11th International Seminar on Inland Waterways and Waterborne Transportation

Brasília/DF, 22th to 24th October 2019

Detecting Possible Near Miss Collisions in Santos Bay from AIS Big Data

Ramiro Fernandes Ramos, UFRJ/COPPE, Rio de Janeiro/Brasil, ramirofr@oceanica.ufrj.br
Maricruz A. Fun Sang Cepeda, UFRJ/COPPE, Rio de Janeiro/Brasil, maricruzcepeda@oceanica.ufrj.br
João Vitor Marques de Oliveira Moita, UFRJ/COPPE, Rio de Janeiro/Brazil, joaov@oceanica.ufrj.br
Gabriel Premoli Monteiro, UFRJ, Rio de Janeiro/Brazil, gabriel_premolimonteiro@poli.ufrj.br
Olav Fiksdahlb, NTNU, Norwegian University of Science and Technology, Trondheim/Norway, olavfi@stud.ntnu.no
Jean-David Caprace, UFRJ/COPPE, Rio de Janeiro/Brasil, jdcaprace@oceanica.ufrj.br

Abstract

The Santos Bay, located in Brazil, holds the largest and busiest container port in Latin America. Many cargo ships pass through this Bay every day and its safety are subject of many researches. Using the Automatic Identification System (AIS) messages sent by those ships it is possible to detect possible near miss collisions events. This study develops an analytical approach to identify the most common cargo ship types involved in near miss collisions in Santos Bay (Brazil) using AIS database. It will also identify the most common type of vessel conflict in this area. The model is applied to rank the severity of an encounter between two vessels based on vessel conflict ranking operator (VCRO). The vessel size and the minimum distance to collision (MDTC) concept are considered in the model. The results show that the proposed methodology is adequate to identify various statistics in near miss collisions. Containers ship is the most common type of cargo ship involved on those situations and the crossing conflict occurs with higher frequency. Understanding the parameters involved in near miss collision around areas of high maritime traffic is important to avoid accidents. For the future, comparisons of data between different areas are suggested.

1. Introduction

Maritime transportation is crucial to the world's economy. Also, it is important for the development of many countries. In 2017, the maritime transportation was responsible for more than 80% of the global trade between all other transportation modes. As well, cargo ships are the most common type of ship, approximately 90% of the world fleet being cargo ships, (UNCTAD, 2017).

Accidents involving ships occasionally occur in the world. The most common types are grounding, collisions and fires (Guedes Soares & Teixeira, 2001). Since the ship itself and the cargo have a high value and there are human lives in risk in those accidents, it is very important to study the conditions that generate those accidents. With the results of those observations it is possible to improve the navigation safety.

Focusing on the accidents involving two or more ships, it can take place in every route where two ships cross each other. The port areas have a highest traffic of ships, so the observation of accidents in those areas has even more importance. Also, passengers' ships are very present on port areas, which increases even more the interest of improving safety in this matter.

Santos Port, located in Santos Bay, is the main Brazilian port and the biggest on the Latin America. It has a high diversity of products and services, including dry bulk, liquid bulk, containers, general cargo and passengers. Even having different types of ships for different purposes, cargos ships are the main type navigating in Santos Bay.

In 2018, there were more than 750 accidents involving navigation in Brazil and 185 people died by reason of those accidents. The accidents statistics in Brazil are divided by Naval Districts (DN). The eighth DN is formed by the state of São Paulo (where the Santos Port is located) and the state of Paraná. Moreover, most part of deaths occurred by those navigation accidents took place in the eighth DN, being 43 deaths in this DN, (DPC, 2019).

For preventing accidents, ships have the Automatic Identification System (AIS). AIS is a mandatory automatic tracking system used on ships and by Vessel Traffic Services (VTS) for identifying and locating vessels by electronically exchanging data with other nearby vessels throughout the world. AIS system required to be installed on ships by the International Maritime Organization (IMO) and the Maritime Safety Administration in several countries, (IMO, 2003).

Since the AIS send messages automatically, the frequency of messages is very high. An AIS receiver in a port area, where there is a high traffic of ships, can receive more than 100 thousand of messages per day. If this receiver tries to store all those messages or if it tries to compare messages of different periods, it will quickly escalate to a problem of Big Data.

As Big Data is a popular subject in the last 15 years, there are many studies using AIS data with Big Data approaches to extract knowledge from those data. For instance, (Zhou, et al., 2019) use AIS data to identify patterns of routes classifying them by the length and beam of the ship. Also, (Cepeda, et al., 2018) use the AIS data to estimate ship emissions for the Port of Rio de Janeiro. As well, (Cepeda, et al., 2017) use the AIS as input for a simulation of offshore platforms.

The near miss collision is a way to identify ships that are close enough that is possible that an accident occurs. In most part of those events, the accident does not occur. Still, the studies on the detection of the near miss collision make possible the improvement of safety. Studies on this subject started recently with (Debnath & Chin, 2010). The near miss collisions studies in the literature are mostly located in Europe and Asia, creating opportunities for studies in other areas such as South America.

In the previous paper (Cepeda, et al., 2018), the AIS data was used to estimate possible near miss collisions in the area of Rio de Janeiro port. It analyzed different types of ships and comparing them by size. The authors developed a model to rank the severity of an encounter between two vessels based on vessel conflict ranking operator (VCRO). The concept of minimum distance to collision (MDTC) was also considered on the model.

This present paper continues the last work, now applying the methodology in the Santos port area and focus only on cargo ships present on this area.

This first section is a general introduction on the subject. The second section explains the data and the methodology used for this search. The third section brings the results from the search. And finally, a conclusion is presented.

2. Data and Methodology

In this paper, AIS data is used to develop an analytical approach to estimate possible near miss ship collisions. In this section, the data and the methodology applied on this data are presented.

2.1 Data

The Automatic Identification System (AIS) is a mandatory collision avoidance system required to be installed on ships by the IMO and the Maritime Safety Administration in several countries. The AIS system makes it possible to locate most vessels throughout the world.

International voyaging ships with a Gross Tonnage (GT) of 300 or more, passenger ships of all sizes, domestic vessels with a GT of 200 or more traveling in coastal waters, and inland ships with a GT of 100 or more, are all required to be equipped with AIS. Special purpose vessels such as military ships, fishery ships, sports ships, and public service ships are exceptions, (Chen, et al., 2018), and (IMO, 2003).

The reported AIS data can be divided into static, dynamic, and voyage-related data categories. Static information includes ship name, ship type, length, breadth, etc. Dynamic data includes ship speed over ground, navigational status (operating mode), heading, rate of turn, position, etc. Voyage-related data includes current draught, description of cargo, and destination, (IMO, 2003). Besides ship information reported by AIS, detailed data for ship type, ship size, date of construction, design speed, gross tonnage and power of the engines can be obtained from the other databases as Marine traffic or IHS Maritime, see Figure 1.

The database used on this paper is the data originating from the AIS messages generate by ships passing by on the region of Santos Bay and Rio de Janeiro Bay. Since the AIS messages gives the longitude and latitude position of the antenna, it is easy to identify ships on the Santos Bay area.

This database contained data from the period of January 2018 to April 2018 and from the period of August 2018 to April 2019. Those two periods together give a ten months database.

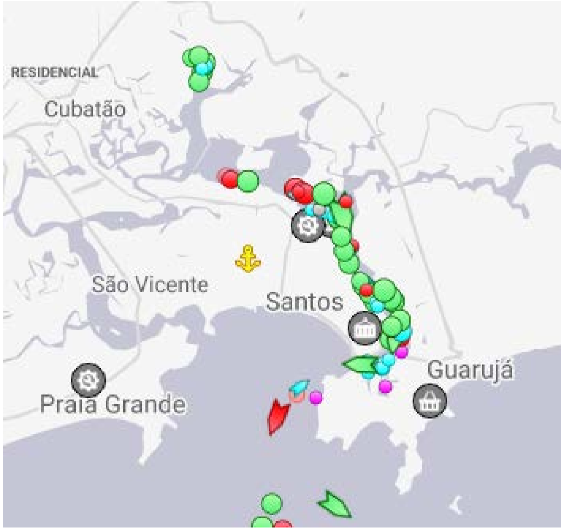

Figure 1 – View of Santos Bay with AIS data, source: Marine Traffic 082019

Furthermore, in this paper we will analyze only the near miss collisions involving cargo ships. This filtering is done after finding all near miss collision on the area. Because there can be cargo ships colliding with non-cargo ships, thus it is not possible to eliminate the messages coming from non-cargo ships before the analyses of near miss collision. Also, since the ship types provide directly by AIS is not enough precise, the ships types were taken from IHS (IHS Markit) database.

2.2 Model

The model used in this paper is the same model used in the previously work made in the Guanabara Bay by (Cepeda, et al., 2018).

The model and risk analysis are based on possible near miss collisions. Such methods aim to identify of areas of high accident risk. The AIS data enable investigation of the spatial and temporal relationship between two vessels, (Wu, et al., 2016). This study proposes the identification and the evaluation of the risk areas.

The VCRO is constructed using a mathematical model based on the generic characteristics of ship–ship encounters. Based on the expert interviews, following factors are included in the model, (Zhang, et al., 2015).

(a) The distance between the two ships. (*b)* The rate of change of the distance in the course of the encounter, determined by the relative speed of the two ships. *(c)* The relative orientation of the two ships, determined by the difference between their headings.

In this study, theoretically, the distance at time between two vessels can be calculated as the Equation(1) based on Euclidian Distance.

$$D_{ij}^t = \sqrt{\left(x_i^t - x_j^t\right)^2 + \left(y_i^t - y_j^t\right)^2} \tag{1}$$

The invasion of ellipse is calculated by the Equation(2).

$$\frac{\left(\left(x_i^t - x_j^t\right) * \cos\alpha_i^t + \left(y_i^t - y_j^t\right) * \sin\alpha_i^t\right)^2}{(1.6 * L_i)^2} + \frac{\left(\left(x_i^t - x_j^t\right) * \sin\alpha_i^t - \left(y_i^t - y_j^t\right) * \cos\alpha_i^t\right)^2}{(4 * L_i)^2} \leq 1 \tag{2}$$

The approach presented in this paper to estimate the vessel collision risk based on AIS data is based on the domain theory presented by (Weng, et al., 2014) and (Weng , et al., 2012) proposed. At first, the relative speed of vessel i over vessel j denoted as $\left|\vec{v}_{ij}^t\right|$ can be determined according to Equation(3), (Wu, et al., 2016).

$$\left|\vec{v}_{ij}^t\right| = \sqrt{\begin{matrix}\left(\left|\vec{v}_i^t\right| \cos\alpha_i^t - \left|\vec{v}_j^t\right| \cos\alpha_j^t\right)^2 \\ + \\ \left(\left|\vec{v}_j^t\right| \sin\alpha_i^t - \left|\vec{v}_j^t\right| \sin\alpha_j^t\right)^2\end{matrix}} \tag{3}$$

And then the relative angle from $\vec{v}_i^t$ to $\vec{v}_i^t$ is in Equation(4) .

$$\theta_{ij}^t = \cos^{-1}\left[1 - \frac{\left(\frac{\left|\vec{v}_i^t\right| \sin\alpha_i^t - \left|\vec{v}_j^t\right| \sin\alpha_j^t}{\left|\vec{v}_{ij}^t\right|} - \frac{x_j^t - x_i^t}{D_{ij}^t}\right)^2 + \left(\frac{\left|\vec{v}_i^t\right| \cos\alpha_i^t - \left|\vec{v}_j^t\right| \cos\alpha_j^t}{\left|\vec{v}_{ij}^t\right|} - \frac{y_j^t - y_i^t}{D_{ij}^t}\right)^2}{2}\right] \tag{4}$$

Then the following criteria can be used to categorize the type of vessel conflict:

- **Overtaking conflict** if $\sin\alpha_i^t * \sin\alpha_j^t > 0\ and\ \left(\theta_{ij}^t \leq 10°\ or\ \theta_{ij}^t \geq 170°\right)$
- **Head-on conflict** if $\sin\alpha_i^t * \sin\alpha_j^t < 0\ and\ \left(\theta_{ij}^t \leq 10°\ or\ \theta_{ij}^t \geq 170°\right)$
- **Crossing conflict** if $\theta_{ij}^t > 10°\ and\ \theta_{ij}^t < 170°$

Where α_i^t and α_j^t are courses of vessels i and j at time t, respectively, and θ_{ij}^t is the relative angle at time t. If one vessel is already within the domain of another at time t, a vessel conflict does happen.

The above rules can be also applied to elliptical domains.

Figure 2 shows these two types of domains. It also demonstrates the speed, course, and domain of vessel. It seems that elliptical domains focus more on conflicts between vessels which share similar or opposite courses, (Min Mou, et al., 2010).

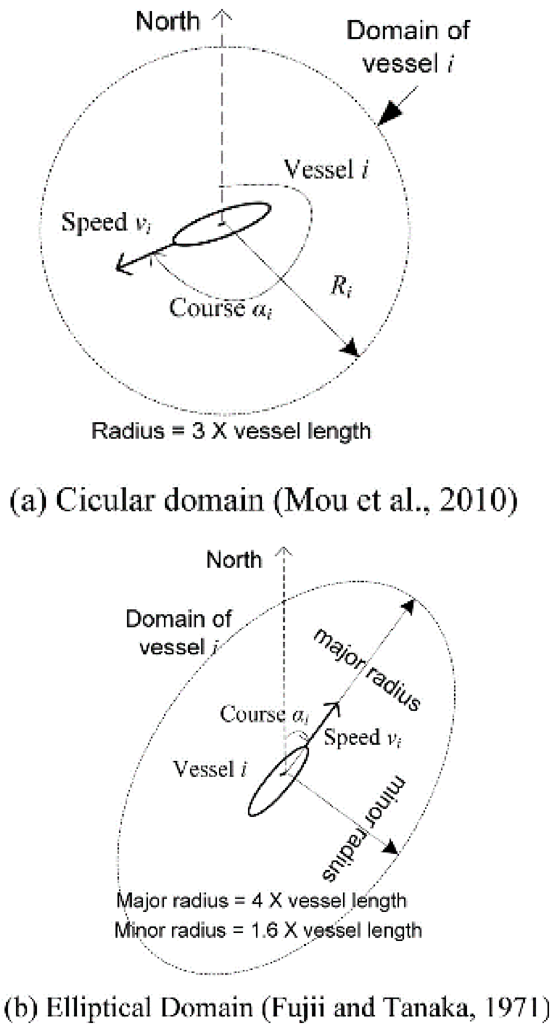

Figure 2 - Demonstration of a vessel's domain, *(Wu, et al., 2016)*.

2.3 Data Filtering

This paper aims to find situations of near miss collisions for cargo ship. Since for each collision there are two ships involved, a filtering in the data needs to be done for eliminate situations where two non-cargo ships are in situation of near miss collision. Each instance of near miss collision in the database stores MMSI code, type of ship and other information for both ships (Ship1 and Ship2) involved in the near miss collision. It is important to reemphasis that two distinct situations can happen: a cargo ship is near colliding with a non-cargo ship or cargo shipping near colliding with another cargo ship.

In addition, there are lots of types of cargo ships described in AIS. For better understand the results, it is recommended to group certain types of cargo ships in a same type, instead of having lots of different types.

As well as the AIS does not give all the information for every message. Sometimes, the type of the ship is not declared (or declared as NULL) or even the type of ship described is too general for classing. To solve this last problem, another database was also consulted to verify if the ship type given by AIS was the true type. This other database is called IHS (IHS Markit).

First step to start filtering is selecting only near miss collisions presented in Santos Bay area. As mentioned, the database contains information about Santos Bay and Rio de Janeiro Bay. Each instance of near miss collision in Rio de Janeiro Bay is excluded.

Second step is eliminating Tug and Pilot boats. Considering that those types of ship are made for contact with another ship, it will be often in a near miss collision situation. So, if an instance of near miss collision that has a tug or pilot as the Ship1 or as the Ship2, this instance is excluded.

After those two steps, it is important to define which ship types are included on the analysis. With this purpose, all the ship types remaining at this point were observed. They are listed in Table 1.

The table separates the types in 3 different categories. The first is the cargo ship types that are well defined. The second is cargo ship types that are not well defined or types that can be cargo or not, and need to be verified with IHS. The third is ship types that are not cargo.

Table 1 – List of ship types involved on near miss collisions

Cargo Ships	Possible Cargo or not	Non-cargo Ships
Bulk Carrier	Cargo Hazard A	Fishing
Chemical Tanker	Cargo Hazard A (major)	Hopper Barge
Container ship	Inland Unknown	Hopper Dredger
Crude Oil Tanker	NULL	Military Ops
Fruit Juice Tanker	Other	Offshore Supply Ship
General Cargo	Unspecified	Passenger Ship
LPG Tanker		Research Vessel
Oil Products Tanker		Research/Survey Vessel
Oil/Chemical Tanker		Sailing Vessel
Ro-Ro Cargo		Tanker Barge
Ro-Ro/Container Carrier		Work Vessel
Tanker		
Vehicles Carrier		

Next step is verifying in IHS database, what it mentions about the ships that are not well defined

or not specified enough. For that, every ship in this list of types is compared using its MMSI code. Doing this is possible to see that for the type 'Cargo Hazard A', the IHS database gives the same answer. So, this type is not changed.
For the type 'Cargo Hazard A (major)', it is noted that is actually 'Container Ship (Fully Cellular)' according to IHS database. Thus, all ships with this type are changed for the new type.
Also, some 'Inland Unknown', 'NULL', 'Other' and 'Unspecified' are Tug ship according to IHS. In those cases, the instance of near miss collision containing a ship that is a Tug ship was excluded. The others 'Inland Unknown', 'NULL', 'Other' and 'Unspecified' that are not Tug, are varied types in the corresponding IHS database.
Still, some ships that have the 'NULL' type are not able to find in IHS database. Those ships are probably not listed with an IMO number. Since the instances of near miss collisions involving them are less than 5% of the total number of near miss collisions and that those ships could be Tug ships, it was chosen to exclude all instances that remain with the type of Ship1 or Ship2 as 'NULL'.
After this comparison with IHS data, five new types were added. It is possible to see that the five new types are types that already exist, only with different names. They are:

- Chemical/Products Tanker
- Container Ship (Fully Cellular)
- Crude/ Oil Products Tanker
- General Cargo Ship
- Products Tanker

A total of 27 types of ships were left after this comparison, between cargo and non-cargo ship types. As mentioned, for better comprehension of the results, the types will be put together in few common types. Those common types were chosen based on the number of collisions of each type (considering its relevance for the analysis). The six resulting types chosen, as well as the correspondence with previous types are shown on Table 2.

Table 2 – Correspondence between AIS/IHS ship types and chosen types

Ship Type	Classification
Bulk Carrier	Bulk Carrier
Container ship	Container
Container Ship (Fully Cellular)	Container
General Cargo	General Cargo
General Cargo Ship	General Cargo
Chemical/Products Tanker	Tanker
Chemical Tanker	Tanker
Crude Oil Tanker	Tanker
Crude/Oil Products	Tanker
Oil Products Tanker	Tanker
Oil/Chemical Tanker	Tanker
Products Tanker	Tanker
Tanker	Tanker
Cargo Hazard A	Other Cargo
Fruit Juice Tanker	Other Cargo
LPG Tanker	Other Cargo
Ro-Ro Cargo	Other Cargo
Ro-Ro/Container Carrier	Other Cargo
Vehicles Carrier	Other Cargo
Hopper Barge	Non-Cargo
Hopper Dredger	Non-Cargo
Offshore Supply Ship	Non-Cargo
Passenger Ship	Non-Cargo
Research Vessel	Non-Cargo
Tanker Barge	Non-Cargo
Fishing	Non-Cargo
Sailing Vessel	Non-Cargo

3. Results

This section presents the results from using the data described in section 2.1 as input data on the model described in section 2.2 and after applying the filtering presented in section 2.3. The results only consider data from Santos Bay and for the period of ten months mentioned on section 2.1.
A first result interesting to analyze is the difference between the number of near miss collisions considering the Tug and Pilot ships (all AIS data), the number of near miss collisions after excluding the instances that contains Tug and Pilot ships, and the number of near miss collisions considering only instances involving cargo ships. This result is presented in Table 3.

Table 3 – Number of near miss collisions in different phases of the analysis

Situation	# of Near-miss Colisions
All AIS data	16517
Without Tug and Pilot	1814
Cargo Ship involved	1344

As expected, the number of near miss collisions is drastically reduced when filtering Tug and Pilot ships. Tug and Pilot ships represent approximately 90% of all near miss collisions. That endorses the fact that those types of ships are constantly in a near miss collision situation given its main purpose. And that is why it is a good choice to exclude those instances.
When comparing the two last results from Table 3, it is possible to see that most part of near miss collisions involves Cargo ships. Almost 75% of near miss collisions are involving cargo ships. This result shows the importance of cargo ships for the area studied. As mentioned, most part of ships in Santos

Bay are cargo ships. Also, since cargo ships tends to be bigger than the other types of ships, it is understandable, following the model of the section 2.2, that they have a bigger Elliptical Domain and are more susceptible to suffer near miss collision situation.

Table 4 – Number and percentage of collisions per ship type

Type of Ship	Collisions	Percentage
Bulk	520	39%
Container	781	58%
General Cargo	102	8%
Tanker	329	24%
Other Cargo	106	8%
Non-Cargo	527	39%

The next result to be presented is the number of collisions per type of cargo ships. This result shows which types of cargo ships are currently more involved in near miss collision situation. Table 4 brings the numbers and Figure 3 represents the percentages.

In this result is important to emphasize that, since there are two ships in each collision (Ship1 and Ship2), it is normal that the sum of all percentage is more than 100% and less than 200%. It is more than 100% because both type of Ship1 and type of Ship2 is counted for each single instance, and that also explain the maximum value of 200%. But it is less than 200% since there are some instances of near miss collision where type of Ship1 and type of Ship2 is the same, so in this case is only counted as one collision for the ships type.

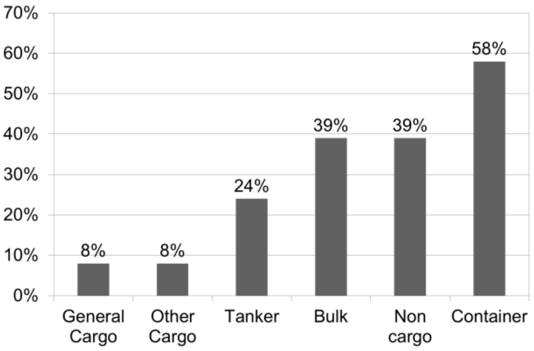

Figure 3 - Percentage of near miss collisions for each type of ship

As it can be seen in Figure 3, container ship is the most common type of ship involved in near miss collisions. It shows that in more than half of instances studied a container ship is presented. Thus, it can be observed that container ship is the most common type of cargo ship on this area and probably the most relevant cargo ship.

Another observation that can be made by this result is that non-cargo ships are highly involved on near miss collisions with cargo ships. It is an also understandable conclusion, since there a lot of ship types there are aggregated in Non-Cargo type. Thus, it will be many cargo ships in a situation of near miss collision with non-cargo ships.

Table 5 – Number of near miss collision per type of collision and per ship type

Type of Ship	Crossing	Overtaking	Head-on
Bulk	509 (98%)	5 (1%)	6 (1%)
Container	757 (97%)	12 (2%)	12 (2%)
General Cargo	100 (98%)	2 (2%)	0 (0%)
Tanker	309 (94%)	14 (4%)	6 (2%)
Other Cargo	104 (98%)	1 (1%)	1 (1%)
Non-cargo	512 (97%)	11 (2%)	4 (1%)

The other types follow the same logic, been Bulk ships more often in Santos Bay than Tankers and so on.

Last result to be presented is the number of types of near miss collisions, Crossing, Overtaking or Head-on as described in section 2.2. In that way it is possible to see which type of near miss collisions should be avoided at most, see Figure 4.

Table 5 brings the number of collisions in each type of collision divided by ship types, and the percentage of the type of collision for each type of ship.

It is clear to see that for all near miss collisions, independent of the ship type, the Crossing type of collision is the most common, being the collision type of at least 94% of collisions for every ship type. The other two collision types are rare and occur on maximum of 5% of collisions.

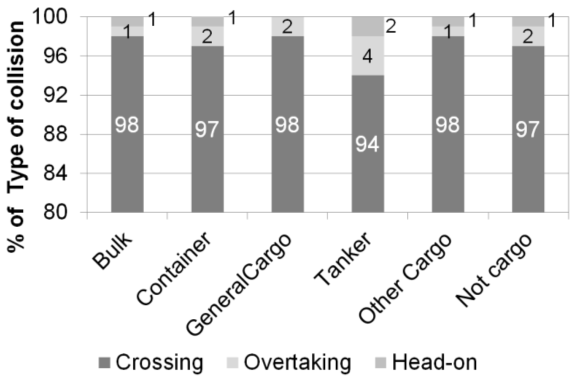

Figure 4 - Percentage of Collision Type for each ship type

This is the main information retrieved from this result. Since it does not depend on ship type, it is better to analyze it for all type of ships together, see Figure 5.

As it can be seen, 97% of all near miss collisions involving cargo ships are a crossing type collision. This result is evident if observed with the geography of Santos Bay, illustrated in Figure 1. Santos Bay has a tight channel that is the access to the Santos Port. Most of ships goes through this channel to access the port and goes out also by this channel.

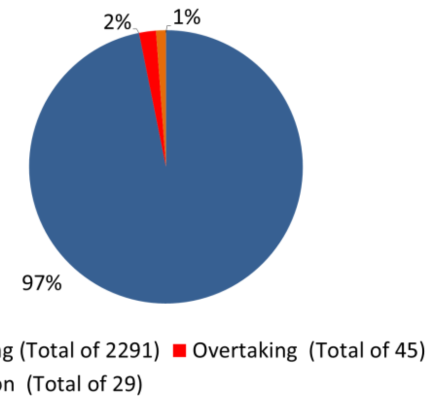

Figure 5 - Percentage of Collision Type for all ship types summed

Since the channel is narrow, it is deduced that few routes are possible to make. And the inner routes are probably very similar to outer routes, only changing the sense. In that case, it will be common that ships going to the port cross with ships leaving the port. And if this cross situation is close enough to characterize a near miss collision situation, it will be a crossing type.

4. Conclusions

The focus of the study is the identification of near miss collision for cargo ship in the Santos Bay for 10 months (January 2018 to April 2018 and August 2018 to April 2019).

After analyzing the results, some conclusions can be made. First is that the cargo ships are very important for Santos Port, but as well are very susceptible to near miss collisions situations, since almost 75% of collisions involve a cargo ship.

Seeing the six different ship types described by this paper is possible to determine that container ship is the most relevant, because more than half of near miss collision situations involve a container ship.

And the last analysis shows that the type of collision is independent of the ship type. The crossing type of collision is the most common for every ship type, representing 97% of all collisions.

These results can aid navigation authorities to better understand what causes incidents on the Santos Bay and it also can be used by the local pilots to improve their routes.

The quality of the database provided AIS is still to be improved. There are some missing values and values that are not always accurate. For instance the ship type is not always present or accurate. That turns more difficult to make analyses using the type of the ship. The ideal is to compare with another more reliable database, like IHS, and choose the most accurate result.

For future researches on the area, would be interesting to compare those results with other region to see if there is a correlation. Also, would be interesting to see if the geography of the port has indeed a major influence on the type of collision as concluded in Santos Bay.

In an operational perspective, the obtained results could be used to create an onboard system to alert ships about the most common near miss collision situations for the specific region where it is passing by. This system could also be used by port administrations to improve the logistic and avoid the near miss collision situations.

5. Acknowledgements

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

The present work was realized with the support of CNPq, Conselho Nacional de Desenvolvimento Científico e Tecnológico – Brasil.

6. References

Cepeda, M. A. F. et al., 2017. *Big Data Analysis of AIS Records to Provide Knowledge for Offshore Logistic Simulation.* Cardiff, COMPIT, pp. 279-289.

Cepeda, M. F. S., Monteiro, G. P., Moita, J. V. M. d. O. & Caprace, J.-D., 2018. *Estimating possible near miss collisions based on AIS big data for Port of Rio de Janeiro.* Rio de Janeiro, SOBENA.

Cepeda, M. F. S., Monteiro, G. P., Moita, J. V. M. d. O. & Caprace, J.-D., 2018. *Estimating Ship Emissions Based on AIS Big Data for the Port of Rio de Janeiro.* Pavone, COMPIT.

Chen, D. et al., 2018. Contribution of ship emissions to the concentration of PM2.5: A comprehensive study using AIS data andWRF/Chemmodel in Bohai Rim Region, China. *Science of the Total Environment,* p. 1476–1486.

Debnath, A. K. & Chin, H. C., 2010. Navigational Traffic Conflict Technique: A Proactive Approach to Quantitative Measurement of Collision Risks in Port Waters. *The Journal of Navigation,* Volume 63, pp. 137-152.

DPC, D. d. P. e. C., 2019. *Inquérito Administrativos sobre Acidentes e Fatos da Navegação (IAFNs),* s.l.: s.n.

Guedes Soares, C. & Teixeira, A. P., 2001. Risk assessment in maritime transportation. *Reliability Engineering & System Safety,* December, 74(3), pp. 299-309.

IMO, 2003. *Guidelines for the Installation of a Shipborne Automatic Identification System (AIS),* London: IMO.

Min Mou, J., van der Tak, C. & Ligteringen, H., 2010. Study on collision avoidance in busy waterways by using AIS data. *Ocean Engineering*, April, 37(5-6), pp. 483-490.

UNCTAD, 2017. *Review of Maritime Transport.* Geneva: UNITED NATIONS.

Weng , J., Meng, Q. & Qu, X., 2012. Vessel Collision Frequency Estimation in the Singapore Strait. *The Journal of Navigation,* April, 65(2), pp. 207-221.

Weng, J., Meng, Q. & Li, S., 2014. *Quantitative risk assessment model for ship collisions in the Singapore Strait.* Washington, DC, s.n.

Wu, X., Mehta, A. L., Zaloom, V. A. & Craig, B. N., 2016. Analysis of waterway transportation in Southeast Texas waterway based on AIS data. *Ocean Engineering,* July, Volume 121, pp. 196-209.

Zhang, W., Goerlandt, F., Montewa, J. & Kujala, P., 2015. A method for detecting possible near miss ship collisions from AIS data. *Ocean Engineering,* Volume 107, pp. 60-69.

Zhou, Y., Daamen, W., Vellinga, T. & Hoogen, S. P., 2019. Ship classification based on ship behavior clustering from AIS data. *Ocean Engineering,* 1 March, Volume 175, pp. 176-187.