AIS data analysis for vessel behavior during strong currents and during encounters in the Botlek area in the Port of Rotterdam

Yaqing Shu[1], Winnie Daamen[2], Han Ligteringen[3] and Serge Hoogendoorn[4]

[1] Department of Transport & Planning, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands, y.shu@tudelft.nl

[2] Department of Transport & Planning, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands, w.daamen@tudelft.nl

[3] Department of Hydraulic Engineering, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands, h.ligteringen@tudelft.nl

[4] Department of Transport & Planning, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands, s.p.hoogendoorn@tudelft.nl

Abstract—**Maritime traffic safety and capacity raise enormous attention nowadays, especially in ports and inland waterways with high traffic density and restricted waterway geometry. However, a limited number of factors is considered in existing maritime models. Especially influences of external factors (wind, visibility and current), vessel encounters and human factors on vessel behavior (speed, course and lateral position) have not been investigated. In order to provide insight into vessel behavior for the development of a new maritime traffic model, possible impacts from current and vessel encounters are investigated using Automatic Identification System (AIS) data. In this paper, equidistant cross sections approximately perpendicular to the navigation direction are used to extract vessel speed, course and position from AIS data. These vessel behavior data together with corresponding data on external conditions, including wind, visibility and current from the Port of Rotterdam, form the basic data set of this analysis. Vessel behavior under weak external influences is defined as unhindered (or reference) behavior. Vessel behavior under strong current is compared to unhindered behavior to investigate the influence of current. In addition, encounters including overtaking and head-on, are investigated to study the influence of other vessels. Statistical analysis is carried out to investigate changing of vessel speed and lateral position during encounters. Analysis results show that current only has impact on vessel speed. Both vessels involved in overtaking change their speeds and deviate in lateral direction to avoid collision. However, vessels only laterally deviate without speed changing in head-on cases.**

Keywords— AIS data; unhindered vessel behavior; current; overtaking encounter; head-on encounter

1. INTRODUCTION

Nowadays, collisions and groundings occur more often in ports and waterways, because of their high traffic density and restricted waterway geometry (Darbra and Casal, 2004). It is important to investigate the influence of external factors on vessel behavior when studying waterway safety and capacity. Maritime traffic models are typically used to assess safety and capacity. However, a limited number of factors is considered in existing maritime traffic models (Pedersen, 1995; Fowler and Sørgård, 2000). In particular, the influences of external factors (wind, visibility and current), vessel encounters and human factors on vessel behavior have not been investigated.

Harre (2000), Eriksen et al. (2006), and Aarsaether and Moan (2009) show that data from the Automatic Identification System (AIS) are very useful to investigate maritime traffic. Ristic et al. (2008) and De Boer (2010) analyze AIS data during a short time

period. Recently, a new maritime traffic model is conceived, based on the application of operations research theory (Hoogendoorn et al, 2012). In order to develop this model, which includes the impact of external factors on vessel behavior, AIS data analysis have been performed to figure out how and to what extent the external factors influence vessel behavior. This paper shows the results of these analysis. The AIS data used in the analysis are provided by the Maritime Research Institute, Netherlands (MARIN). Data of external conditions including wind, visibility and current are provided by the Port of Rotterdam. The period of AIS data is from January 2009 to April 2011. As we can see in Fig. 1, the research area is the Botlek area in the Port of Rotterdam, the Netherlands. This is an ideal area to do this research since it comprises high traffic density. Four navigation directions (Sea-Nieuwe Maas, Nieuwe Maas-Sea, Sea-Oude Maas, Oude Maas-Sea) have been investigated in the research. As an example, some results are shown in this paper. Equidistant cross sections approximately perpendicular to navigation direction are used to extract vessel speed, course and position from the AIS data set. The distance between cross sections is around 50 m.
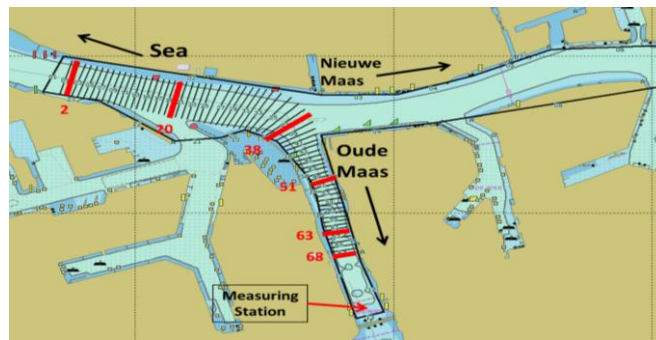

Fig. 1. Research area and selected cross sections (red) for current research

To investigate influence of current on vessel behavior, we need to connect AIS data and current, which has measured data only in measuring station. However, simulating the current for two years long period is difficult. In this research, tide (neap and spring) and river discharge are considered as the main factors influencing current. The simulation of current changes in the Port of Rotterdam during one day with extreme current conditions is carried out using Delft3D model. Some assumptions are used and described in detail in chapter 3 to extrapolate time periods of extreme current of that day to the complete research period on selected cross sections. It should be noted that current difference in lateral and vertical direction is not considered. The current velocity is taken at NAP -5 meters depth, corresponding with the recording depth at the measuring station.

In the International Regulations for Preventing Collisions at Sea 1972 (COLREGS), overtaking and head-on encounters are indicated as main encounters. Influence of overtaking and head-on encounters on vessel behavior are investigated in this paper. AIS data on each cross section are used to select these overtaking and head-on cases. Then, statistical analysis is carried out.

This work on current and encounters is a continuation of the research on vessel behavior in the same area in Shu, et al. (2012), presented in the 2012 workshop. The results of both papers provide insight into the influence of external factors on vessel behavior, which will be included in the new maritime traffic model. These analysis results can also be used for model validation and calibration. In the remainder of this paper, methodology is introduced in chapter 2. Influence of current and encounters on vessel behavior is investigated respectively in chapter 3 and chapter 4. The paper ends with findings and discussions in chapter 5.

2. METHODOLOGY

In this paper, we analyze the influence of current and encounters on vessel behavior as shown in Fig. 2. Some thresholds are used here to eliminate influence from other factors.
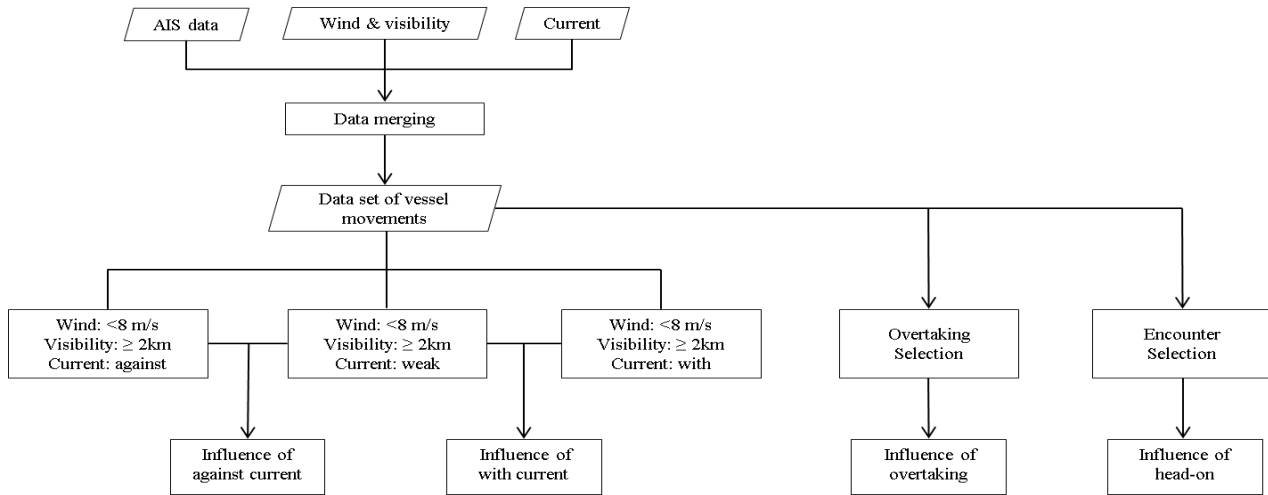
Fig. 2. Framework of data analysis

Historical current data during the research period in the measuring station are provided by the Port of Rotterdam. Distribution of current velocities in the measurement station is shown in Fig. 3. However, current varies in time and space both in longitudinal and lateral direction along the waterway. The instantaneous current in the area is influenced by the river discharge and the tidal condition. The tide in this area is semi-diurnal (one cycle has a duration of 12.4 hours) and its amplitude varies from about 0.75 m during neap tide to 1.5 m during spring tide in a period of about 7.5 days. It is not possible to simulate the currents for the entire research period (about 2 years) in such a large area. Therefore, the choice has been made to investigate the current effects for a number of typical combinations of extreme river discharge and tidal condition. The historical discharge and distribution of daily discharge in the research period and area is provided by the Port of Rotterdam. It can be found that daily discharge mostly ranges from 1000 m^3/s to 3000 m^3/s. These data come from outside the tidal influence. To get insight into the current relationship between different parts in the research area, simulation of current changing in the Port of Rotterdam during one day is carried out using Delft3D model under different conditions. Neap tide with average discharge and spring tide with average discharge are simulated. Current conditions for lower and higher river discharge have been examined, but these did not give substantially different conditions. The average discharge in the simulation model is taken at 2300 m^3/s. Simulation results show that there is a similar phase difference between the measuring point and cross sections for both neap and spring. Then, it is assumed that there is a phase difference between each cross section and measuring point.
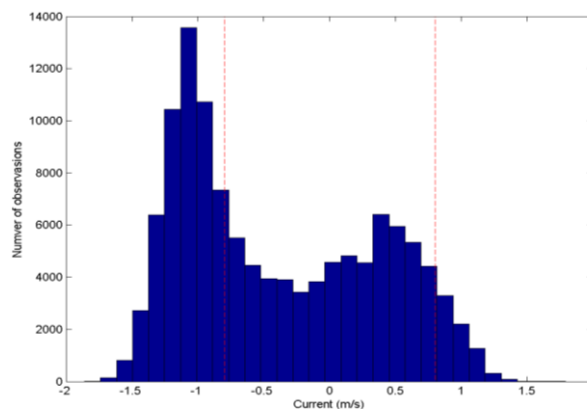

Fig. 3. Measured current distribution

In measuring point, a current speed larger than 0.8 m/s implies that vessels sail "with" the current; with a current speed smaller than -0.8 m/s vessels sail "against" the current. Current speeds between -0.8 and 0.8 m/s are considered as weak currents, which are assumed not to influence vessel behavior. Based on phase difference and current for measuring point in research period, we calculate time periods of "Against current", "With current" and "Unhindered" on Cross sections 2, 20, 38, 51, 63 and 68 in Sea-Oude Maas (read lines in Fig. 1). These cross sections uniformly distribute along the waterway. Then, we connect AIS data with these time periods to classify vessel behavior into groups of "Against current", "With current" and "Unhindered". By comparison of vessel behavior between these groups on these cross sections, the influence of current on vessel behavior is investigated.

Overtaking and head-on encounters are investigated in this paper. To eliminate the influence of bend geometry of the waterway, we study encounters only in Sea-Nieuwe Maas and Nieuwe Maas-Sea, where the waterway is approximately straight. For overtaking encounters, overtaking and overtaken vessels sail in the same direction. Their behavior is selected from a data set based on the moment they pass adjacent cross sections. For example, vessel A passes cross section *n* later than vessel B and it passes the next cross section *n+1* earlier than vessel B. Then, vessel A overtakes vessel B. Vessel speed and lateral position for both overtaking and overtaken vessels are investigated. In head-on encounters, two vessels sail in different directions. Similar to overtaking encounters, these vessels are selected from the data set according to the moment they pass adjacent cross sections. For vessel A sailing in Sea-Nieuwe Maas, it passes adjacent cross sections *n* and *n+1*. If vessel B appears between cross sections during this period, then, a head-on encounter occurs. Based on the definition above, 146 and 106 overtaking encounters occur respectively in Sea-Nieuwe Maas and in Nieuwe Maas-Sea. Furthermore, 2544 head-on encounters between sea and Nieuwe Maas are investigated. For these encounters, vessel behavior, such as speed changing and path deviation, are investigated.

3. INFLUENCE OF CURRENT

In this chapter, the influence of current on vessel speed (over ground), course and path is investigated. As an example, results of small GDC vessels (< 3600 gross tonnage) are shown in this section. Based on the approach described in chapter 2, vessels are classified in groups of 'Unhindered', 'Against current' and 'With current'.
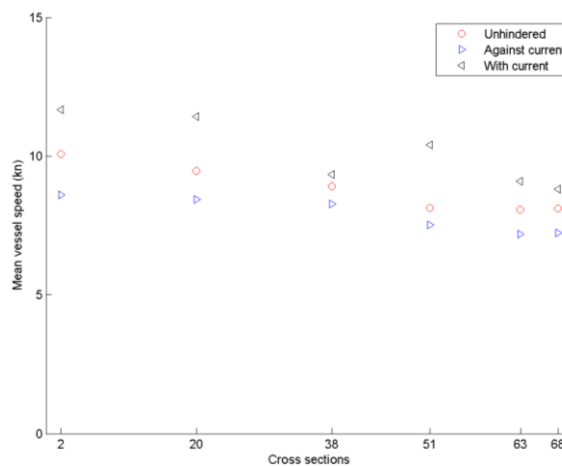

Fig. 4. Vessel speed as a function of current condition on Sea-Oude Maas

A. Speed

In Fig. 4, it can be seen that unhindered mean vessel speed is different at different cross sections. It means that vessel speed is influenced by the waterway geometry. Vessel speed in a wide waterway (Cross section 2 and 20) is larger than vessel speed in a narrow waterway (Cross section 51, 63 and 68). On Cross section 38 (bend), speed difference between "With current" and

"Unhindered" is very small. It can be explained that vessels decrease their speed in the bend area when sail with strong current. Generally, vessel speed of "With current" is higher than the unhindered vessel speed and vessel speed of "Against current" is lower than unhindered vessel speed for all these six cross sections, which is as expected.

Table 1 shows the statistical analysis results, when applying the t-test to test whether the difference between unhindered and hindered vessel speed is significant. "-" means there are not enough data (10 observations) in that case. It can be seen that in all cases of "Against current", vessel speed is rejected as equal to unhindered vessel speed. For cases of "With current", equal vessel speed is rejected as well, except "With current" on the Cross section 38 (shadowed), where is the middle part of the bend waterway. It can be concluded that vessel speed is influenced by current, with the exception of the bend area where bridge teams reduce the speed extra for safety reasons.

TABLE 1.   MEAN VESSEL SPEED COMPARISON BETWEEN UNHINDERED AND HINDERED

Cross sections		2	20	38	51	63	68
Unhindered	Speed (kn)	10.08	9.46	8.91	8.14	8.08	8.12
Against current	Speed (kn)	8.61	8.44	8.28	7.53	7.2	7.23
	H	1	1	1	1	1	1
	P-value	0	0	0	0	0	0
With current	Speed (kn)	11.66	11.44	9.34	-	-	-
	H	1	1	0	-	-	-
	P-value	0	0	0.24	-	-	-

B. Course

In Fig. 5, it can be seen that the differences of mean vessel course between "Unhindered", "Against current" and "With current" are very small. T-tests show that in most cases vessel course is not significantly different compared to unhindered course, except "Against current" on Cross section 51 with a P-value 0.04 (close to acceptance value of 0.05). It means that vessel course is not influenced by current.
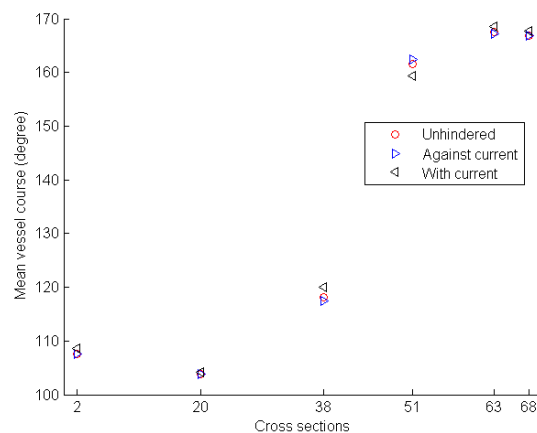

Fig. 5. Vessel course as a function of current condition in Sea-Oude Maas

C. position

Fig. 6 shows mean vessel position (distance to the starboard bank) for "Unhindered", "Against current" and "With current" on six cross sections. The differences seem small for all cases. In the t-tests, vessel lateral position is accepted as equal to unhindered vessel position for all cases. It means that vessel path is not influenced by current.
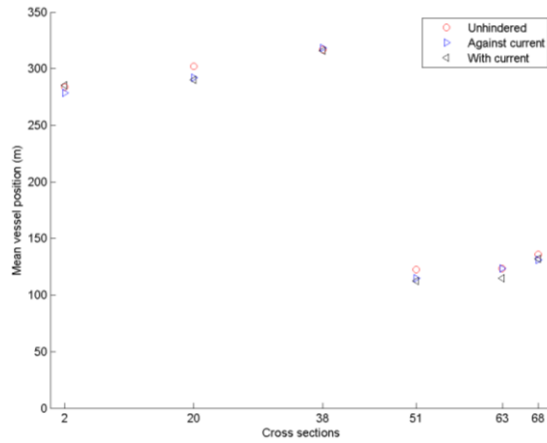
Fig. 6. Vessel position as a function of current condition in Sea-Oude Maas

It can be concluded that current has influence on vessel speed, but not on vessel course and path. In detail, "With current" and "Against current" respectively increase and decrease vessel speed and bridge teams reduce the speed extra for safety reasons.

4. INFLUENCE OF ENCOUNTERS

This chapter shows results of influence of both overtaking and head-on encounters on vessel behavior.

A. Overtaking encounters

In this section, 146 and 106 overtaking encounters are investigated respectively in Sea-Nieuwe Maas and in Nieuwe Maas-Sea. To get enough encounters, vessel type and size are not considered in this chapter, nor the next chapter. Then, 'Cross section 0' is the cross-section nearest to the Closest Point of Approach (CPA). We define negative ids (-1, -2, …) for cross sections before the overtaking takes place and positive ids (1, 2, …) for cross sections after the actual overtaking. The analysis results for vessel speed and lateral position are shown in Fig. 7 and Fig. 8. Fig. 7 (a) and Fig. 7 (b) show vessel speed changing for overtaking and overtaken vessels in both Sea-Nieuwe Maas and Nieuwe Maas-Sea. It can be seen that overtaking vessels increase their speed before overtaking and decrease their speed after overtaking. Overtaken vessels do exactly the opposite. The difference of vessel speed in Fig. 7 (c) and Fig. 7 (d) shows that relative speed is increased before Cross section 3, which means the overtaking and overtaken vessels still increase and decrease their speed, respectively, between Cross section 0 and Cross section 3. All these behaviors can decrease the overtaking duration. In Fig. 7 (e) and Fig. 7 (f), the distribution of relative speed on Cross section 0 is shown. The average relative speed when they overtake is around 4.4 kn.
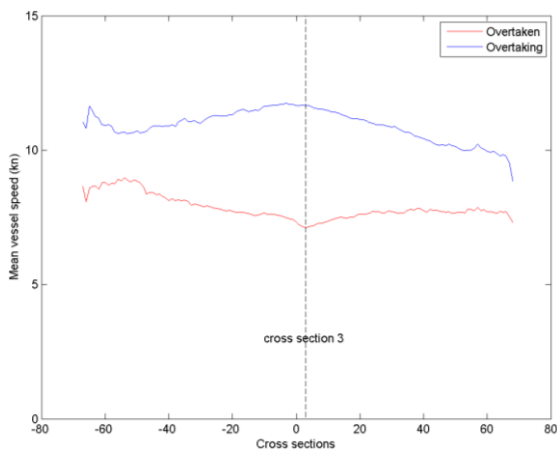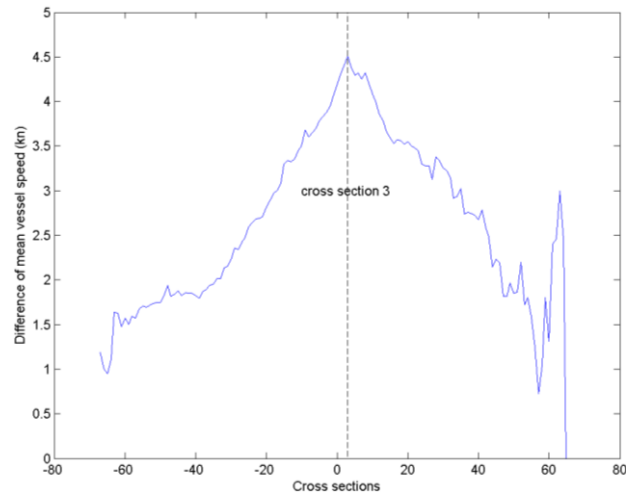

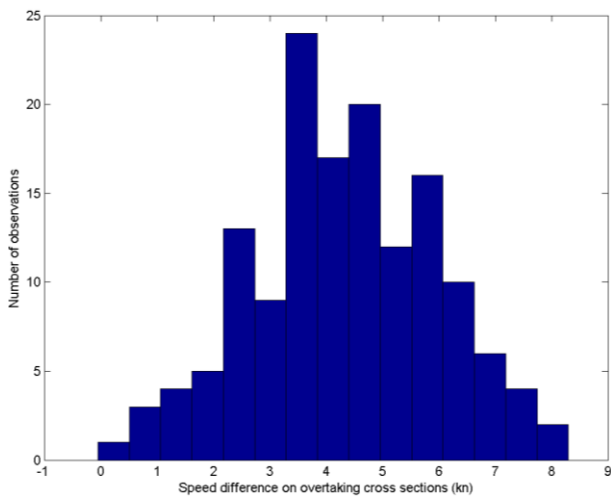a. Vessel speed changing in Sea-Nieuwe Maas
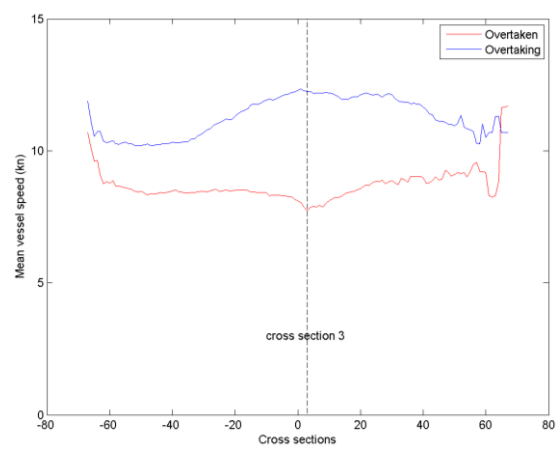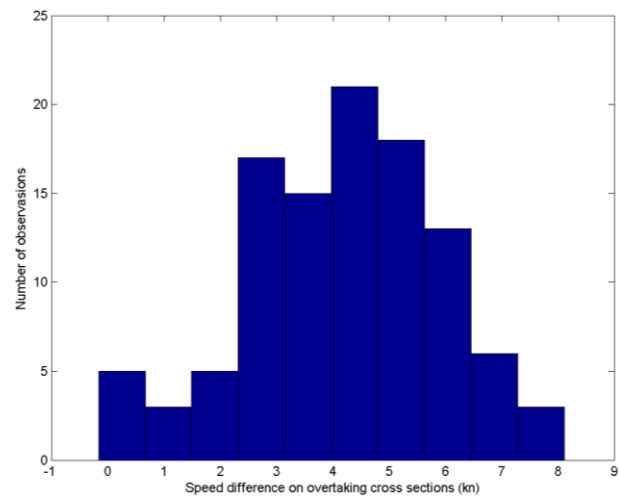

b. Vessel speed changing in Nieuwe Maas-Sea
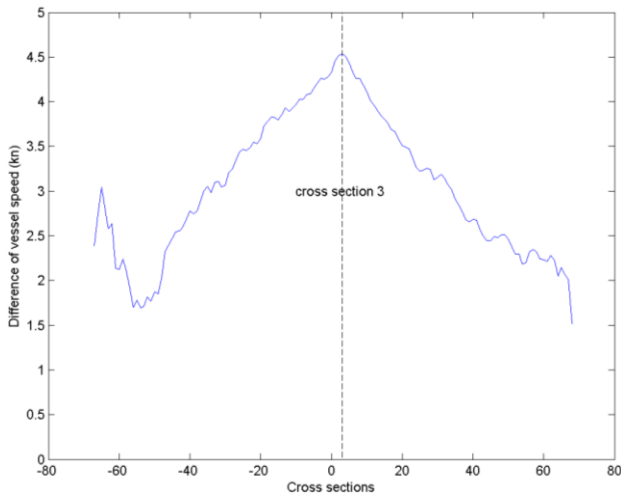
c. Difference of vessel speed in Sea-Nieuwe Maas

d. Difference of vessel speed in Nieuwe Maas-Sea

e. Distribution of speed difference in Sea-Nieuwe Maas
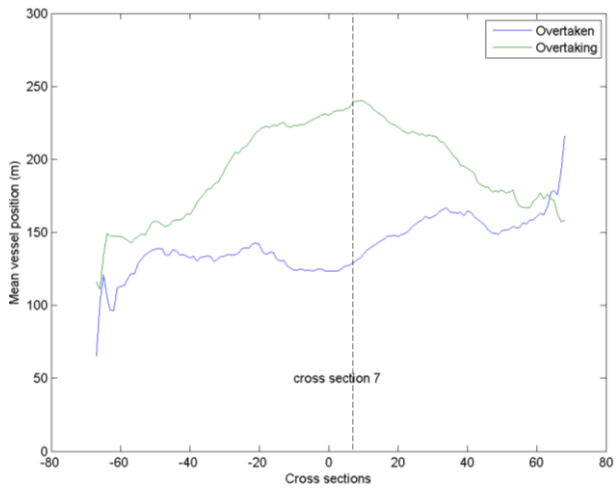

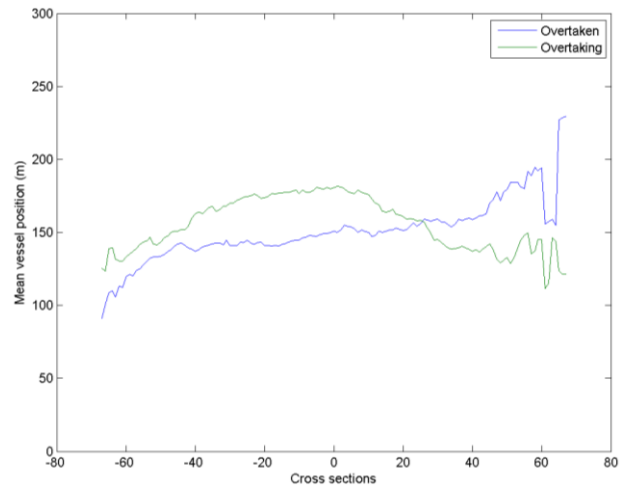f. Distribution of speed difference in Nieuwe Maas-Sea

Fig. 7. Vessel speed for overtaking in Sea-Nieuwe Maas and Nieuwe Maas-Sea

In Fig. 8 (a), it can be seen that vessel lateral distance to the starboard bank is increased before overtaking and decreased after overtaking. Both overtaking and overtaken vessels deviate from their planned path to keep a large lateral distance when they overtake each other. These are also shown in Fig. 8 (c), which is the changing of lateral distance between both vessels. The lateral distance has the maximum value on the Cross section 7, which is around 350 m far from the overtaking position. This can be explained by following reasons. The speed of the overtaking vessels is quite fast and keeps increasing until Cross section 3 after overtaking, meanwhile the overtaken vessels keep decrease its speed, as demonstrated previously. In order to reduce the risk of collision, bridge teams therefore may decide to further increase the lateral distance after overtaking due to inertial operation and safety consideration. Fig. 8 (e) shows the distribution of lateral distance in Sea-Nieuwe Maas, which normally ranges from 50 m to 200 m. The average lateral distance is 116 m. Even though the average lateral distance in Fig. 8 (f) has similar value as the value in Fig. 8 (e), one third of the vessels overtake other vessel on the right side in Nieuwe Maas-Sea in Fig. 8 (f). These results show that the overtaking can be carried out at either side of the vessel considering the safety of both vessels. Large portion of overtaking is from left side of overtaken vessels in Sea-Nieuwe Maas. This may due to berths in the starboard bank.
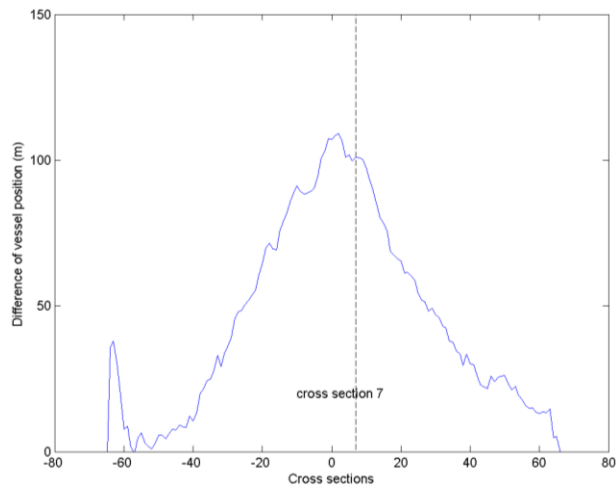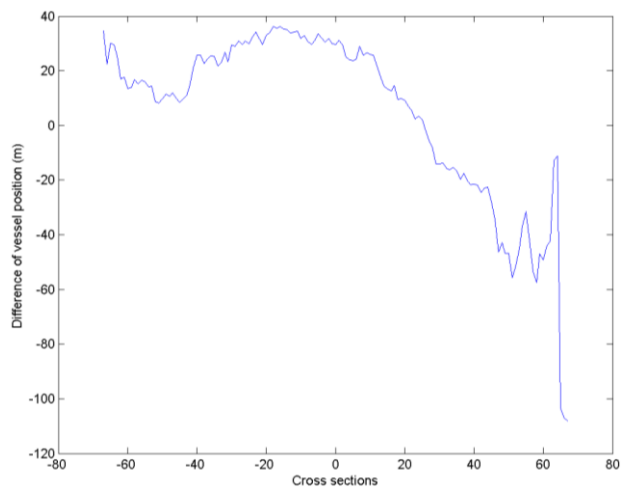
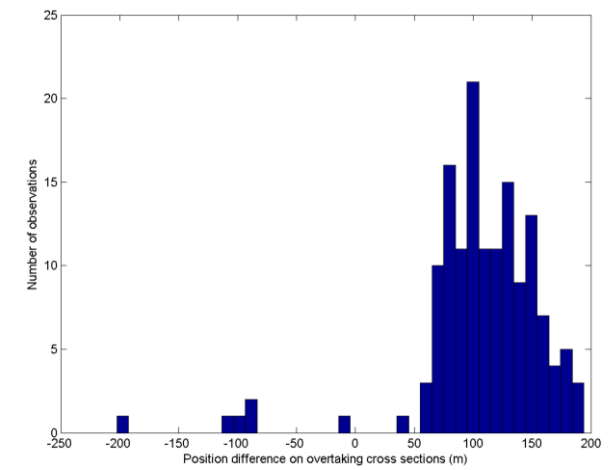a. Vessel position changing in Sea-Nieuwe Maas

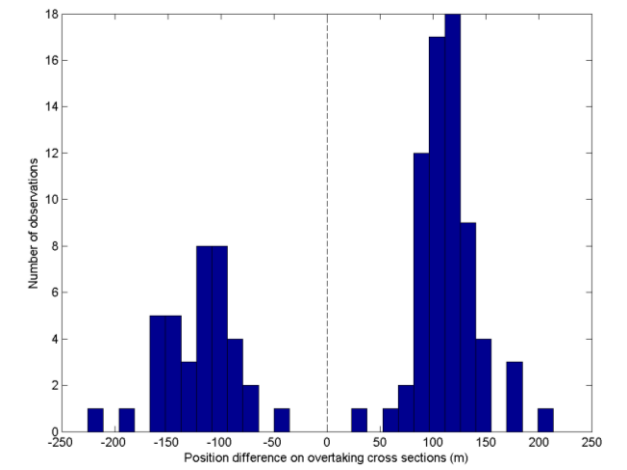b. Vessel position changing in Nieuwe Maas-Sea

c. Difference of lateral position in Sea-Nieuwe Maas

d. Difference of lateral position in Nieuwe Maas-Sea

e. Distribution of lateral position difference in Sea-Nieuwe Maas

f. Distribution of lateral position difference in Nieuwe Maas-Sea

Fig. 8. Vessel lateral position for overtaking vessels in both Sea-Nieuwe Maas and Nieuwe Maas-Sea

B. Head-on encounters

In this section, 2544 head-on encounters between Sea and Nieuwe Maas are investigated. For head-on cases, we investigate vessel speed and lateral position in a similar way as for overtaking encounters. In Fig. 9, it can be seen in the left figure that vessel speed has upward trend in Sea-Nieuwe Maas and downward trend in Nieuwe Maas-Sea, which means vessel speed is influenced by waterway geometry. However, mean vessel speed is slightly decreased on cross section 0 for both vessels. Relative vessel speed in the right figure shows this clearly. Fig. 10 shows difference of lateral position before and after encounters, as well as its distribution on the pertaining cross sections. In the left figure, it can be found that the distance to the bank for both vessels are decreased before encounters and increased after encounters. It means vessels deviate to keep a larger lateral distance during head-on encounters. The maximum lateral distance is achieved on Cross section 0. The right figure shows the distribution of lateral distance on Cross section 0. The mean value on Cross section 0 is 150.9 m.
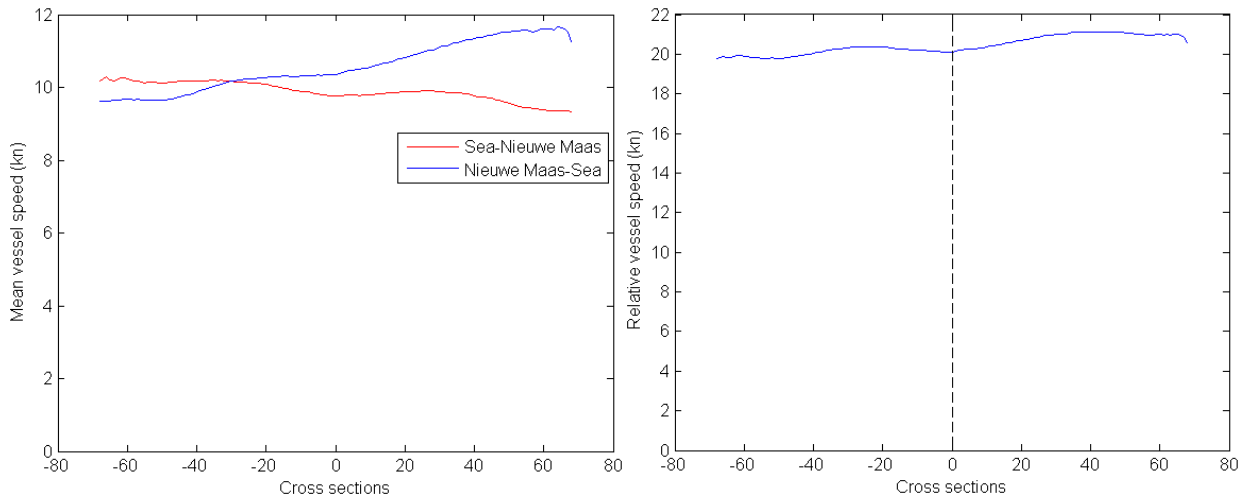
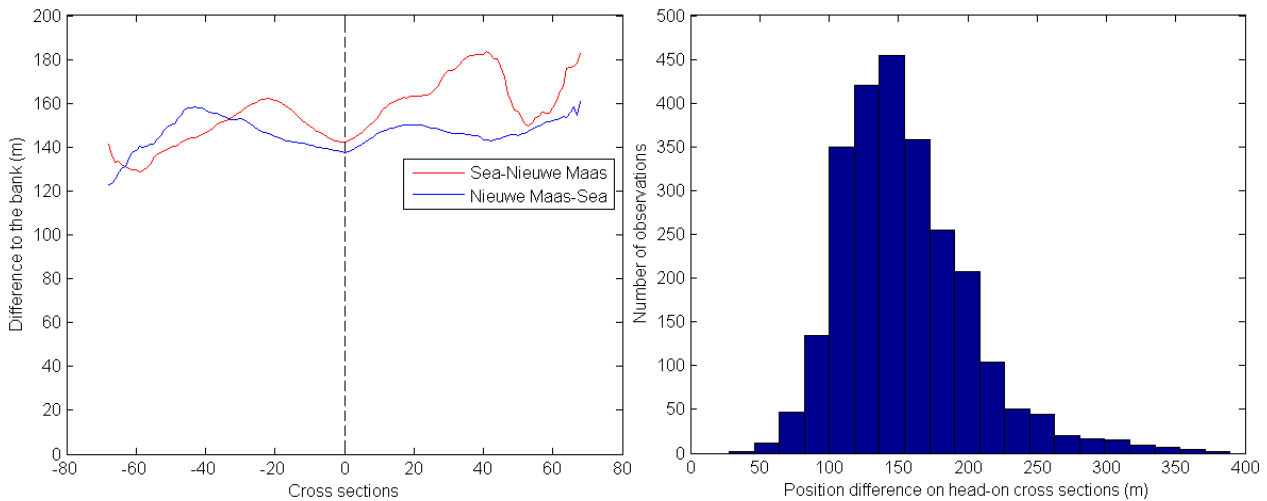

Fig. 9. Vessel speed and relative speed for head-on cases

Fig. 10. Difference of lateral position and its distribution on head-on cross section

5. FINDINGS AND DISCUSSION

This paper presents an AIS data analysis on the influence of currents and encounters on vessel behavior in the Port of Rotterdam, the Netherlands. It is shown that current influences vessel speed. In the cases of "Against current" and "With current", vessel speed is respectively decreased and increased compared to unhindered vessels. Overtaking vessels increase their speed before the

overtaking and decrease their speed after overtaking. Overtaken vessels do the opposite. Both overtaking and overtaken vessels deviate from their planned path during encounters. Head-on sailing vessels slightly change their speed during the encounter. They deviate from their planned path to keep larger lateral distance between each other during encounters. For both overtaking and head-on encounter, vessel course is influenced because of deviation from the planned path.

A limited number of factors is investigated in this paper. However, more factors that could affect vessel behavior will be considered in future research, such as human error and the presence of tugs. For the influence of current, an approximate value of current speed is defined based on the phase differences obtained from simulation models. With respect to encounters, vessel size and type have not been considered yet. The findings of this paper can be further used to build the new maritime traffic model and enhance maritime traffic safety and capacity. The analysis results should be compared with 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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