas-Sea are defined to investigate vessel behavior for each vessel category.

All cross-sections are formed by linking two points at 5 meter depth contours on two sides of the waterway. Usually, the water depth is an important factor to take into account for the bridge team considering vessel draught. Buoys are set in some places to indicate shallow water in waterways, but there are only two buoys in this area (red diamonds in Fig. 2). The bridge team decides vessel path based on the buoys, the maritime chart and their experience. As a result, sailing vessels normally do not pass 5 meter depth contour. Therefore, the 5 meter depth contour is chosen as the reference line to calculate the distance between vessels and the centerline of waterways. It should be noted that there is no 5 meter depth contour in the junction area on one side of the waterway, so there a smooth curve is defined between the adjacent 5 meter depth contours.

As mentioned before, most vessels in this area navigate with a speed of 0-14 knots. For a vessel sailing with 10 knots, which is around the average speed in the research area, vessels should be able to send at least one AIS message between two cross-sections. Thus, we choose 50 meters as the distance between two cross-sections. The cross-sections between the 5 meter depth contours

are approximately perpendicular to the navigation direction.

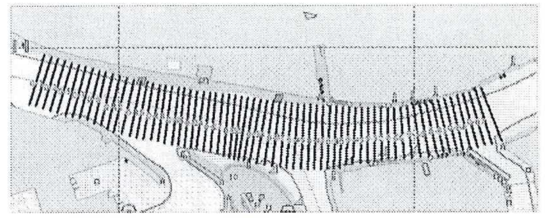


Fig. 2 Cross-sections in Sea-Nieuwe Maas and Nieuwe Maas-Sea.

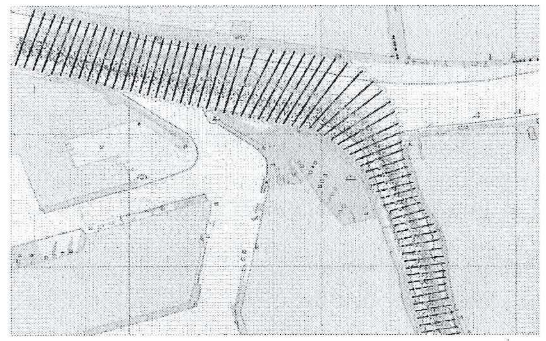


Fig. 3 Cross-sections in Sea-Oude Maas and Oude Maas-Sea.

For each navigation direction, vessel's sailing information including vessel position, speed, and course is interpolated on each cross-section using the information from the last record before and the first record after the cross-section. This way, AIS data on cross-sections are calculated and will be used for analysis in the following research. This data set can be combined with wind, visibility and current data to describe vessel behavior depending on these external conditions. The next section will use this combination to investigate unhindered vessel behavior.

4. UNHINDERED VESSEL BEHAVIOR

In this section, unhindered vessel behavior including vessel speed, course and path without influence of external factors and encounters is calculated on each cross-section mentioned before for the four navigation directions. The analysis has been carried out for all vessel types, but the results presented in this paper are mostly related to container vessels, unless otherwise indicated.

First, the AIS data set is combined with wind and visibility data to select the vessel data without influence of wind (less than 8 m/s), visibility (more than 2,000 meters) and encounters (with a minimum distance to other vessels larger than 1,000 meters). These thresholds are set to keep enough data for both investigation of unhindered vessel behavior and influence of external factors. The current speed is time and location depended, so the influence of the current is investigated independently in the section 5. In this section, the influence of vessel type and size (gross tonnage) on vessel behavior will be investigated as well.

4.1 Unhindered vessel speed (question 1)

Fig. 4 shows the median vessel speed (solid lines) and the 90% confidence interval (dotted lines) along the waterway for five categories of container vessels for the navigation direction Sea-Nieuwe Maas. Here, we use x-axis 'distance to the first cross-section' to indicate the longitudinal distance along the waterway. It can be seen that '<5100 GT' category has the largest speed, while '> 35000 GT' category navigates with the lowest speed. The results of other vessel categories show the same trends and their curves are approximately parallel. They show that smaller vessels have larger speed than larger vessels. For all categories, vessel speed changes along the waterway correspondingly. It means that vessel speed is influenced by the waterway geometry and vessel size.

In Fig. 5, median speed from Fig. 4 is compared with the same vessel categories in Nieuwe Maas-Sea (dotted lines). Mostly the dotted lines are higher than the solid lines. It means that incoming vessels have lower speed than outgoing vessels. It can be explained that the waterway in the east is more zigzagged compared to the waterway is the west. Thus, vessel speed is influenced by navigation direction, as well as the waterway geometry.

In the same way, Fig. 6 shows the comparison of median speed for Sea-Nieuwe Maas (solid lines) and median speed for Sea-Oude Maas (dotted lines) for the two smallest categories (as the larger size categories do not have sufficient vessel passing). Compared to vessels in Sea-Nieuwe Maas, vessels in Sea-Oude Maas decrease their speed by about 20% after the bend. The reasonable explanation is that vessels have lower speed in a narrower waterway and vessels decrease their speed when they pass the bend area.

To compare the influence of vessel type, we choose vessel groups with similar gross tonnage of '3500-6500 GT' from different vessel types to compare their speed distribution in Fig. 7. This range is chosen since in this category the largest number of vessels is observed for each vessel type. The figure shows the probability density functions of speed of five vessel types on cross-section 2. The skewness and kurtosis for each vessel type are listed in the figure, where the skewness is always within the interval [-1, 1], and the kurtosis is around 3, except for the value for tanker vessels (4.42). Thus it can be concluded that vessel speed are indeed approximately normally distributed. Statistical test function 'ttest2' in Matlab only accept 'means are equal' for Container-RoRo and GDC-Dredger. It means vessel speed is influenced by vessel types in most cases. It should be notified that 95% confidence level is used in all remaining of this paper.

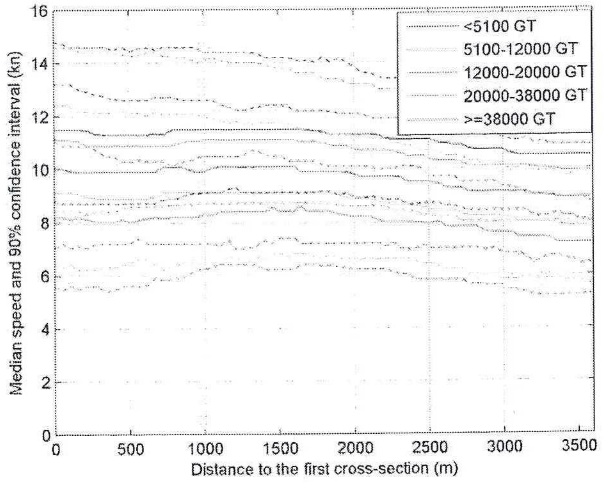


Fig. 4 Median speed of container vessels as a function of waterway geometry (solid lines) and 90% confidence interval (dotted lines) in Sea-Nieuwe Maas

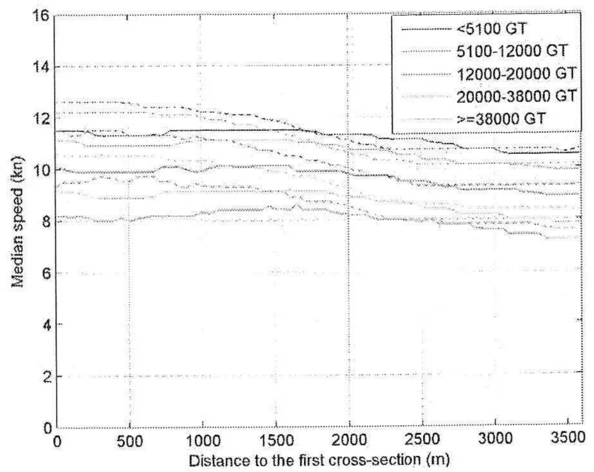


Fig. 5 Comparison of median speed of container vessels in Sea-Nieuwe Maas (solid lines) and Nieuwe Maas-Sea (dotted lines)

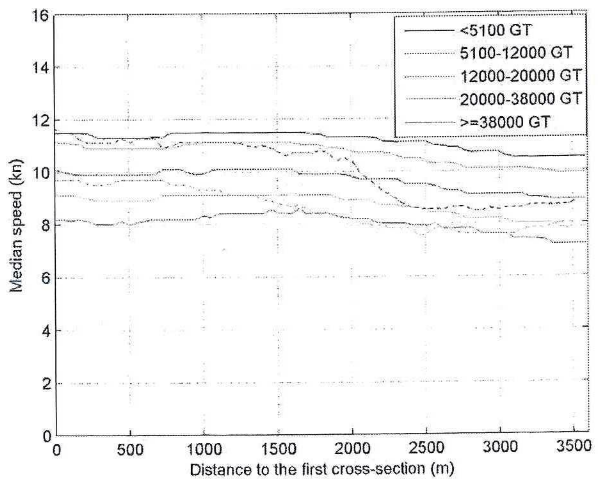
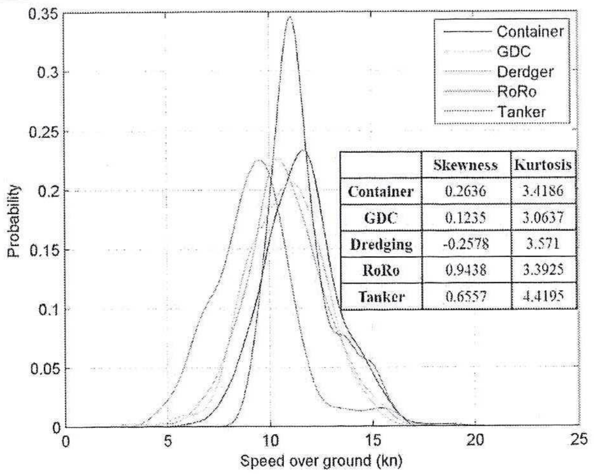


Fig. 6 Comparison of median speed of container vessels in Sea-Nieuwe Maas (solid lines) and Sea-Oude Maas (dotted lines)



	Skewness	Kurtosis
Container	0.2636	3.4186
GDC	0.1235	3.0637
Dredging	-0.2578	3.571
RoRo	0.9438	3.3925
Tanker	0.6557	4.4195

Fig. 7 Vessel speed distributions for five vessel types in Nieuwe Maas-Sea on cross-section 2

4.2 Unhindered vessel course (question 2)

Fig. 8 (Sea-Nieuwe Maas) and Fig. 9 (Nieuwe Maas-Sea) show that the median course for different container vessel categories in both directions is approximately equal.

In Fig. 10, it is shown that the vessel course distribution of five container categories on cross-section 2. According to the skewness and kurtosis, vessel course does not follow a normal distribution. The statistical tests show mostly 'means are equal' is accepted. It means that vessel course does not depend on vessel size.

Fig. 11 presents course distributions for vessels of '3500-6500 GT' from different vessel types on cross-section 2. In the statistical test, 'means are equal' is accepted in most cases. Then, we draw the conclusion that the mean course value is approximately equal for different vessel types, which means that vessel course is not influenced by vessel type.

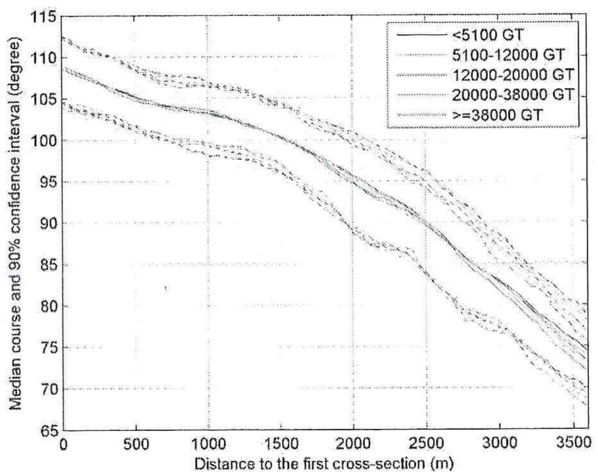


Fig. 8 Median course of container vessels as a function of waterway geometry (solid lines) and 90% confidence interval (dotted lines) in Sea-Nieuwe Maas

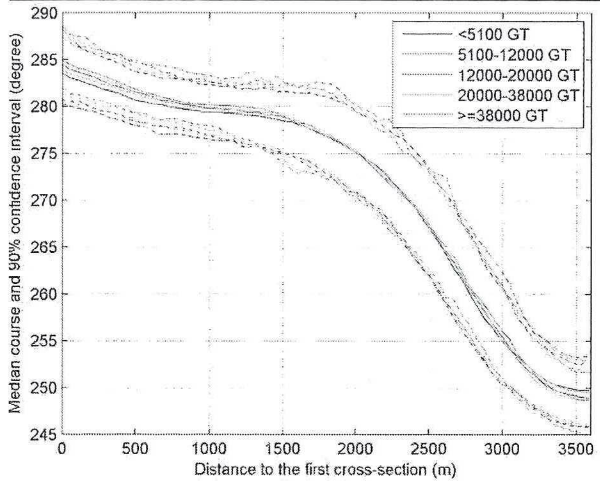
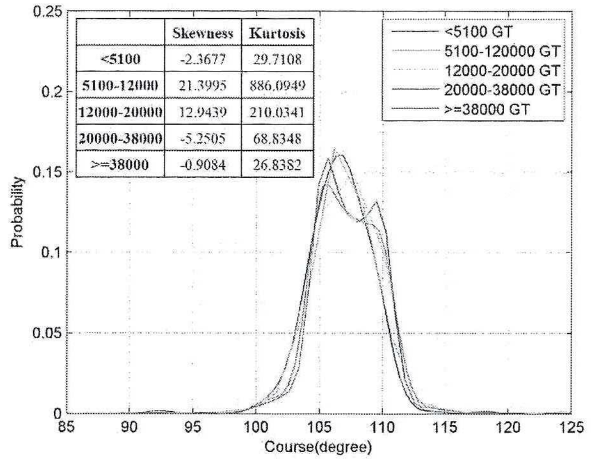
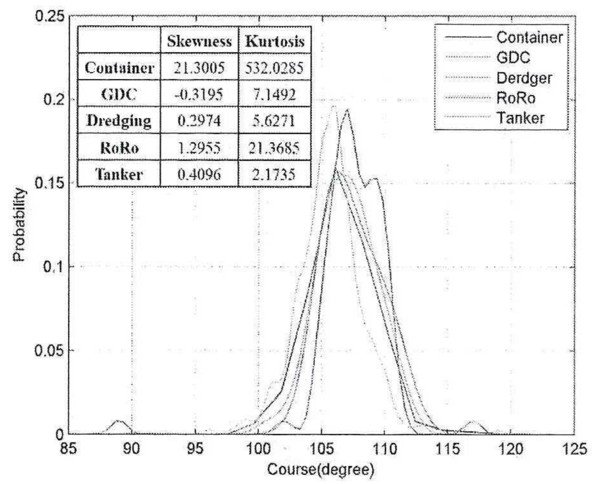


Fig. 9 Median course of container vessels as a function of waterway geometry (solid lines) and 90% confidence interval (dotted lines) in Nieuwe Maas-Sea



	Skewness	Kurtosis
<5100	-2.3677	29.7108
5100-12000	21.3995	886.0949
12000-20000	12.9439	210.0341
20000-38000	-5.2505	68.8348
>=38000	-0.9084	26.8382

Fig. 10 Comparison of vessel course of container vessels in Sea-Nieuwe Maas on cross-section 2



	Skewness	Kurtosis
Container	21.3005	532.0285
GDC	-0.3195	7.1492
Dredging	0.2974	5.6271
RoRo	1.2955	21.3685
Tanker	0.4096	2.1735

Fig. 11 Comparison of vessel course for five vessel types in Sea-Nieuwe Maas on cross-section 2

4.3 Unhindered vessel paths (question 3)

Smaller vessels usually have a smaller beam and draught, so they can sail closer to the starboard bank. Taking the centerline formed by the middle points of all cross-sections as reference, unhindered vessel path is investigated by the distance to the centerline.

In Fig. 12 it can be found that the smallest vessels keep the largest distance to the centerline and the largest vessels keep the lowest distance to centerline on all cross-sections. For other vessel categories, some curves overlap in the middle part of the figure. It might be caused by berthing vessels, which have actual influence on calculated vessels. For example, a vessel sails to the berths at the south side of the waterway. The behavior of this vessel is not included in the data base for unhindered vessel behavior. However, the influence of this vessel on other sailing vessels cannot be eliminated in the calculation. Especially for Sea-Nieuwe Maas, vessel behavior is affected by vessels arriving at and departing from the berths at the south bank of the waterway.

Compared to Sea-Nieuwe Maas, Fig. 13 shows that the path for direction Nieuwe Maas-Sea is not strongly affected by berthing vessels which makes the distance to the centerline throughout inversely proportional to vessel size. Thus, the vessel path is influenced by vessel size and waterway geometry.

Fig. 14 and Fig. 15 show the path for direction Sea-Oude Maas and Oude Maas-Sea. Due to the relatively low number of data for the larger vessel sizes, only two categories are analyzed. For Sea-Oude Maas, the distance to the centerline decreases with increasing vessel size, while for Oude Maas-Sea very little influence can be observed. The latter is probably due to the fact that vessels all keep port in anticipation of the turn to be made towards sea.

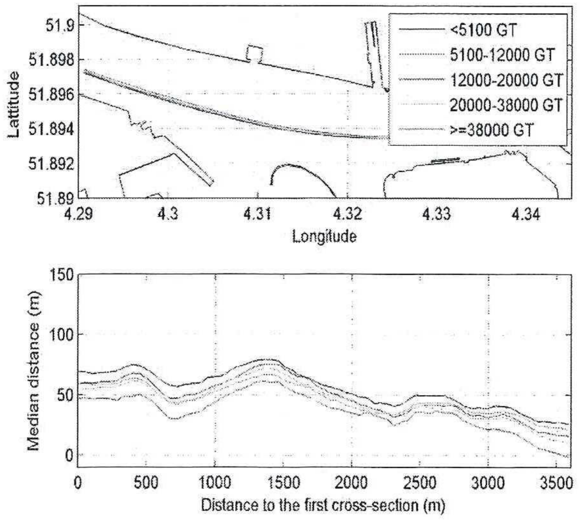


Fig. 12 Median path of container vessels as a function of waterway geometry in Sea-Nieuwe Maas

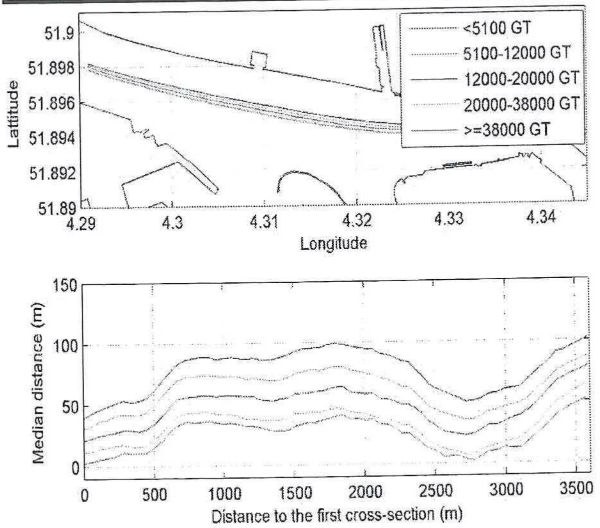


Fig. 13 Median path of container vessels as a function of waterway geometry in Nieuwe Maas-Sea

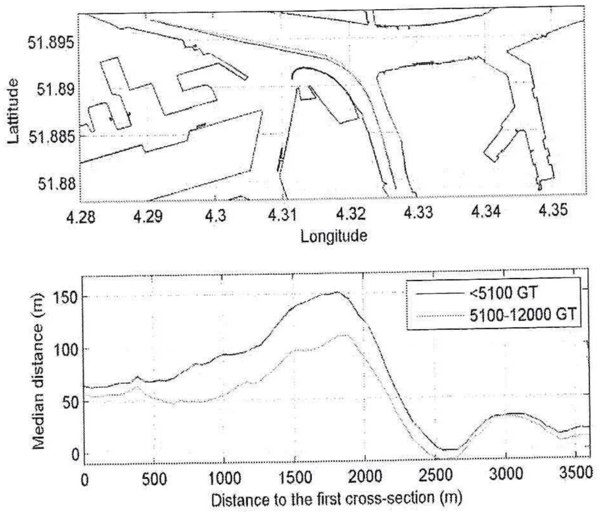


Fig. 14 Median path of container vessels as a function of waterway geometry in Sea-Oude Maas

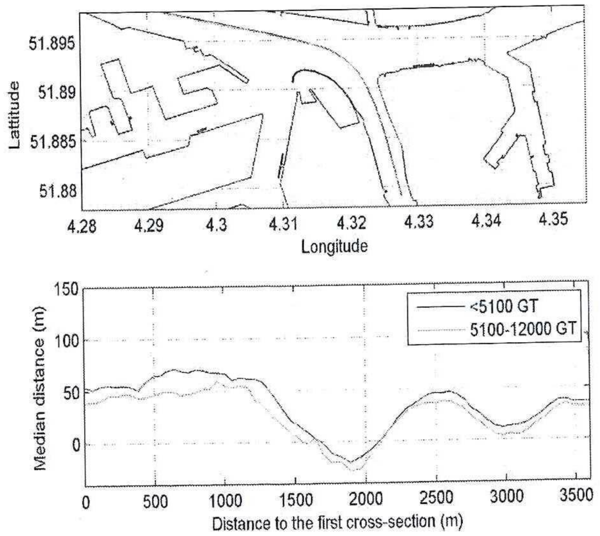


Fig. 15 Median path of container vessels as a function of waterway geometry in Oude Maas-Sea

5. INFLUENCE OF EXTERNAL FACTORS

5.1 Influence of the wind (question 4)

Wind speeds larger than 8 m/s are chosen to investigate the influence of wind to compare to unhindered vessel behavior.

Fig. 16 shows the angle distribution between vessels and wind. Most angles are between 60 and 85 degrees, which reflects the prevailing strong wind direction. Thus, we only investigate strong cross wind influence in this range.

In the remaining three figures, distributions of vessel speed, course and path under wind influence are shown. In the statistical test, mean value of speed (11.27 knots) and course (107 degrees) are accepted as same as the values from unhindered vessel behavior. However, mean value of distance to the centerline (136.93 meters) is rejected as same as the unhindered vessel behavior. It means the wind has influence on vessel path, but does not affect vessel speed and course.

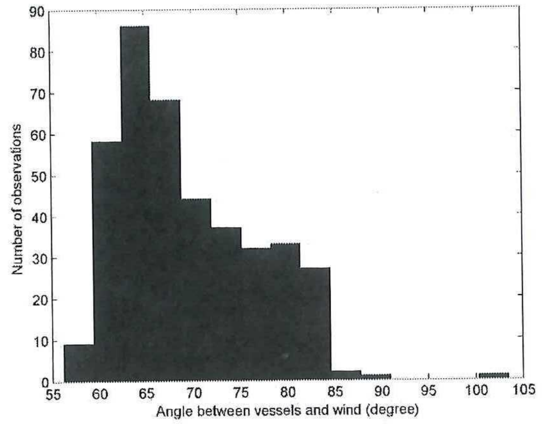


Fig. 16 The distribution of angle between vessels and wind

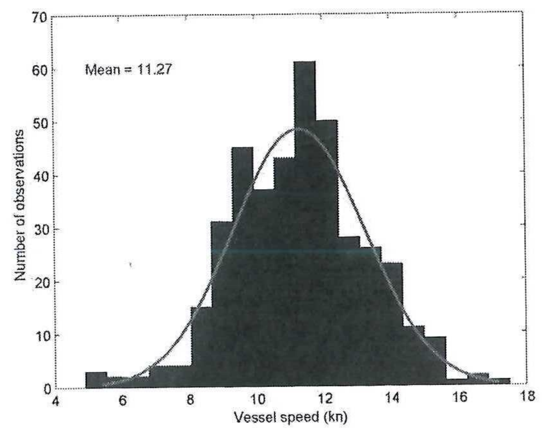


Fig. 17 The distribution and mean value of vessel speed under wind influence

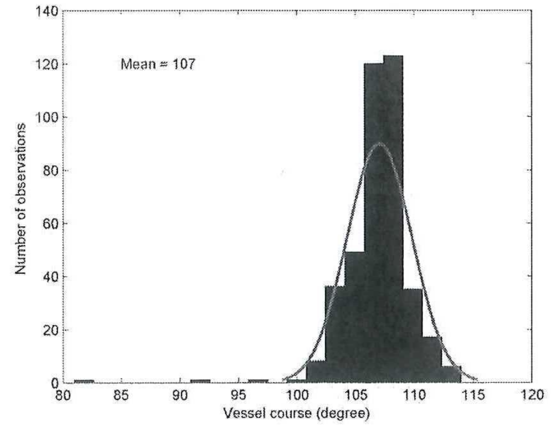


Fig. 18 The distribution and mean value of vessel course under wind influence

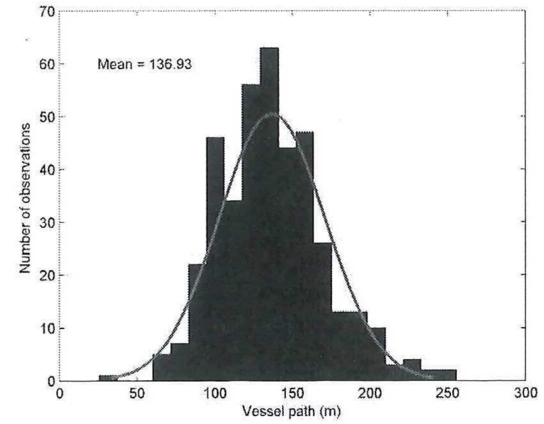


Fig. 19 The distribution and mean value of vessel distance to the centerline under wind influence

5.2 Influence of the visibility (question 5)

Using the same method as for the influence of wind, we investigated the influence of bad visibility, which is less than 2 km.

Fig. 20 shows that the mean speed (10.45 knots) is somewhat lower than the unhindered median vessel speed (11.25 knots). In Fig. 21, mean value of vessel course (107.27 degrees) is almost equal to the value of unhindered vessel behavior. The mean value of distance to the centerline (130.67 meters) shown in Fig. 22 is obviously lower than the value of unhindered vessel behavior.

In the statistical test, mean value of vessel course is considered as same as the value from unhindered. For vessel speed and vessel distance to the centerline, tests are rejected. It means vessel course is not influenced by bad visibility, but bad visibility affects vessel speed and path. It can be explained that bridge teams decrease their vessel speed when the visibility is bad, and vessels stay nearer to the bank, which they can see.

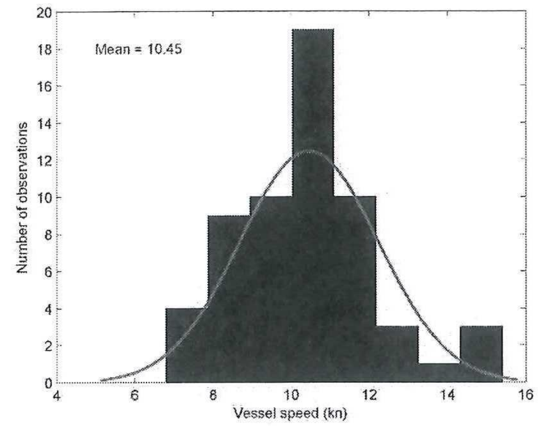


Fig. 20 The distribution and mean value of vessel speed under visibility influence

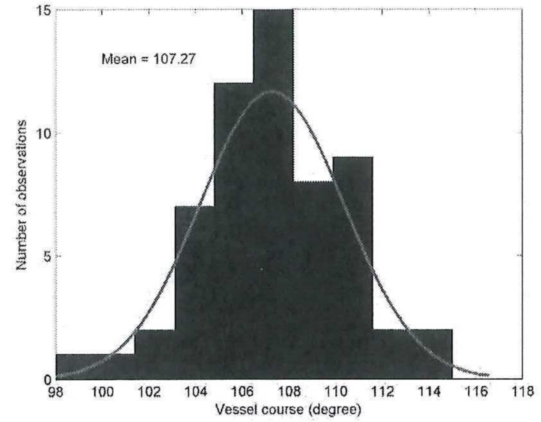


Fig. 21 The distribution and mean value of vessel course under visibility influence

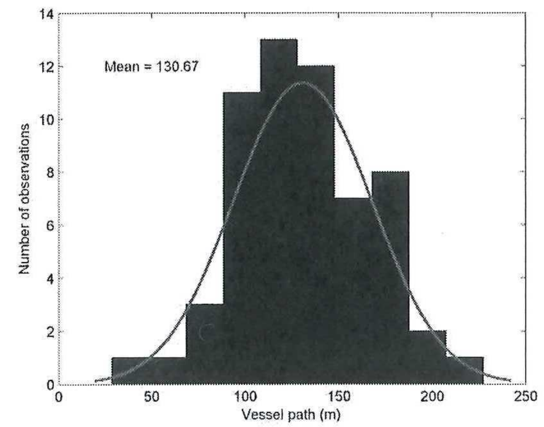


Fig. 22 The distribution and mean value of vessel distance to the centerline under visibility influence

5.3 Influence of the current (question 6)

Based on the flow simulation results from the Port of the Rotterdam, we found that the difference between the time of peak current in Sea-Nieuwe Maas and the time of peak current in south boundary in Sea-Oude Maas is 1 hour. So we use the measured data near the south boundary as the reference for current in Sea-Nieuwe Maas. Then we link the measured current data to the time instant in AIS data. In this way, we choose the periods with a current velocity larger than 0.8 m/s to investigate the influence of flood (west-east) and ebb (east-west) current on vessel behavior. We compare the value of speed, course and distance to the centerline with the unhindered vessel behavior shown in Table 1. As an example, in this paper we present current influence on the category 1 (<3600 GT) of GDC vessels in Sea-Nieuwe Maas.

Table 1. Unhindered vessel behavior with current less than 0.8 m/s

Parameters	Median value	Standard deviation
Speed (kn)	11.4	1.9
Course (degree)	106.9	4.9
Distance (m)	140.6	35.23

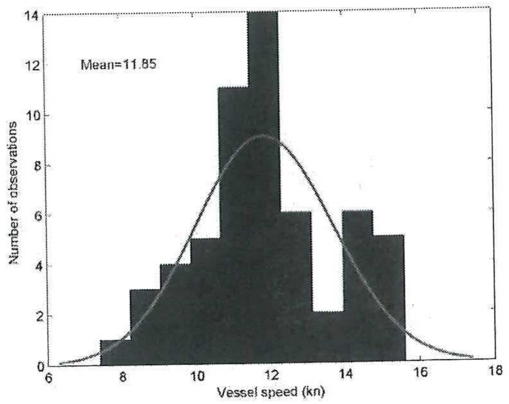


Fig. 23 Flood GDC vessel speed distribution in Sea-Nieuwe Maas

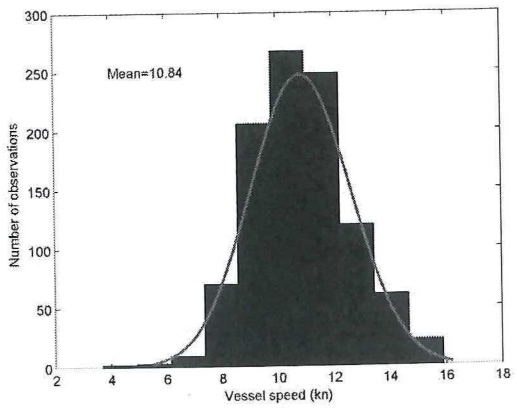


Fig. 24 Ebb GDC vessel speed distribution in Sea-Nieuwe Maas

It can be seen in Fig. 23 and Fig. 24, that the mean vessel speed increases with flood current and decreases with ebb current. Statistical tests show that flood vessels sail in same speed as unhindered vessels, however, ebb vessels speed is lower than unhindered vessels.

Fig. 25 and Fig. 26 both show that mean vessel course is equal to unhindered vessel course. Statistical test show that vessel course is not influenced by the current.

In Fig. 27 and Fig. 28, mean vessel distance to the centerline is slightly different with unhindered vessel behavior. Statistical tests show that vessel path is not affected by the current.

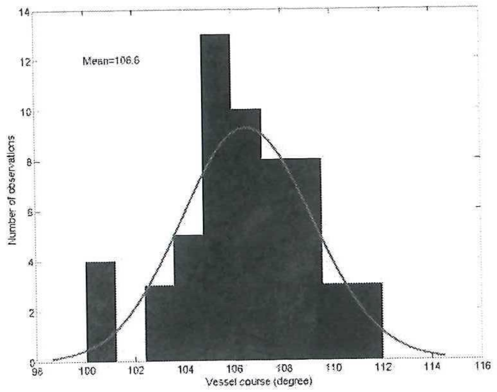


Fig. 25 Flood GDC vessel course distribution in Sea-Nieuwe Maas

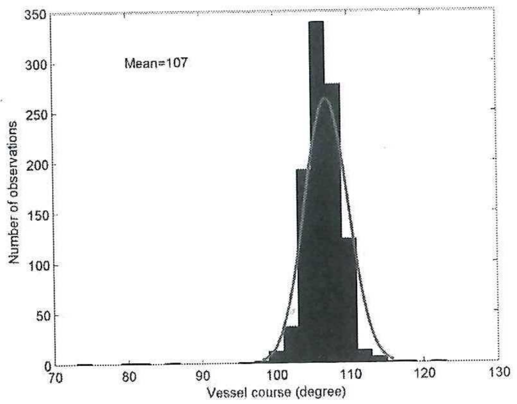


Fig. 26 Ebb GDC vessel course distribution in Sea-Nieuwe Maas

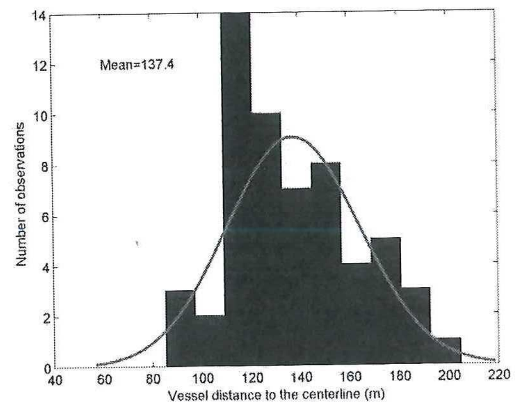


Fig. 27 Distribution of flood GDC vessels distance to the centerline in Sea-Nieuwe Maas

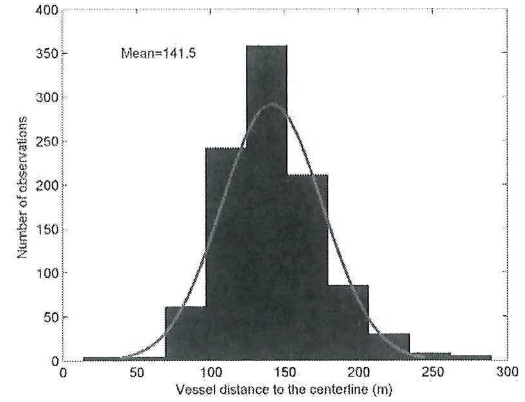


Fig. 28 Distribution of ebb GDC vessels distance to the centerline in Sea-Nieuwe Maas

The current has influence on vessel speed, but does not affect vessel course and path. Especially for vessels in strong upstream current, their speed will be effectively decreased.

6. CONCLUSIONS

This paper presents the results of AIS data analysis of unhindered vessel behavior and the influence of external factors in the Botlek area in the port of Rotterdam, the Netherlands. In this paper, vessel categories are defined based on vessel type and size. Vessel behavior is characterized by three parameters: vessel speed, course and path (distance to the waterway centerline). By analysis of these parameters of vessels under strong wind, bad visibility and strong current, the influences of these external factors are identified.

The results show indeed different vessel behavior for different vessel categories. Firstly, vessel speed is influenced by waterway geometry, navigation direction, vessel type and size. In detail, smaller vessels have larger speeds in this area, where outgoing vessels navigate with larger speed than incoming vessels. In addition, vessels in a wide waterway sail faster compared to vessels sailing in a narrow waterway. Secondly, vessel course is hardly depending on vessel size and vessel type, but it is depending on waterway geometry and navigation direction. Thirdly, vessel path is influenced by vessel type, vessel size and waterway geometry. It should be noted that smaller vessels keep a larger distance to the waterway centerline.

The influence of external factors shows that (cross) wind has effect on vessel path, but not on vessel speed and course. The visibility affects vessel speed and vessel path, implying that bridge teams decrease their vessel speed when visibility decreases, but does not influence vessel course. The current influences vessel speed and does not influence vessel course and path.

In future research, more factors influencing vessel behavior should be included, such as encounters. The analysis results should be compared with those of other port areas, with the objective of obtaining a generalized set of parameter distributions, as boundary conditions for the new maritime traffic model, and for verification and validation of this model.

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