AN APPLICATION OF AGENT-BASED TRAFFIC FLOW MODEL FOR MARITIME SAFETY MANAGEMENT EVALUATION

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SUMMARY

This paper aims to analyse maritime traffic safety assessment via a traffic flow simulation model. The model developed via NetLogo platform, agent-based modelling and simulation approach. And it is implemented on an open sea area, at the Aegean Sea to show its applicability. The model is verified through experiments conducted in the area. The simulation outputs give the risky locations and scores. Risky locations and risk scores in the area are determined as the outputs of the simulation runs. A traffic separation scheme is established to prove the suitability of the model as adaptable and updatable. After the scheme is implemented, it shows that the potential collision locations and scores change considerably. The developed model is convenient to simulate various conditions by changing the input parameters on maritime traffic safety.

KEYWORDS

Maritime traffic; Maritime safety; Maritime traffic simulation; Traffic flow simulation; Agent-based model.

1. INTRODUCTION

Maritime traffic environment is a dynamic and complex system, and safety is a key instrument for the sustainability of marine traffic. Although there have been established many rules and regulations for safety by maritime authorities, there have still been loss of lives, injuries, total loss, and damages in properties. According to Allianz Global and Speciality, in the last decade, the total loss in cargo vessels was 40% of all incidents (AGCS, 2020).

Researchers have mostly seen modelling methodology as a tool to comprehend and enhance safety in maritime traffic (Almaz & Altiok 2012; Goerlandt & Kujala 2011; Ince & Topuz 2004; Qu & Meng 2012; Xiao et al. 2012, 2013; Zhao et al. 2019). Computer simulation is the sole proven approach to evaluating maritime traffic capacity, also planning, and management, analysing, designing navigation systems (Huang, W. J. Hsu, *et al.*, 2013; Gunal, 2018; Xiong and Xie, 2018).

Simulation application areas can be classified as open water or restricted/confined water area in maritime traffic. Researchers have not treated multi-ship interactions in open water in detail. A limited number of studies involving multi-ship encounters have been conducted in open water areas.

These studies have been conducted in heavy traffic areas (Fang, Tsai and Fang, 2018) (such as channels, busy straits, and harbour entrances) (Davis, Dove and Stockel, 1982; Camci *et al.*, 2009; Qu and Meng, 2012; Xiao *et al.*, 2012; Hasegawa and Yamazaki, 2013; Bayezit *et al.*, 2019; Özlem, Or and Altan, 2021; Qi *et al.*, 2021), traffic separation schemes (Davis, Dove and Stockel, 1982; Colley, Curtis and Stockel, 1984) and coastal and inland waterways (Beschnidt and Gilles, 2005).

In the literature, many large-scale maritime traffic environments have neglected areas. These areas may contain many encounters and arriving ships from any direction, a few ports, and traffic separation lanes. However, investigating traffic and identifying risky areas in a large and complex region are crucial steps for maritime traffic safety. In cases such as opening a new port, creating new navigation routes, adding traffic control vehicles, traffic capacity, traffic management and similar cases, it is necessary to examine traffic conditions and identify risky areas. Especially in cases such as the opening of a new port, set up of new navigational routes, the addition of traffic control tools, traffic capacity, and traffic management etc.

Agent-based Modelling and Simulation (ABMS) is one of the modelling and simulation paradigms. This paradigm has been widely used in the maritime transportation industry since 2000. ABMS has mostly been used in maritime and related issues such as the analysis of maritime traffic, piracy and maritime security, the efficiency of port equipment, and search and rescue operations (Çelik and Zorba, 2019).

This article aims to develop an agent-based simulation model for analysing maritime traffic in terms of safety assessment. Besides, the traffic flow simulation model also aims at identifying potentially unsafe and risky areas in terms of maritime transport safety. The present research calls into question this maritime traffic flow simulation application for its ability to determine whether it defines risky areas for traffic safety. The article is based on two main research questions: Firstly "Is identifying potential collision locations possible in advance" and secondly "Is, through re-organization of maritime traffic, it possible to reduce or eliminate the potential of collision in these regions?".

It is shown that it is possible to investigate the present traffic conditions and future traffic situations (for instance, berth capacity changes, traffic capacity, new routes, and compulsory safety rules) by using the presently developed model. The recommendations derived from the model enhance traffic safety and its impact on the navigation system can be monitored on the simulation model. Presently, the simulation environment has been designed for the Aegean Sea to assess maritime traffic safety for this area in the NetLogo platform.

This paper is organized as follows. First, maritime traffic safety tools and maritime traffic simulation studies are surveyed in Section 2. After literature survey, the methodology and model variables are determined. The model development, design concepts, experiments, and the validation and reliability of the model are explained in Section 3. The results and discussion of the study are given in Section 4. Finally, the paper is concluded in Section 5 with the assessment of the results.

2. LITERATURE REVIEW

Maritime traffic safety assessments tools have been presented in the literature such as SAMSON, GRACAT, MARCS, SHIPCOF, MARTRAM, DYMITRI and IWRAP Mk II (Harris and Falconer, 2004; Friis-Hansen, 2007; Pimontel Bsc, 2007; Nyman, 2009; de Boer, 2010). SAMSON is the first tool to assess accidents such as grounding, collision, and fire. Only GRACAT can be accessed free of charge from the Technical University of Denmark. DYMITRI allows interactions between ships and can simulate the traffic conditions, but it has a limitation of accessibility like other assessment tools. IWRAP is a powerful tool for estimating the frequency of collision and grounding. Yet, basic version is available for the International Association of Marine Aids to Navigation and Lighthouse Authorities, previously known as International Association of Lighthouse Authorities (IALA) members.

Knowledge of traffic flow is based on transport engineering, usually road transport. Basic variables of traffic flow form the basis of all methods applied in the design, operation, and development of transportation systems (Gökçek, 2018). The flow models in the traffic discipline are classified in terms of their details that they are interested in (Knoop, 2018). Traffic models can be divided into three interrelated subcategories (Banos, Lang and Marilleau, 2017): macroscopic models, which consider vehicle flows microscopic models considering individual vehicles and their interactions, and mesoscopic models, which are between these two categories.

Traffic flow theory forms the basis of the maritime traffic flow concept and is applied to maritime traffic (Huang, Yip and Wen, 2019). Marine traffic flow simulation is a kind of simulation test using computer technology in the marine traffic flow model. This is a technical method for investigating maritime traffic by developing, operating, and implementing the traffic system in a laboratory environment (Xiong and Xie, 2018). Recently Zhou et al. (2021)'s study, has proposed a macro model to detect near miss situations.

The simulation approach uses as a tool to identify accident probabilities, risks, and various economic and technological problems in maritime studies. This approach can be classified as simulations for port/terminal operations and logistics, modelling of vessel traffic on waterways for scenarios, and policy assessments (Almaz and Altiok, 2012). Simulation approach started with Davis's study (Davis et al., 1980). Modelling and simulation (M&S) have many applications in the field of maritime traffic with various purposes. For examples, through M&S, researchers have been studying visual simulation environments (Numano, Itoh and Niwa, 2001; Itoh, Numano and Pedersen, 2003), decision support system (Perez *et al.*, 2007; Yazici and Otay, 2009), narrow or swallow waters such as ports, channel, strait or river (Köse *et al.*, 2003; de Boer, 2010; Altiok, Almaz and Ghafoori, 2012; Rayo, 2013), ship interactions (van de Ruit, Schuylenburg and Ottjes, 2010; Goerlandt and Kujala, 2011; Montewka *et al.*, 2011; Blokus-Roszkowska and Smolarek, 2013), modelling the complexity of maritime traffic flow (Wen *et al.*, 2015). According to the water area and the different purpose of M&S applications, models containing a different range of individual ship behaviour details have been developed. Zhou et al., (2019)'s study has revealed ship behaviour details in terms of modelling paradigms and characteristics in both confined and open water.

Existing literature on maritime traffic flow studies were surveyed. 29 studies and the variables used are listed, in the Table 1. The variables are followed by the frequencies in parentheses: velocity (23), ship length and beam (22), ship type (16), ship course (15), ship positions (12), distance to other ships (11), safety domain (06), ship interval time (06), ship behaviour and manoeuvrability (05), traffic flow density (04), current (03), movement of ships in navigation lanes (02), trajectory (2). In this study, ship type, ship positions, ships length, velocity, ship course, distance to other ships, acceleration, deceleration, turning constant, and turning ability variables are used in the model.

ABMS has been used to study, examine or analyse in a wide variety of applications including physical, biological, social and management sciences, technological, traffic and transport system (Davidsson *et al.*, 2007; MacAl and North, 2010). The strength of this paradigm is based on its ability to explain and model the complexity of real-world interactions accurately and clearly (Berryman and Angus, 2010). Besides, there are some advantages of ABMS applications in traffic: recreating traffic environment

Table 1: The used variables in the existing literature

Variables & Author(s)	(Goodwin, 1983)	(Almaz, *et al*, 2006) (Almaz *et al.* 2006)	(Puszcz,, *et al*,2011) (*x*2011)	(Camci *et al.*, 2009)	(Xianbiao *et al.*, 2009)	(Ruit *et al.* 2010)	(Xiao *et al.* 2012)	(Wu and Cheng, 2012)	(Feng, 2013)	(Huang *et al.* 2013)	(Rayo 2013)	(Xiao, 2014)	(Xiao *et al.*, 2013)	(Xu *et al.*, 2013)	(Yip, 2013)	(Blokus-Roszkowska & Smolarek 2013)	(Wen *et al.* 2015)	(Xu, Liu and Chu, 2015)	(Huang *et al.* 2016)	(Gucma, Bąk and Sokołowska, 2018)	(Liu *et al.* 2017b)	(Liu *et al.*, 2017a)	(Sang *et al.*, 2017)	(Teng, Lau and Kumar, 2017)	(Kang, Meng and Liu, 2018)(Kang, Meng and Liu, 2018)(	(Tasseda and Shoji, 2018)	(Huang, Yip and Wen, 2019)	Frequencies
Ship Type	■	■	■	■	■					■		■	■	■		■		■	■		■	■	■			■		16
Ship Positions		■		■					■	■		■	■				■		■		■	■			■	■		12
Ship Length and Beam	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■		■		■	■	■	■	■		■		22
Ship Course		■	■	■	■		■			■		■	■	■			■	■	■	■	■	■						15
Velocity			■		■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	23
Safety Domain										■	■				■				■	■				■				6
Distance to Other Ships			■					■	■	■	■	■	■						■	■	■	■						11
Time Distance to Other Ship																						■						1
Rudder Angle							■																					1
Wind Direction													■															1
Wind Velocity											■		■															2
Current											■		■		■													3
K, T Indices							■						■															2
Ship Behaviors &Maneuver	■						■				■		■			■												5
Movement of Ships in Nav. Lanes											■					■												2
Traffic Flow Density	■															■									■		■	4
Draft		■			■						■									■	■	■						6
Trajectory														■			■											2
Ship Interval Time										■	■			■				■	■							■		6

and the participants, and it is able to monitor each participant, and heterogeneity (Klügl and Bazzan, 2012). As mentioned before in Qi et al., (2021)'s paper, maritime traffic emulation is not easy in terms of vessels variation as size, type, velocity, and manoeuvrability (Qi *et al.*, 2021). ABMS paradigm provides heterogenic traffic and matches the research questions of the present article.

3. METHODS

Agent-based modelling and simulation (ABMS) paradigm has been used for analysing complex systems in recent years (Siegfried, 2014). It defines characteristics of this paradigm, agent, agent behaviour, and interactions between agents and their environments (Macal, 2016). It autonomously acts in that environment usually by a simple set of rules to accomplish its objectives. There is also heterogeneity between agents, where each agent can be identified by its attributes (Downey, 2012; Siegfried, 2014; Taylor, 2014). The key notion of Agent-Based Modelling is that many (if not most) phenomena in the universe could be reliably modelled via agents, an environment, agent-agent and, agent-environment interactions (Wilensky and Rand, 2015).

NetLogo offers a relatively simple but efficient programming language, is eminently suggested even for complex models for development and testing and also useful graphical interfaces (Railsback, Lytinen and Jackson, 2006). NetLogo was chosen as a tool in the present research study. The reasons are that it is relatively easy to learn, open source, easy to integrate with other systems, suitable for academic papers and well-documented. Also, literature shows that NetLogo platform has been the most preferred simulation tool in articles and post-graduate theses for ABMS methods in maritime transport (Wilensky and Rand, 2015; Çelik and Zorba, 2019).

3.1 MODEL DEVELOPMENT

This paper is presented in accordance with the Overview, Design concepts and Details Protocol (ODD Protocol). ODD Protocol was proposed (Grimm *et al.*, 2006). The protocol is a standard reporting for an agent-based model. It has three structural parts: The Overview, Design concepts and Details and their elements.

The article is an attempt that real maritime traffic flow environment is transferred into the computer environment by considering the individual characteristics of ships and to evaluate sea traffic in terms of safe management according to possible changes. It aims to detect possible risky locations in this model. This model also allows for the monitoring of individual realistic ship behaviours.

3.1 (a) Overview

The simulation process composes of sequential events and procedures are displayed in Figure 1. It starts with setup procedure, is one of the basic structures in NetLogo. Generating Ships is composed of "create-ships" and "ship-type-probability", and "interval-ships-arrival" procedures. For the application area, the ships are generated at five different zones to emulate the real traffic. Each ship is assigned a ship type, velocity, LOA, and attributes such as turning-constant, turning-ability, velocity-min, velocity-max, acceleration constant, and deceleration constant in accordance with the type of ship. The ship type probability of a ship is assigned stochastically. In the model, the "interval-ships-arrival" procedure is defined as the time for the next ship, fit for the Poisson statistical distribution. These parameters were set in the input data section.

In the paper, the essential state variables are LOA, velocity, velocity- min, velocity- max, engine-command, origin, destination, ship-type, turning-ability, turning-constant, acceleration-cons, deceleration-cons, close-ships, close-ship-distance, and danger-status. The variables that characterize the ships define each ship's attributes. Each ship is produced at origin coordinates and navigates to destination or to the waypoints. The ports have connections with one another.

Each ship has velocity limits according to the ship type. Any ship aims to navigate from origin to destination with its own velocity. When the ship is at the destination, the ship (agent) leaves (dies) the system. There is an exception if the destination is a port. When the ship's destination is port, the distance to port is calculated, according to the ship's velocity.

The process of approaching the ports is divided into steps to make the ships move more realistically. If distance to port is less than half an hour, the ship's engine-command turns to half ahead. If the distance of the port is less than 3 nautical miles (nm), the ship's engine-command turns to slow ahead; if less than 1 nm, the ship's engine-command turns to dead slow ahead. The ship arrives at the port, a new destination is assigned randomly, then it navigates to a new destination. If distance from the port is more than 1 nm, the ship's engine-command turns to slow ahead. If distance is more than 1 nm and less than 3 nm, the ship's engine-command turns to half ahead; if distance from the port more than half an hour distance, the ship's engine-command turns to full ahead.

Each ship has a perception area, called "vision-radius" slider that is controlled by the user on the interface. It assumed the area (2nm radius, like ship domain) surrounds the ship. In the model, interactions between ships include, however has limits. If the ships are encountered in this area and their vision angle is 60 degrees, they behave according to the International Regulations for Preventing Collisions at Sea (COLREG) and each ship alters her course to the starboard side. Avoidance from the head-on situation they follow back to their course. Each patch has a danger status. If there is a possible head-on situation in a

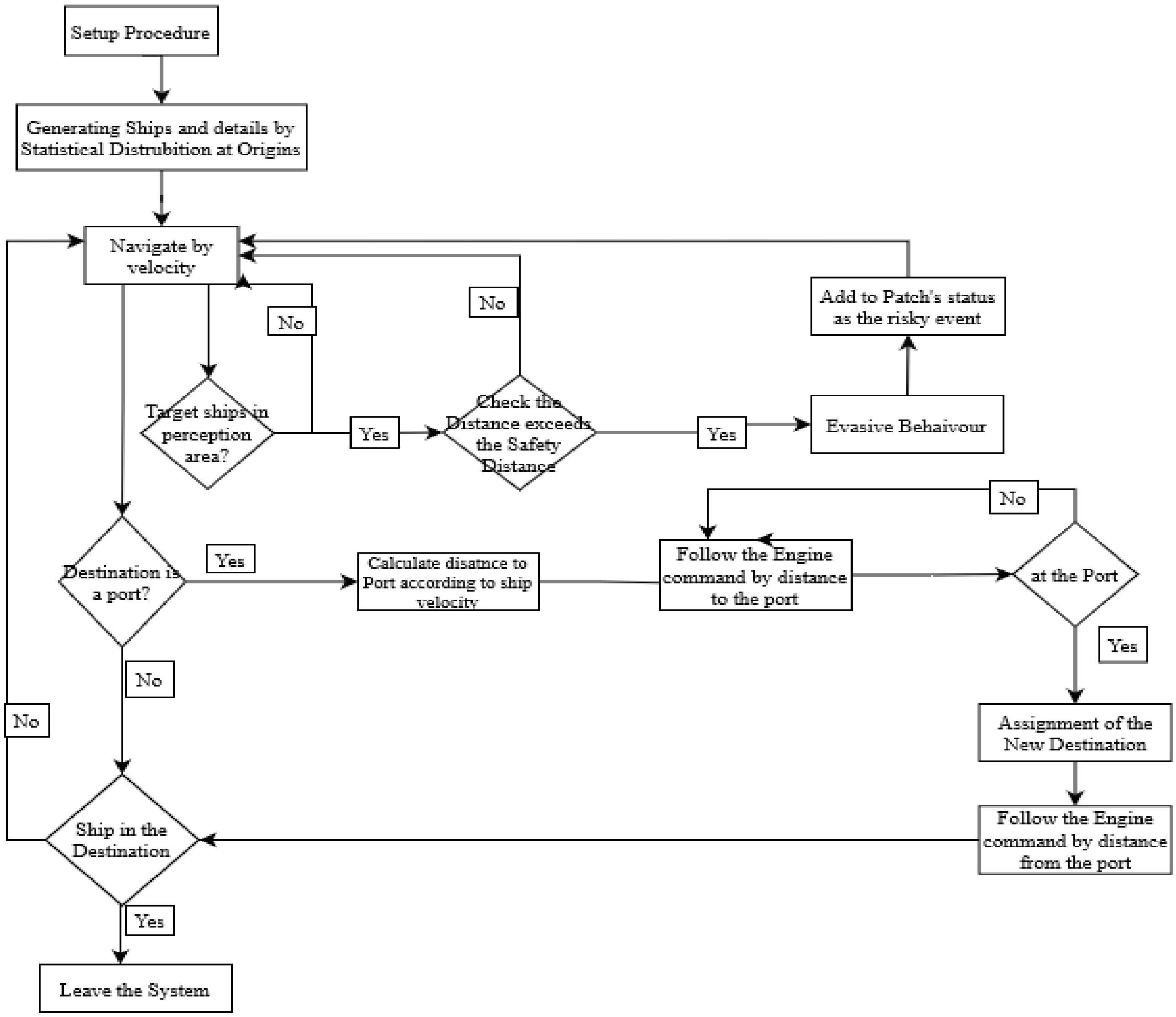


Figure 1. The layout of the event processes during each time step.

designated patch, the danger status of that particular patch is increased.

"Safety-distance" slider is controlled by the user. If the ships' destinations are the same and the distance between ships is safety-distance (assumed 1 nm), the last ship must slow- down in the model.

Real maritime traffic conditions and ship behaviours are not easy to emulate. Therefore, some assumptions and

abstractions made. The following assumptions are valid for this simulation model:

- A ship is produced at predefined coordinates, the origin. According to the origin, it has options to navigate different destinations.
- A ship navigates from the origin to the destination. Some ships must navigate to a waypoint, because of geographical boundaries. It depends on the origin-destination pair.
- A ship arrives at the waypoint, turns the new course. The ships have a turning constant, according to the ship type. Turning ability is calculated by LOA and turning constant.
- Ships are produced at predefined velocity limits at the origins. A ship's velocity changes acceleration-cons and deceleration-cons to the ship types. Container ships accelerate and decelerate faster than the other types.
- A ship navigates to blind navigation assumption. A ship can view the ship when the ship is in the range determined and the angle in the model interface with sliders.
- It is assumed that a ship is just a one-dimension entity, navigating on the sea surface. Draft is not considered. Depth dimension is accepted safe for all ships. The model includes potential collisions but not groundings.
- Potential collisions mean in this model for a ship, there is another ship in the determined distance range, 1 nm, that can a candidate for a collision, at least. This distance between two experimental vessels is used 1

nm for all encounter types in the experiments, as by Kim (2020) and by Zhang *et al.* (2021).
- Meteorological data and current which could change the navigation conditions in real are not included in the model.

In the simulation model, position of each ship is updated with each tick that are assumed a minute. When model starts, time counter (ticks) is zero. A day consist of 1440 ticks. For Aliaga, Foca, and Izmir ports total number of ship arrivals are ranged as min 6686, max 7397, average 7042 from 2011 to 2019. Simulation time is 150.000 tick; it is a quarter year that can be finished in half an hour of time on a R5-3500U CPU computer.

3.1 (b) Design Concepts

NetLogo has 4 types of agents: Turtles (mobile agents), Patches (inactive agents, environment), links and the observer. Two agents are connected by links. Observer can command all the agents; it represents the user. There are two types of entities that are turtles-related (ships and their attributes) and patch-related (navigation environment).

The mobile agents are ships. Each ship has characteristics such as ship-type, ship LOA, origin, destination and, turning-ability. The model is a 70 x 40 patches world that represents the part of the Aegean Sea. Each patch represents 1 nm, 1852 m. Each patch computes a danger status and, patch variable to define the risky conditions. Patches in the model represent along 70 nm latitude, 40 nm longitude. This region has 4 port areas: İzmir, Aliaga, Foca, and Dikili. This area is a navigation area where ships navigate from different routes, multiple arrivals, and departure areas. Ships arrive and depart from both the Mediterranean and the Black Sea. Some ports have connections with one another, like Aliaga. Thus, this region is one where complex traffic is likely to occur. Each tick represents one minute.

In the model, a ship is reproduced at the origin, and assigned a ship type with a random choice. During the simulation, the number of each ship type is close to the average of all. When the ships are reproduced, it is the emergence that they can be in each other's perception area at five origin areas. The below rules used for model design:

- Each ship adapts her heading according to her position from the origin to the destination.
- Agents' objectives are the same: to navigate from the origin to destination with each velocity and particulars. Some agents (ships) navigate to the waypoint before the destination.
- The ships are not able to forecast the behaviour of the other ships in the model. This model is not a collision-avoidance approach. However, this model can detect the collision candidates based on the distance, and the ships can avoid head-on situations.
- Ships are aware of their position, velocity. They can sense the other ships on the system if they are in vision (ass. 2 nm), in radius area (ass. 60 degrees), and minimum safe distance (ass. 1nm) in the model. They need certain limitations to sense other ships, otherwise, all the ships would detect each other, and the system would not work properly.
- This model uses the interactions between ships in two ways. One is a head-on situation based on COLREG regulation and the other one is ship following behaviour situation that is based on the car-following theory. They change their course to avoid a collision, then they return to their routes. If the ships navigate to the same destination and the distance between ships is decreasing to the safe distance, the following ship slows down via deceleration constant to ship type.
- There are many random variables used in this model. First, the ships are generated at defined area, but the latitude and longitude are randomly matched. Second, the time differs between two produced ships at origins, and ship intervals are generated by random numbers from a Poisson distribution. Third, ships' destinations are chosen randomly. All origin and destination options are predefined with codes. Fourth, ship types are generated by predefined categories as containers, general cargo, tankers, or bulks. Last, Ship's LOA, turning ability, turning constant, velocity-min and, velocity-max attributions are generated by predefined values to the type of ship. Used ship types in the model can be seen in Table 1.

These variables provide, presents different ship types, ship behaviour that emulates the real practice based on 1-week observations in the Aegean Sea.

This simulation produces several outputs that can be demonstrated on the interface, during the simulation. There are 9 counters to learn the ship numbers on the interface. "Current Number of Ships" to the ship types and "Total Number of Ships", and "Number of Ships to the Ports" counters are shown on the screen. The user can change the ship size on the screen with the "Ship-size" chooser. Users can also display those risky areas with the "Danger Status" graph.

3.1 (c) Details

The area has origins, destinations, and waypoints. 8 area predefined are origins and destinations indicated with (C1, …, C8), 9 area predefined waypoints indicated with (M1, …, M8) as seen in Figure 2.

The coordinate system and an image of the Aegean Sea are integrated into the NetLogo code part. This image represents the area, 70 * 40 nm² part of the Aegean Sea. When the simulation is started, the time and the counters are set as zero and the area is empty as seen in Figure 3.

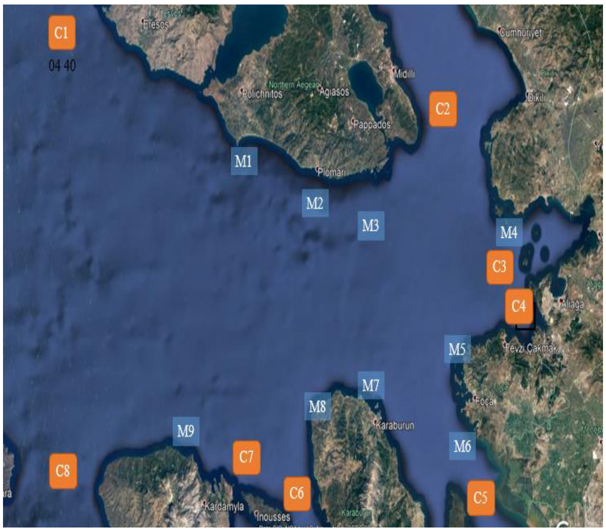


Figure 2. Origin and Destinations and Waypoints on the step of initialization.

Ship tracks can be seen as coloured lines by the ship type. The user can control “track?” switch on the interface, which is optional. Besides, there is a “ship size” chooser to control the visual of ship size. When ship sizes are realistically represented, they seem to be quite small, and it could not be seen properly.

During the simulation, the user can control the visualise. It does not affect the simulation results; however, it affects the visual experience of the user. The coordinate system can be adjusted for different sizes and track, or trackless options are the initial setups for the simulation model. The measure of ship size can be seen in Table 2. It is based on the observation of this area.

Table 2: Ship types, and their sizes and numbers on the region.

Ship Types	N. of Ships	LOA (m)			Length on the Patch (nm)		
		Min	Max	Avg.	Min	Max	Avg.
G.Cargo	48	75	139	111,8	0,0404	0,075	0,060
Tankers	27	71	294	156,3	0,0383	0,158	0,084
Bulks	14	104	229	165	0,0561	0,123	0,089
Containers	9	133	211,4	172,2	0,0718	0,114	0,114
Passenger	2	138	140	139	0,0745	0,075	0,075
Total Ships	100						

Statistical data related to the ships’ input (Initial positions and velocities, sizes, types, time intervals between the two sequential ships) was collected from field observation by the authors via the “www.marinetraffic.com” website. In the 1-week observation conducted to obtain information about the maritime traffic in the region, Dikili-Lesbos Island in the north- northeast, Foca and İzmir port entrance in the east- southeast, arrivals, and departures from the Cesme Channel in the South. The origin and destination areas of the ships were determined based on the tracks of traffic density map on the website (see Figure 5). The observation process was completed when the number of ships located, departed, or approaching ports reached the number of 100. From the observation, the values are classified and defined according to the ship types, shown in Table 1. During the simulation, these inputs are generated according to predefined values, shown in Table 3.

Table 3: Velocity of ships in the model.

Ship Types	Colour	Average Range (Nautical Miles per Hour)		Average Range in The Model (Patch / Minute)	
		Min	Max	Min	Max
General Cargo	Green	12	16	0,200	0,266
Tankers	Red	11	16	0,183	0,266
Containers	Yellow	14	24	0,233	0,400
Bulks	White	10	15	0,166	0,250
Passenger	-	15	25	0,250	0,416

This model has three submodels. “ship-type probability” procedure defines the selection of the ship type with equal probability. 4 ship types were defined as containers, general cargo, tankers, and bulks in the model. “change-engine-command” procedure uses for deceleration and acceleration to ports, or from ports “change-course” runs for collision avoidance in head-on situations. “risk-status” to determine the risk degree for patches (positions). During the simulation one can obtain risky values of the locations as a “.csv” file. There is some part of “ship-type-probability” procedure in Figure 4.

In this model, 4 ship type defined. It is seen in the Figure 4, ship – related variables colour, velocity range, LOA, turning constant, ability change according to the ship types. Ship type is random produced by the simulation, and other variables such as velocity range, LOA, turning constant, ability change are defined to the ship type.

3.2 VALIDITY, RELIABILITY OF THE MODEL AND EXPERIMENTS

The real ship tracks in the region and produced ships track by the simulation model are shown in Figure 5, respectively. Images of the actual ship tracks and the

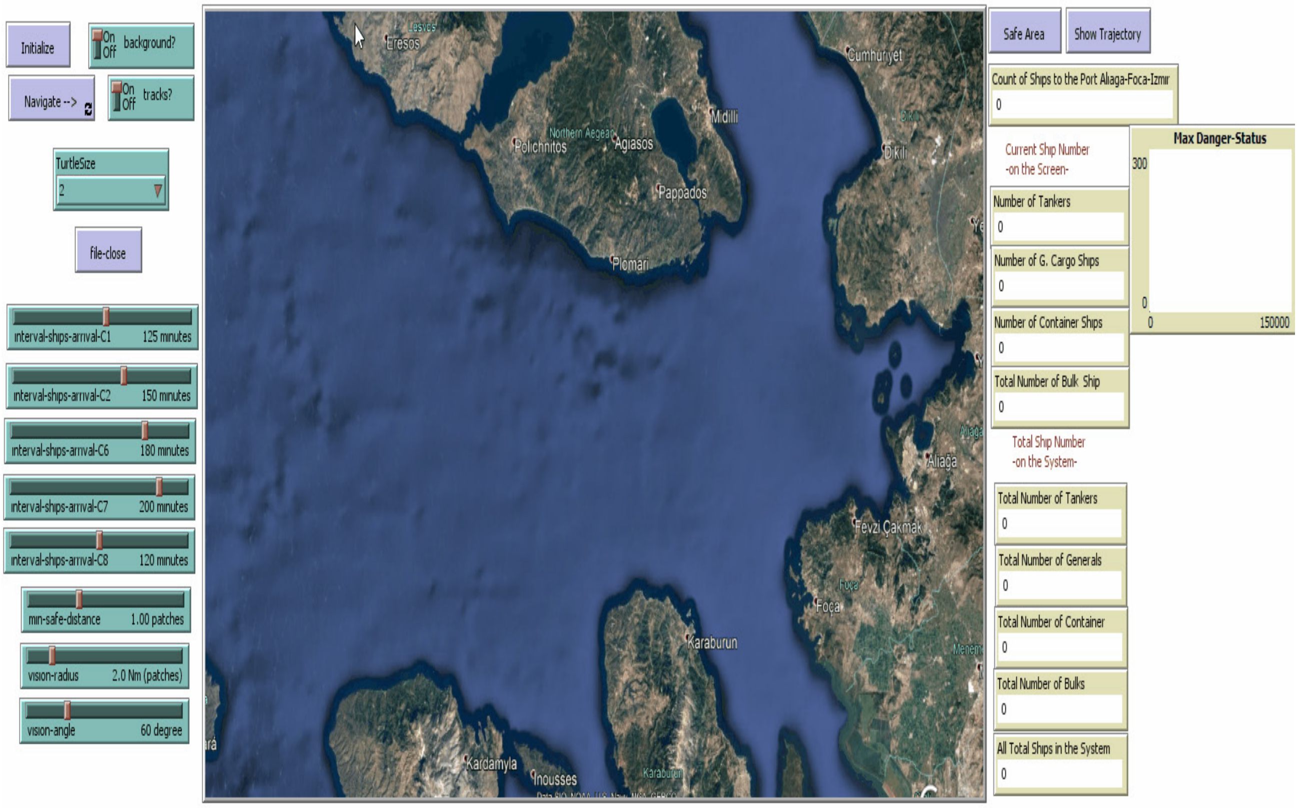
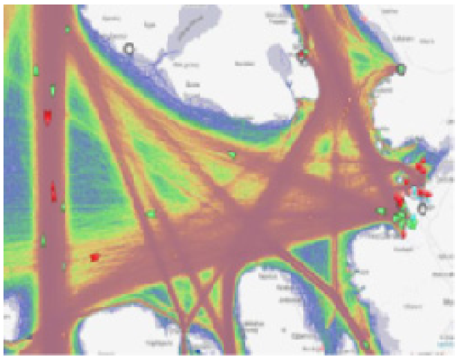


Figure 3. The appearance of the interface in the initialization step.

```
to ship-type-probability
 let ship-type-list [1 2 3 4]
 set ship-type one-of ship-type-list
  if ship-type = 1 [ ; Tanker
  set color red
  set velocity  precision (0.183 + random-float (0.086)) 3
  set velocity-min precision (velocity  - (velocity  * 0.375)) 3
  set velocity-max 0.266
  set f-LOA precision (0.038 + random-float (0.120)) 3
  set total-tankers total-tankers + 1
  set turning-constant 2
  set turning-ability (f-LOA * turning-constant )
  set acceleration-cons 0.01
  set deceleration-cons 0.01
 ]
 if ship-type = 2 [ ;  General Cargo
  set color green
  set velocity  precision (0.200 + random-float (0.066)) 3
  set velocity-min precision (velocity  - (velocity  * 0.375)) 3
  set velocity-max 0.266
  set f-LOA precision (0.040 + random-float (0.035)) 3
  set total-generals total-generals + 1
  set turning-constant 1.5
  set turning-ability (f-LOA * turning-constant )
  set acceleration-cons 0.01
  set deceleration-cons 0.01
 ]
```

Figure 4. A part of the submodel procedure for ship types.



Before the TSS

After the TSS

Figure 5. The comparison of real ship tracks and produced ships' tracks by simulation.

generated ship tracks match closely. Thus, it can be inferred that the presently developed simulation model is valid and represents the real maritime traffic flow for the region.

The data for incoming and outgoing ships were obtained from the numbers arriving at ports due to the lack of collected data in the open sea region. Maritime statistics have been collected by the Ministry of Transport and Infrastructure Administration, for the last 9 years on the ports of Aliaga, Foca, and Izmir. These data are shown in Table 4.

Table 4: Number of arrivals ships at the ports by year.

Years/ Name of the Ports	Aliaga	İzmir	Foca	Aliaga+ İzmir + Foca
2011	4983	2584	121	7688
2012	5208	2556	117	7881
2013	4937	2495	108	7540
2014	4814	2432	123	7369
2015	4861	2136	102	7099
2016	4959	2182	128	7269
2017	5202	2139	196	7537
2018	5241	2047	232	7510
2019	5135	1551	----	6686
Number of Annual Ship	Min 6686	Avg. 7397		Max 7881

The model runs for a one-year duration, in an experiment. One experiment lasts between 8 and 10 hours. The data size obtained during each time step (tick) progress was about 3.5 to 4 Gb for a single experiment. 150000 tick was preferred to represent the model for more than three months to demonstrate the reliability and to reach the risks of locations in the region from the data obtained. In this case, for 150000 ticks proportionally, the minimum number of ships is determined as 1908, the maximum is 2250, and the average is 2111. The comparison of the number of ships arriving in Port Areas by year and the number of produced ships in the model experiments conducted are shown in Table 5.

Table 5: Number of Ships Arrivals to Port Areas in the Experiments.

Exp. No	Arrival/ Departure Number of Ships to the Port Areas	V*	Exp. No	Number of Ships Arrivals at the Port Areas	V*
1	2155	V	6	2228	V
2	2130	V	7	2119	V
3	2137	V	8	2193	V
4	2123	V	9	2157	V
5	2180	V	10	2193	V

V*: Valid, Compatible with Real Numbers.

According to the real traffic data, the number of ships going to ports is expected to be in the range from 1908 to 2250 when the model is run. The experiment results are seen in Table 3, which shows that the number of ships going to the port areas is compatible with the actual values. The average number of ships going to port areas is 2161 ships for the experiments presently conducted. Figure 6 shows the number of ships expected for the duration of 150,000 simulation studies in the designated sea area and the number of ships produced in the model.

The expected values and produced in the experiments are seen in Figure 6. For 150000 ticks time, the average number of ships produced is expected to be 2111 in the experiments, with a standard deviation of 94.32.

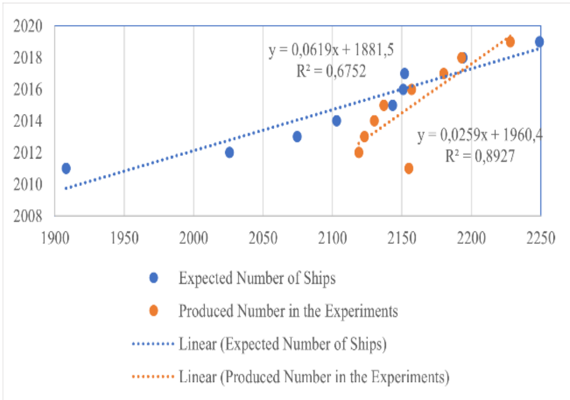


Figure 6. Comparison of ship numbers between forecasting values to years and the conducted experiments.

As seen in Figure 7, it can see as a part of the running of the simulation. Ships are shown with remarkable size to gain visibility, in this huge simulation area. As a result of the experiments, the average number of ships produced in the simulation is 2161, and the standard deviation is 32.04. If one compares the number of ships obtained from the simulation experiment results and the real situation, it is shown that the simulation experiments successfully reflect the real situation.

The reflection ratio is the ratio between forecasting numbers of ships to the years and produced ship numbers in the simulation experiments. These values are 0,9821; 0,9470; 0,9931; 0,9905; 0,9293; 0,9310; 0,9851; 0,9773; 0,8846, and the average is 95,78%. It could say similarity between the real situation and the experiments is high. This value means simulation reflects the real situation. This agent-based model is a valid model that is compatible with real values. There is a counter in the procedure, if the ships are closer than 1nm (safety-distance), risky areas start to show on the screen. Risky areas are represented from minimum to maximum, respectively by yellow, middle risk by orange, and by red.

We implemented a traffic separation scheme (TSS) on the simulation to reduce potential collisions and to improve

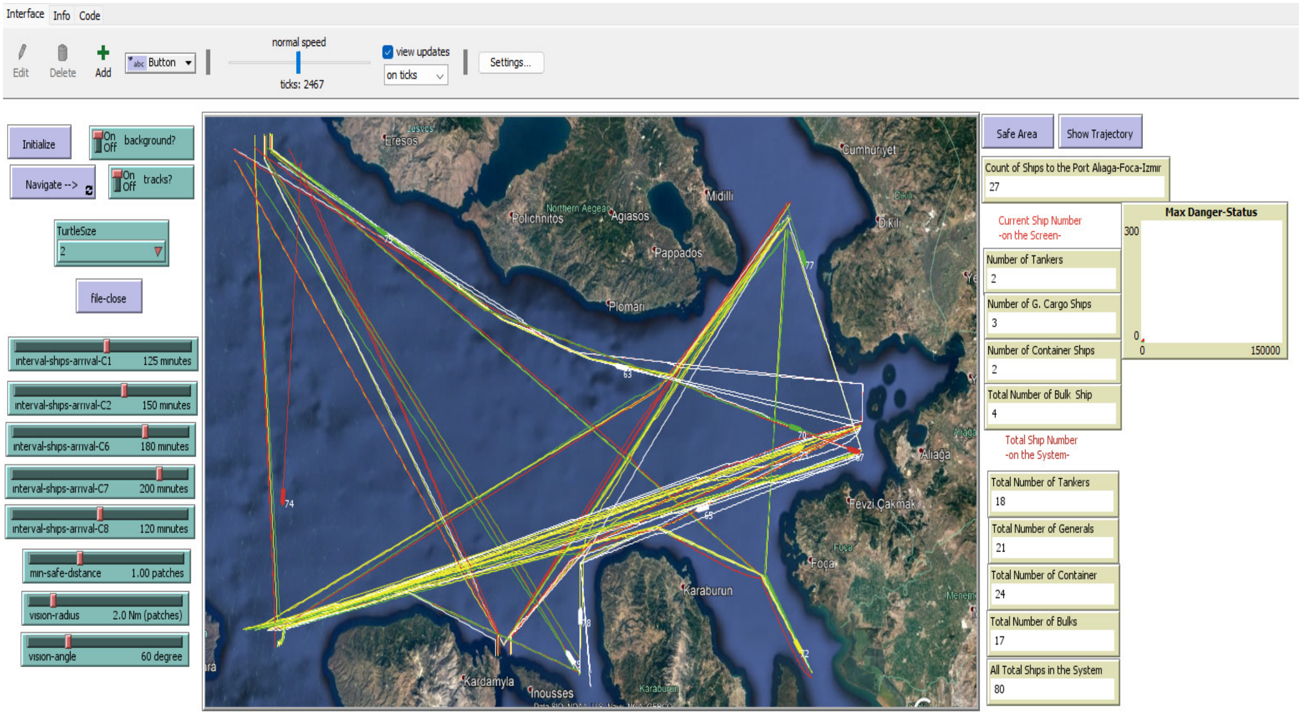


Figure 7. Running of the simulation, on NetLogo Platform.

safety of vessel traffic flow in risky areas. Initially, we acquired the coordinates that are yellow, orange, and red as output from the simulations. Then, we specified a waypoint around the north-western Karaburun Peninsula and traffic lanes for arrivals and departures.

After conducting a TSS, 10 independent replications of simulation experiments were conducted under the same conditions as the present conditions. The experiments indicate that conducting a TSS has changed the risk score and the potential collision locations in the region. Table 6 demonstrates examples of risk scores and images.

As seen in Table 6, through reorganising the maritime traffic, potential collisions eliminated in the Peninsula region. The potential risk areas have shifted to the entrance of Cesme, and Chios Island waters represented by C7 in Figure 2. C1 and C8 origin areas have still high-risk points because there are relatively shorter time intervals between two sequential ships than the other origin areas.

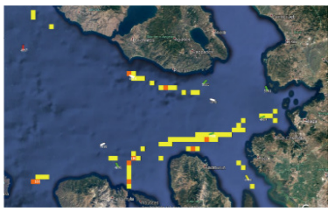
After we applied TSS, we also compared whether the ship traces changed or not. Figure 8 shows the comparison of ship track in real and after the TSS was conducted. Figure 8 show the comparison of ships track in real and after the TSS conducted.

4. RESULTS AND DISCUSSION

According to the results of the simulations for the present conditions, one of the highest risk scores among the

Table 6: Comparison of Images and Risk scores before and after TSS

One of the experiments before TSS implimention

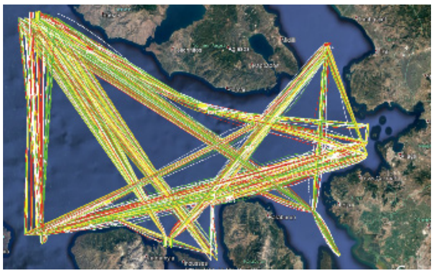


x-loc	y-loc	Risk score
07	05	158
06	05	116
08	06	109
35	25	100
27	28	98
28	05	93
09	06	88
59	18	85
43	14	84
07	06	83

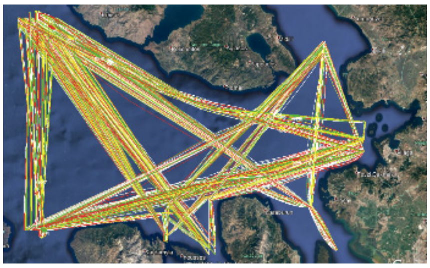
One of experiments after TSS implimention

x-loc	y-loc	Risk score
28	10	110
7	5	103
44	14	99
27	28	98
6	5	93
27	9	86
35	25	86
41	12	85
27	5	82
45	14	74

locations is defined as C8 origin area ((07,05), (08,06), (09,06), (09,05), (06,05), (07,06)). One of the other locations is defined as C1 origin area (06,40) having one of the highest risk scores. This may be due to the fact that the time between ship arrivals is relatively shorter than in other regions. Most potential collision situations have occurred in this environment. It may be caused by the ships are entering the system, generated at the areas "C8 and C1 origins", and leaving the system in the same areas. The location (35,25) is south of Lesbos Island; thus, it is a region outside the territorial waters of Turkey. (34,10) location is seen as a high-risk region in the north-western of Karaburun.



The ships track before TSS



The ships track after TSS

Figure 8. The comparison of real ship tracks and after implementation TSS.

A traffic separation scheme has been proposed for organizing the maritime traffic in this region. As a result of the experiments conducted after the traffic separation scheme was adopted the risk scores in the region have changed. The risk values have decreased in the locations defined as C8 area (07,05), (08,06), (09,06), (09,05), (06,05), (07,06). After the TSS was applied, as shown in the map in colour with yellow, orange, and red in the north-western part of the peninsula, risky locations have appeared to be shifted to the west. The ship encounter frequency decreased in this region, which influence the other regions, changing the risk scores map.

The ship tracks can be available at all the areas where ships move on the map. The ship tracks, before and after TSS are seen in Figure 8. Ship tracks change by conducting TSS. Ship tracks implemented after TSS are different from those before TSS. The tracks are more complex than before TSS.

In this paper, a maritime traffic flow simulation model has been developed to enhance safety in traffic. The simulation model has used an agent-based modelling and simulation paradigm, that fits the nature of dynamic, complex nature of maritime traffic considering individual ship characteristics, in terms of safety management of traffic. The paper is presented step by step according to ODD protocol. The model is developed in NetLogo simulation platform, particularly designed for the part of the Aegean Sea which is an open water and 3 ports area. The simulation model outputs, with ship tracks on "Marine Traffic" website data, have shown similarity. Ship behaviours and attributes were transferred to NetLogo environment to make simulations. The model has difficulties to emulate a ship's collision avoidance behaviours. According to (Zhou et al., 2019), ships are defined by agents that are popular on maritime traffic models, but just a few models include manoeuvrability details, and therefore agent-based modelling paradigm is not sufficient for maritime traffic models. One could say that ABMS has some limitations for ship behaviours and dynamics, however, it is useful to define heterogeneity of maritime traffic participants.

The present model gives the output as the potential ship counter locations with colours. These risky locations mean that a ship is detected by another ship within 1 nautical mile. The experiments have been conducted with current conditions and it was determined that the northwest region of Karaburun is one of the regions where the ships encounter the most. Kundakçi and Nas (2018)'s paper shows the cargo ships have the highest traffic density in the Northern Aegean Sea area. Previously, a spatial analysis of ship accidents was conducted at the Aegean Sea, by (Büber and Töz, 2019) which indicates that the collision accidents are the 3rd ranking in the accident types.

A traffic separation scheme has been implemented in this region to reduce the potential collisions, and the experiments have been carried out with new traffic rules. This simulation model shows that potential alterations in traffic patterns are possible. Therefore, it can be concluded that the present model is able to give safety recommendations, as was aimed by the present article.

This simulation model comes into prominence in some respects from the model tools in the literature. The model gives a map as an opportunity to analysing water area including potential ship encounters and ship traffic density, however, it does not include the potential groundings as in SAMSON, GRACAT, DYMITRI models. However, it is possible to use this model as a handy tool for groundings analysis with some changes in the model procedures. Previous analysing tools, SAMSON, and MARCS are not a traffic simulation model. Even though DYMITRI and this agent-based simulation model are both traffic models, however, DYMITRI is a commercial one, therefore requires a charge. The present model was developed in NetLogo which is an open-source platform made by authors. As with the SAMSON, and MARTRAM tools, external environmental conditions were not included in the model. Zhou et al., (2021)'s macro model is also lack of hydro-meteorological conditions.

The simulation has ship type characteristics and related particulars to its type. It is possible to add a ship type and its characteristics, ship behaviours for other application areas are required. It is known that ABMS has been already used in piracy, because of these features (Vaněk *et al.*, 2013; Varol and Gunal, 2015).

Notwithstanding some studies chosen a standard ship (Ruit, Schuylenburg and Ottjes, 2010; Wen *et al.*, 2015; Fang, Tsai and Fang, 2018) or without ship characteristics models such as (Gunal, 2018) and Köse et al., (2003)'s papers in the existing literature. However, the present article is the first to carry out a huge simulation application contains ship details according to the types. This paper has used mesoscopic traffic simulation features. The traffic unites and, ship characteristics have been included in the model, similar to the papers (Itoh, Numano and Pedersen, 2003; Ince and Topuz, 2004; Perez *et al.*, 2007; Camci *et al.*, 2009; Goerlandt and Kujala, 2011; Qu and Meng, 2012; Huang, W.J. Hsu, *et al.*, 2013; Huang *et al.*, 2016). Also, the developed model in this paper allows to track the number of ships, velocities, flow, and density values, instantly.

5. CONCLUSION

An agent-based simulation model has been developed in the present article to emulate the real traffic conditions in computer environment to enhance safety. Ships, their particulars, and behaviours are represented by agents in the model. Interactions of ships in defined states are included in the model. The model is explained systematically according to the ODD Protocol. A case study of the Aegean Sea is conducted for demonstrating its applicability. 10 independent replications of simulation experiments were implemented, obtaining the risk scores and locations, which mean potential collision coordinates. After some changes in the model procedures, a traffic separation scheme was established in one of the top 10 of risky locations. This in turn changes the risk scores and the locations in the region. The model is suitable to answer "What-if questions" since it can make some experiments on changes in traffic patterns with new routes or new ports, altering traffic control tools.

Since 2000, agent-based modelling and simulation paradigm has found useful applications in maritime industry, especially in piracy and traffic issues. The model is flexible and can be adapted for different maritime traffic conditions, defining different ship types, environmental, and meteorological impacts. As potential improvements to the present model, it is possible to add some further effects to the model, particularly those of small-scale maritime environment. By adding related variables and procedures, the present model can also be used for grounding analysis.

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