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MAPPING MARINE TRAFFIC DENSITY BY USING AIS DATA: AN APPLICATION IN THE NORTHERN AEGEAN SEA

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ABSTRACT

Automatic Identification System (AIS) data is used for monitoring the movements of vessels live movements through instant transmission of vessel information while, at the same time, historical AIS data is used for marine traffic analysis by researchers. There are several methods and computer programs developed for the analysis of marine traffic by the use of AIS data.
Combining the intersection algorithm proposed by Antonio (1992) and distance calculation method, this study develops a method to analyse vessel distribution on a selected cross sectional line (SCS) in the Northern Aegean Sea. As a complementary to the new methods proposed, a desktop application is developed in C# programming language to visualize the vessel distribution on the SCS line. SQL server is used for AIS data storage and analysis. The study is conducted over 7-day AIS data, specifically 2.382.469 rows and 42.884.442 data in total, belonging to the Northern Aegean Sea marine traffic. As a result, the mapping of the movements of different types of vessels in the Northern Aegean Sea is effectively performed and Frequency-Distance, Draught-Distance, SOG-Distance, SOG-COG distributions on the SCS line are successfully analysed by the new method introduced.

Keywords: Automatic Identification System; Marine Traffic; Marine Traffic Analysis

INTRODUCTION

The AIS is developed as a tool that allows for the instant monitoring of ships, as well as the analysis of marine traffic by using historical data gathered through these devices. It is possible to map the marine traffic density [26,19,27], calculate the probability of collision and/or grounding [10,6,18,14], carry out the analysis of marine traffic and reveal the intense areas [13,17,1,12] by means of the AIS data.

The AIS devices operate as demonstrated in Figure 1. These devices transmit and receive data through Very High Frequency (VHF) radio frequency and their range varies according to the shape of the earth, the islands and mountains in the vicinity and wave propagation [5,23]. The exchange of data can be ship-to-ship, ship-to-shore station and shore station-to-ship. Such data exchange allows for the monitoring and control of the marine traffic [22] which consequently enhances the safety of navigation.

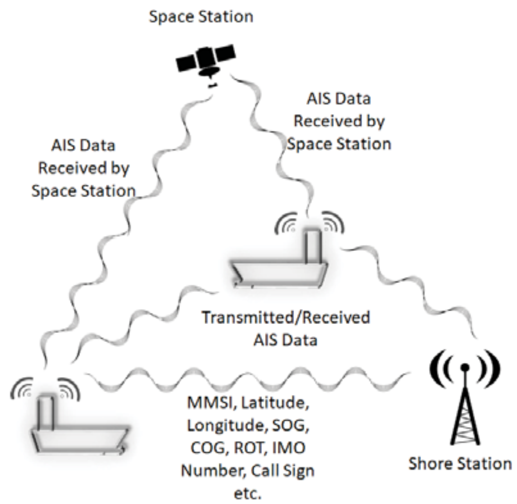


Fig. 1. The Working Principle of the AIS (Developed from [25])

There are basically two types of AIS devices on vessels which are Class A and Class B [23]. Class A AIS devices are used on all ships over 300 GRT engaged on international voyage and passenger ships irrespective of size, while Class B AIS devices are used on small ships such as the ones that operate in the fishing industry and pleasure crafts [15,16]. AIS devices can also be used as an aid to navigation on buoys, lighthouses and additionally it is exploited as a virtual navigation aid, to mark dangerous navigation zones such as shipwrecks and shallow waters [20].

AIS devices transmit static, dynamic and navigation data appropriately [9] and use time division multiple access (TDMA) which eliminates the risk of overlapping of signals transmitted [4]. There are also Self-Organizing (SOTDMA), Random Access (RATDMA), Incremental (ITDMA) and Fixed Access (FATDMA) protocols for the proper operation of the system. Thus, a random time slot is allocated to the AIS device at the beginning, and the next signal transmission time slot is determined by ITDMA while FATDMA is reserved for shore stations [8].

Time slots and the ITDMA working principle are shown in Figure 2 below. According to Figure 2, the AIS device broadcasts the information of the ship in a time slot to the receivers and then reserves another time slot for the next broadcast. This system prevents multiple transmissions or transmission overlap from different devices in a single time slot.

The data, both instant and historical, sent by AIS devices are of great value for researchers and analysts since they provide critical information, with regard to marine traffic, by locating the current and past positioning of ships [11,21]. There is multiple studies in literature on the investigation and analysis of marine traffic by the use AIS data. While some studies have focused on the mapping and analysis of the regional or global marine traffic [15,16,19,27] some others have concentrated on the analysis of the probability of the collision and/or grounding accidents [10,6,14]. Aimed at analysis in marine traffic, a study by Xiao et al. (2015) [28] compared the differences in the movements of vessels in a narrow channel in the Netherlands with a larger channel in China. The study examined the distribution of vessels passing across presumed cross sectional lines through the channels with regard to the variables such as speed and ship type. In another study, Altan and Otay (2017) [1] analysed vessel navigation patterns and the distribution of vessels in the İstanbul Strait according to their sectors of operation.

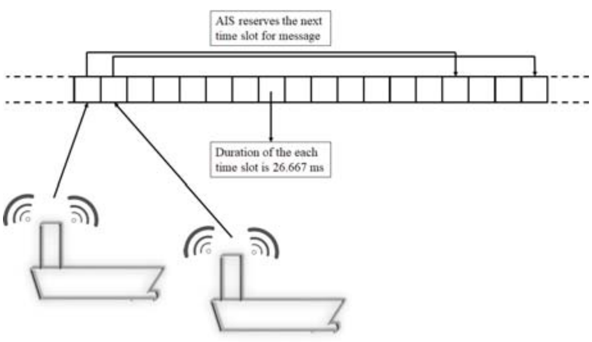


Fig. 2. AIS ITDMA Working Principle (Adapted from [8])

In this study, a desktop application is developed by using intersection algorithm and distance calculations for analysing the distribution of the vessels on a selected cross sectional (SCS) line similar with the Xiao et al. (2015) [28].

METHODS

The AIS data comes in sequence and appear as a point on the map that shown in Figure 3. In order to reveal ship distributions on a selected cross sectional (SCS) line, it is necessary to demonstrate that the SCS line is intersected by two consecutive points of a vessel.

There are various intersection algorithm such as line, polygon etc. It was found out that the line intersection algorithm is more suitable than the others in our study. Intersection of those lines in Figure 3 can be a trivial question to answer for most people but to get the same answer from a computer is not an easy process [29]. For a computer, there are 4 different points, 8 coordinates (X, Y) that represents the start and end points of the lines. The computer need to calculate those lines (4 points) whether they intersect or not. There are different algorithms to calculate this intersection [29, 30] but line intersection method proposed by Antonio (1992) [2] was most suitable, efficient and easy to use for this study.

In this study the authors propose a method in which the line intersection algorithm proposed by Antonio (1992) [2] and distance calculation method are used together to analyse vessel distribution on a SCS line. A desktop application is developed accordingly in C# programming language to visualize vessel distributions on the SCS line and an SQL server is used for AIS data storage and analysis. For the purpose of this research, the intersection algorithm is employed to calculate the passage of vessels across the SCS line taken for the study. The AIS data of the intersected vessels are gathered in a table in the SQL server. Distance calculations method is used to measure the distances on the map.

INTERSECTION OF TWO LINES.

As the AIS data come in sequence, vessel positioning information transmitted from the vessel is as shown in Figure 3. The dots marked by the numbers from 1 to 7 show any ship pattern on the map. Intersection between SCS line and the ship pattern line is calculated by means of the intersection algorithm, which is a practical way of calculation, within the framework of the study to analyse ship distribution on that pattern.

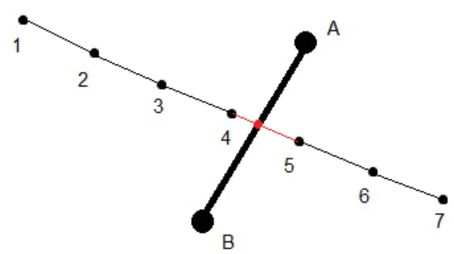


Fig. 3. Symbolic View of the AIS Data and SCS Line.

The intersection algorithm calculates the intersection of two lines and the intersection points. The lines are presented in Figure 4 below.

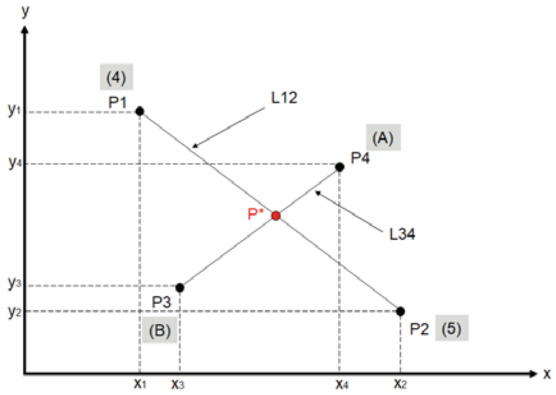


Fig. 4. Line Intersection in 2D Space (Adapted from [2])

Formulas 1, 2, and 3 below are used for the computation of the intersection of the two lines, namely L12 and L34. In Figure 4, P3 and P4 points represent the selected points, L34 shows the SCS line, P1 and P2 represent the vessel position, L12 shows the ship pattern.

$$A = P2 - P1$$
$$B = P3 - P4 \quad (1)$$
$$C = P1 - P3$$

$$\alpha = \frac{B_y C_x - B_x C_y}{A_y B_x - A_x B_y} \quad (2)$$

$$\beta = \frac{A_x C_y - A_y C_x}{A_y B_x - A_x B_y} \quad (3)$$

With formula 1, X and Y coordinates of the points can be calculated. After that, formula 2 and 3 can be calculated. For example, to calculate the value B_y in formula 2, Y value of the P4 should be subtracted from the Y value of the P3. This process should be done for all values in formula 2 and 3. In this study, X and Y values represent the Latitude and Longitude values of the vessels and SCS lines.

After the calculations, if α and β take any value between [0, 1], this means that L12 and L34 intersect. Once the values for α and β are calculated, the formulas 4a and 4b below are applied to compute the intersection point P* on Figure 4.

$$P^* = P1 + \alpha(P2 - P1) \quad (4a)$$

$$P^* = P3 + \beta(P4 - P3) \quad (4b)$$

To calculate the intersection point P*, X and Y coordinates should be calculated separately by using the formula 4a or 4b. Both formulas give the same values. For example, to calculate the X coordinates of the intersection point, $P1_x + \alpha(P2_x - P1_x)$ should be calculated. In this study, X and Y values of the intersection points represent Latitude and Longitude of the intersection point.

DISTANCE CALCULATION

The distance of the SCS line and the distance of the intersection point to the selected points can be found by means of distance calculation. 'Departure' and 'Distance' calculations are required to find the distance between two latitude and longitude points that are given. The required values for these calculations are [3]:

- 'Dlat' is the difference between two latitudes.
- 'Mlat' is the mid latitude. For the position on the same hemisphere, it can be computed by the sum of the two latitudes divided by 2.
- 'Dlong' is the difference between two longitudes.
- 'Departure' is the distance between two longitudes and generally defined in nautical miles (NM).
- 'Distance' is the distance of the line between two positions. This line makes the same angle with all meridians.

Distance between two given points of latitude and longitude is shown in Figure 5.

There are different sailing types and distance calculations according to those sailings. *"Middle-latitude sailing is a method of converting departure into difference of longitude, or vice versa, by assuming that such a course is steered at the middle or mean latitude; if the course is 090° or 270° true, it is called parallel sailing... Meridian sailing is used when the course is 000° or 180° true."* [3]. For this study, because of the different latitude and longitude of the points, distance can be calculated according to the middle latitude sailing calculations.

In the next step, the formulas 5, 6, 7 and 8 below are used to find the distance between the two given points of latitude and longitude. Specifically, the difference value between the latitudes is calculated through formula 5 while the difference value between longitudes through formula 6, and the departure value is calculated by formula 7 while the distance value by formula 8.

THE MODEL OF THE STUDY

There is an incessant transfer of versatile data from AIS stations. This data transfer occurs in the directions of ship-to-ship or ship-to-shore and vice versa and the transferred data can be stored. The scope of this study begins with the receipt of the AIS data from Turkey's Directorate General of Coastal Safety. The AIS data analysed for the purpose of this study encapsulate seven (7) days in September 2014 and covers the latitude between 38° 18,0' N - 38° 58,0' N and the longitudes between 026° 21,0' E - 027° 12,0' E longitudes. There are 2.382.469 rows and totally 42.884.442

(2.382.469*18=42.884.442) AIS database. Visualisation of the vessel movements and ship distribution on SCS line is analysed in the following step. Figure 6 depicts the model of the study.

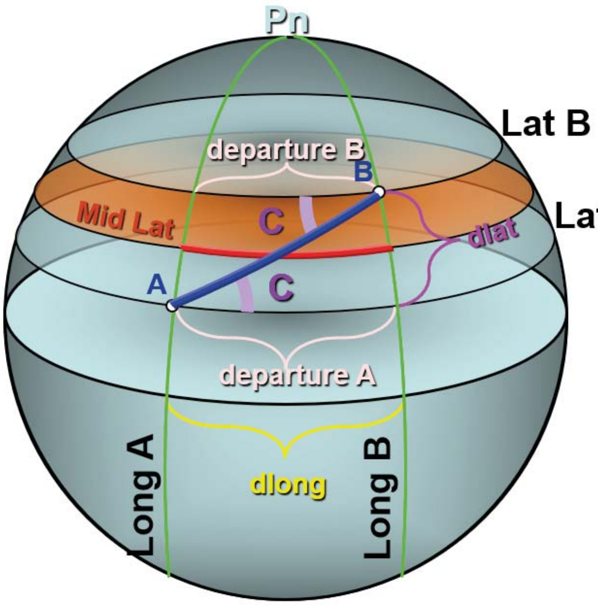


Fig. 5. Distance between Two Given Points of Latitude and Longitude [25]

$$\text{Dlat} = \text{Lat A} - \text{Lat B} \quad (5)$$

$$\text{Dlong} = \text{Long A} - \text{Long B} = \text{Departure} / \text{Cos(Mlat)} \quad (6)$$

$$\text{Departure} = \text{Dlong} * \text{Cos(Mlat)} \quad (7)$$

$$\text{Distance} = \text{Dlat} / \text{Sin}(C^\circ) = \text{Departure} / \text{Cos}(C^\circ) \quad (8)$$

Visual Studio Community 2017 software is used along with the C# programming language for the visualization of the vessel movements and distributions. Furthermore, the dataset was added to the MSSQL Server 2016 database to enable quick data processing and to ensure data security. Table 1 below exhibits an example of the tabulated dataset in the MSSQL server. The AIS data is stored in different columns in the tables according to the data type as shown in Table 1.

Tab. 1. Data Type in the Database

Column Name	Data Type	Column Name	Data Type
MMSI	int	CallSign	nvarchar(50)
Lon	float	ShipandCargo	int
Lat	float	Draught	float
Report Date	nvarchar(50)	Type	int
SOG	float	NavigationalStatus	int
COG	float	DimA	float
HDG	float	DimB	float
ROT	float	DimC	float
IMO	int	DimD	float

Mapping of ship movements is performed according to ship types and the type of a ship can be identified by the 'ShipandCargo' column. The ship and cargo codes are grouped according to the ship types as listed in Table 2 below.

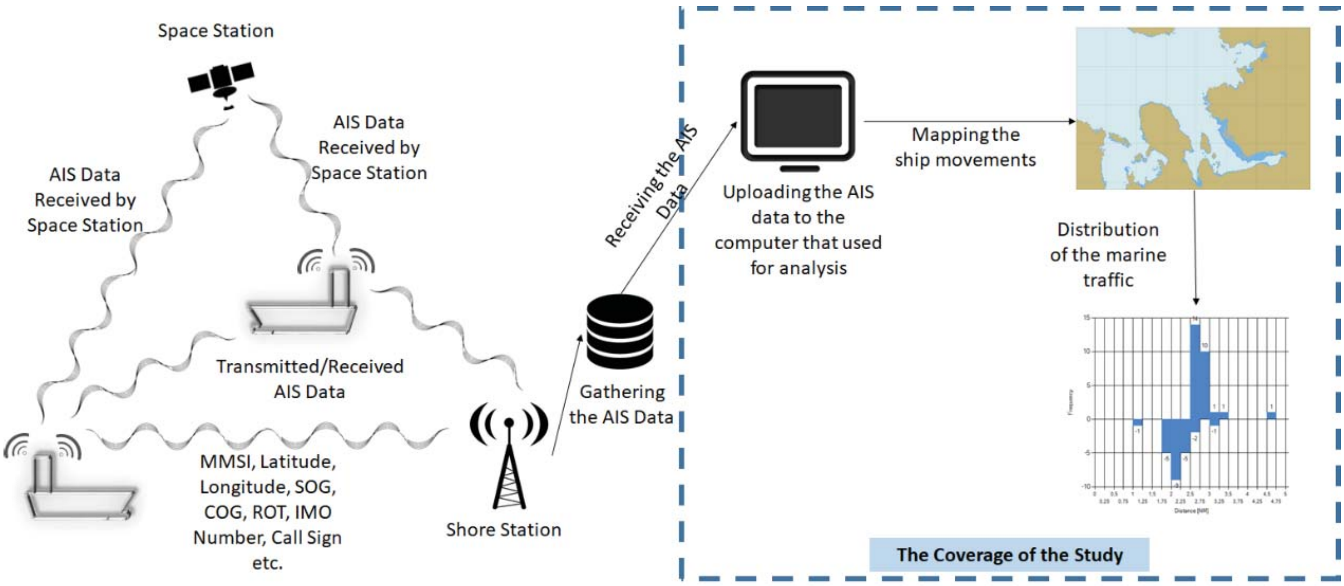


Fig. 6. The Model of the Study

Tab. 2. Ship Types and Ship and Cargo Codes

Ship Types	Ship and Cargo Code
Cargo Vessels	70, 71, 72, 73, 74, 75, 76, 77, 78, 79
Tankers	80, 81, 82, 83, 84, 85, 86, 87, 88, 89
Passenger Vessels	60, 61, 62, 63, 64, 65, 66, 67, 68, 69
High Speed Crafts	40, 41, 42, 43, 44, 45, 46, 47, 48, 49
Tug / Towing	31, 32, 52
Special Crafts	33, 34, 35, 36, 38, 39, 50, 51, 53, 54, 55, 56, 57, 58, 59
Fishing Vessels	30
Pleasure Crafts	37
Other types of Ships	20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99
Unspecified	0, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19
All types of Ships	

MAPPING OF THE NORTHERN AEGEAN SEA MARINE TRAFFIC DENSITY

In the first step, for the purpose of mapping, the map of the Northern Aegean Sea, which covers 38,3° N – 39,0° N latitudes and 026,0° E – 027,3° E longitudes, exhibited in the Figure 7 is picked. Every row in the database is equalised to 1 pixel on the map in order to demonstrate the ship pattern in the Northern Aegean Sea.

Fig. 7. Application Area of the Research (The Part of the Northern Aegean Sea)

In the Mercator projection, distance scale is changing considering the latitude. In this study, only the middle latitude of the application area chart is taken as a reference for the distance scale. This creates a scale error of no more than 0.6 NM between the north and south latitudes of the application chart. This scale error is caused by the Mercator projection. When comparing the size of the field with the analysed area this error was insignificant and not taken into account and the map is taken as a proper rectangular area. Different types of vessels are symbolised by different colours on the map. The ship-colour matching is demonstrated in Figure 8 below.

Fig. 8. The Colour Code according to the Ship Type

DISTRIBUTION OF THE MARINE TRAFFIC

In the second step of the analysis, two random points are selected on the map and the distribution on the SCS line is shown on the screen. The computer application has calculated the intersection of the AIS dots and the SCS line for every AIS data respectively and updated the Intersection_Table in the database by data relating to intersection position, draught, speed over ground (SOG), course over ground (COG) as well as other related data. Distance-Frequency, Distance-Draught, Distance-SOG and COG-SOG distributions have become visible at this phase. The interval of the Distance-Frequency distribution could optionally take 0,25, 0,5 or 1,0 NM values. The screen interface of the application is shown in Figure 9.

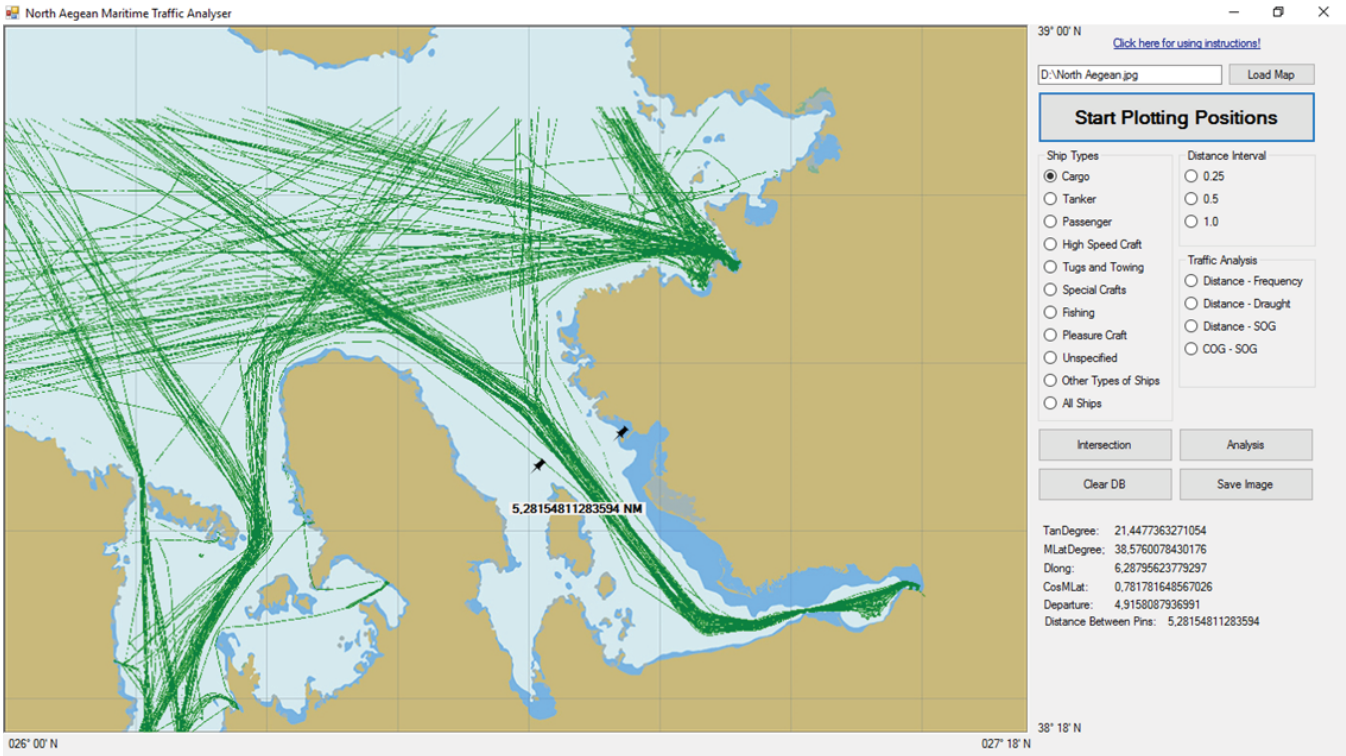


Fig. 9. Screen Interface of the Application

RESULTS

The statistical results of the analysis of the seven-day AIS data belonging to the Northern Aegean Sea are shown in Table 3 below. The dataset revealed in Table 3 consists of 2.382.469 rows of data belongings to 723 vessels.

Tab. 3. General Information Related to the Researched Area

Average SOG of the vessels	6,56 knots
Average draught of the vessels	2,87 meter
Average LOA of the vessels	67,78 meter
Cargo Vessels	
Ship count	304
Average SOG	8,00 knots
Average LOA	124,70 meter
Average draught	5,47 meter
Passenger Vessels	
Ship count	83
Average SOG	5,18 knots
Average LOA	60,55 meter
Average draught	1,79 meter
Tankers	
Ship count	57
Average SOG	6,54 knots
Average LOA	114,23 meter
Average draught	5,67 meter
Fishing Vessels	
Ship count	108
Average SOG	3,37 knots
Average LOA	24,66 meter
Average draught	0,62 meter
Tug / Towing	
Ship count	29
Average SOG	0,66 knots
Average LOA	22,46 meter
Average draught	2,28 meter
Special Crafts	
Ship count	60
Average SOG	31,05 knots
Average LOA	20,86 meter
Average draught	0,70 meter
Pleasure Crafts	
Ship count	55
Average SOG	2,29 knots
Average LOA	20,91 meter
Average draught	0,46 meter
High Speed Crafts	
Ship count	1
Average SOG	5,01 knots
Average LOA	70 meter
Average draught	2 meter
Other Types of Ships	
Ship count	10
Average SOG	2,92 knots
Average LOA	25,33 meter
Average draught	0,01 meter
Unspecified	
Ship count	16
Average SOG	2,44 knots
Average LOA	14,75 meter
Average draught	0,38 meter
Total Number of Ships	**723**

The ship distribution according to the length over all (LOA) is as shown in Figure 10.

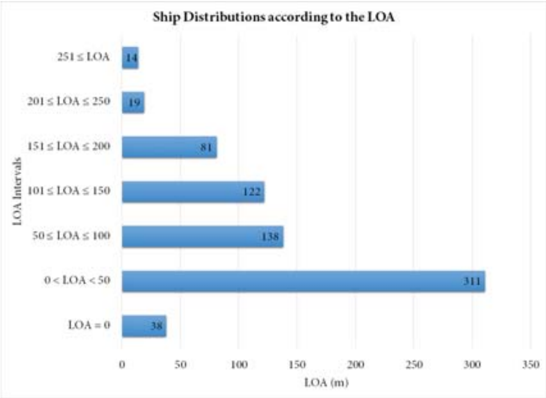


Fig. 10. Ship Distributions according to the LOA

The marine traffic map according to the ship types is as shown in Figure 11.

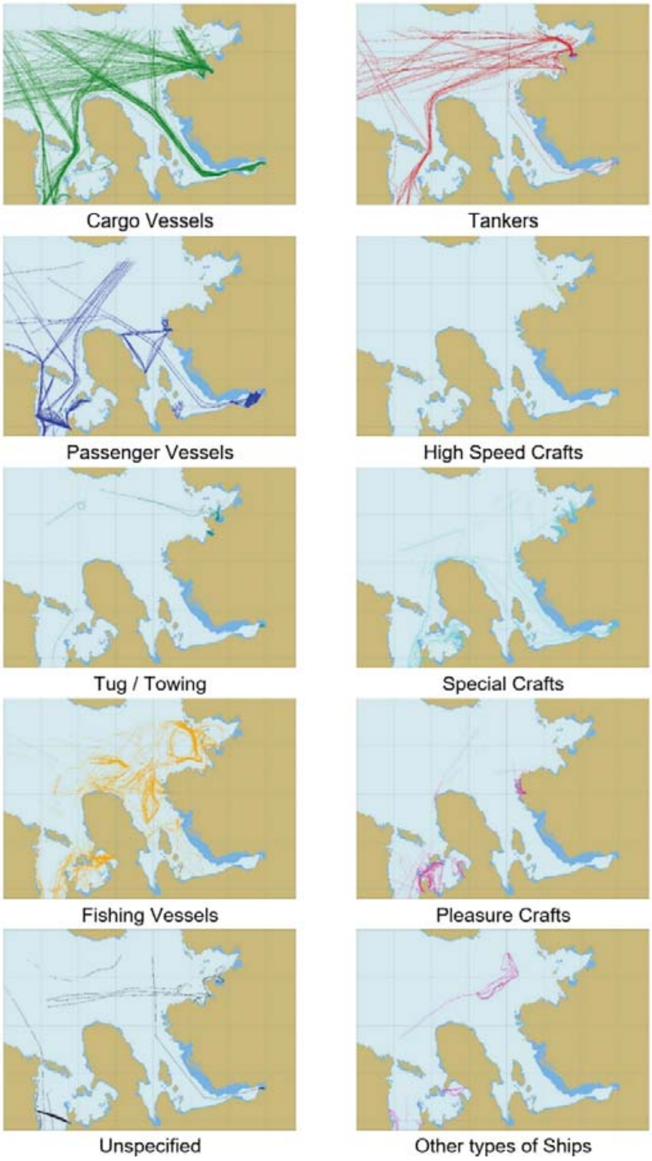


Fig. 11. The Marine Traffic Map according to the Ship Type

The marine traffic of the cargo ships and points A and B that are randomly selected are shown on the in Figure 12.

Whereas the calculation of intersection may vary according to the size of the data, the process lasted about 25-30 seconds in this example. The distribution of cargo vessels on the SCS line is as shown in Figure 13.

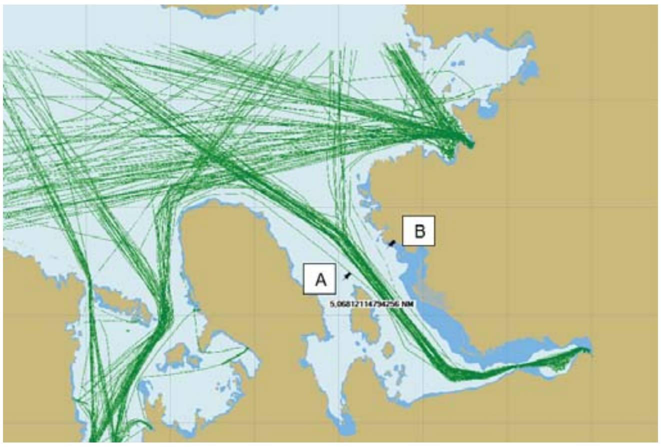
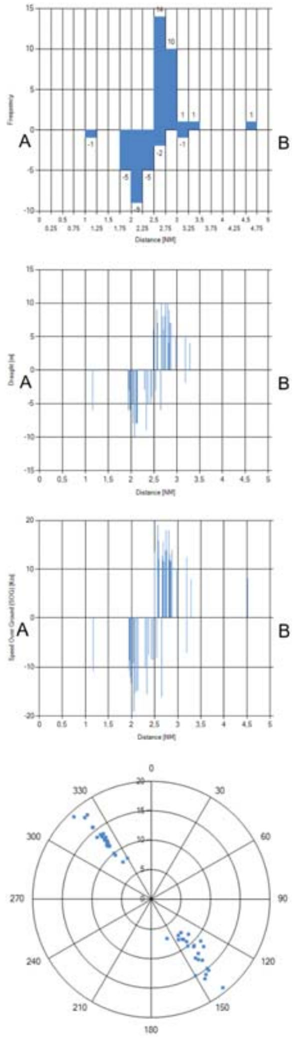


Fig. 12. The Marine Traffic Map of the Cargo Ships and the Selected Two Points



Frequency – Distance Distribution
It can be seen from the Figure 13 that 3 ships inside the red circle used the same line with NW'ly navigated vessels.

Draught – Distance Distribution
Draughts of the vessels and the using line can be seen from the Figure 13.

SOG – Distance Distribution
SOG of the vessels and the line used can be seen from the figure.

COG – SOG Distribution
General Distribution of the COG and SOG can be seen from the figure.

Fig. 13. The Distribution of the Cargo Vessel on the Selected Cross Sectional Line (Cont')

DISCUSSION AND CONCLUSION

The quest in the scholarly circles for enhanced marine traffic safety has always been vivid. Researchers have been exploiting historical AIS data in the examination of traffic distributions on Selected Cross-sectional (SCS) lines and density of marine traffic for risk evaluation, for example through the detection of high risk areas, and accident prevention purposes. Notwithstanding of many studies in the literature, the authors study is the first one that employed the intersection algorithm proposed by Antonio (1992) [2] and the method of distance calculation for the analysis of vessel distribution statistically. The analysis in this study can be used as in the study done by Xiao et al. (2015) [28]. Xiao et al. (2015) [28] investigated the ship distributions in a narrow and wide channel. Some cross sections were taken from the channel and the passages of the vessels were investigated. It is possible to investigate the ship distributions by taking similar SCS lines in the same way by using the methods mentioned in this study. Some of the similar analysis can also be done as in the study done by Altan and Otay (2017) [1]. SOG, COG or draught distribution on a SCS lines can be analysed by using the methods mentioned above.

Using seven-day period data, this study has analysed, mapped and visualised the 723 ships on the Northern Aegean Sea with regard to variables such as the number of ships, SOG, COG and draught. Visualisation included, but was not limited to, the mapping according to ship types and Frequency-Distance, Draught-Distance, SOG-Distance and COG-SOG distributions. The study exhibited that AIS data are rich and practical data sources for researchers and research that focus on marine traffic.

The model and the method developed here in this study can be exploited to investigate ship distributions in sections of a target area. The revealed vessel distributions can be used for the calculation of the probability of grounding or collision in further studies. For example with regard to grounding accidents, variables such as passage distance of vessels to shallow water, draught or SOG of the vessel can be analysed and risk assessments can be carried out. Similarly, SOG, COG or draught distributions on a selected cross sectional line can be analysed by using the methods mentioned above, which then may help the advancement of measures for waterway traffic safety. Similar analyses can be performed in traffic separation schemes to find routes and distributions of vessels navigating on the opposite side of the line or in the mid-line and take precautions accordingly. Hence, the model, method and the desktop application developed in the authors study can be used by decision-makers as a decision support system and by the researchers working in the region.

The desktop application developed within the framework of this study enables visualisation of vessel movements. It helps to map the ship movements according to vessel types and enables analysts to evaluate waterway traffic density in the target area. For example, one can view the activities of any type of vessel in a target zone, such as fishing or cargo vessel activities. The desktop application can further be developed for detailed analysis for different purposes such as economic and environmental needs.

Researchers should be aware of any missing values in the AIS datasets, as experienced in the existing study, and should bear in mind the possibility of wrongly added data as reported by Harati-Mokhtar et al. (2007) [7].

This study covered a limited (seven day) time period AIS data belonging to a specific region, the Northern Aegean Sea. Future studies may target a wider time period and use dynamic global maps for the global mapping of marine traffic and analysis.

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