Maritime traffic safety and port capacity is increasingly important nowadays. Due to the fast development of maritime 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 a 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 worldwide trade with more than 50,000 merchant vessels as indicated in Dovol (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 the influence of external factors on vessel behavior as in Sutulo and Moreira (2002) and Sariz and Narli (2003), others investigated the models calculating the maritime traffic safety index, such as Pedersen (1995), Fowler and Sangrd (2006), 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 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.

## 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 Harat-Molcho 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 analyze 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 Hoyle (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:

1. Which factors influence the speed of an unhindered vessel?
2. Which factors influence the course of an unhindered vessel?
3. Which factors influence the path of an unhindered vessel?
4. Does wind influence vessel speed, course and path?
5. Does visibility influence vessel speed, course and path?
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 wind, visibility and current. This way, we can investigate the influence of external factors on vessel behavior by adding these elements to the vessel behavior with opposite thresholds individually. When wind is less than 8 m/s, we set wind as less than 8 m/s in wind, visibility and current. When wind is less than 8 m/s, we set wind as less than 8 m/s in wind, visibility and current. Then, we add wind to the vessel behavior with opposite thresholds individually. When wind is less than 8 m/s, we set wind as less than 8 m/s in wind, visibility and current. Then, we add wind to the vessel behavior with opposite thresholds individually. Finally, further recommendations are given.

Sutulo and Moreira (2002) and Sariz and Narli (2003), others investigated the models calculating the maritime traffic safety index, such as Pedersen (1995), Fowler and Sangrd (2006), 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 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.
cross-sections are used to extract vessel behavior from raw AIS data in ShowRoute, which is dedicated to investigating 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 the most data from the most recent years. In addition, more vessels have installed AIS in the research area compared to previous years. Although we already have more data, the data set depends on the size of the Access file, which should be less than 2G and will get slower when this file gets larger.

The research area is shown in Fig. 1. The Oude 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 maneuvering patterns. 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 criteria 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 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.

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 dependent, so the influence of the current is investigated independently in the section 5. In this section, the influence of vessel type and size
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.

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 '5100-12000 GT' from different vessel types on cross-section 2. According to the skewness and kurtosis, vessel course does not depend on vessel size.

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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.
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. 17 The distribution and mean value of vessel speed 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.
In this way, we choose the periods with a current velocity larger than 0.8 m/s to investigate the current on vessel behavior. We compare the value of influence of flood (west-east) and ebb (east-west) on the category 1 (<3600 GT) of GDC vessels in example, in this paper we present current influence than 0.8 m/s

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

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Median value</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (kn)</td>
<td>14.4</td>
<td>1.9</td>
</tr>
<tr>
<td>Course (degree)</td>
<td>106.9</td>
<td>4.9</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>140.6</td>
<td>35.23</td>
</tr>
</tbody>
</table>

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.

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 influence on vessel speed, but not on vessel course and speed. 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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REFERENCES


