ON THE POSSIBILITY OF COLREGS/STM INTEGRATION

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Acknowledgments

The presented paper was supported by the research project EUREKA - Adriatic-Ionian joint approach for development and harmonisation of procedures and regulations in the field of navigation safety, funded by INTERREG V-B Adriatic-Ionian ADRION Programme 2014-2020.

Abstract

In the shipping industry, Sea Traffic Management (STM) system aims to represent a new paradigm in maritime safety. The idea of the STM implementation is to share information between all stakeholders, making shipping more efficient, safe, and environmentally friendly. With the growing market and related increase in marine transport and traffic, the risk of marine accidents is increasing as well. The STM provides numerous features for personnel on-board and shore to support decisions for safe navigation and operation based on real-time data.

One of the services is the ship-to-ship route exchange, providing prediction of potentially dangerous situations and planning the vessel's movement in advance. Analyses of marine accidents show that ship collisions are one of the most frequent types of marine accidents, the reason of which among all others, questions human error related to the knowledge of the collision avoidance. This paper elaborates the possibility of COLREGs/STM integration based on the use of STM ship-to-ship route exchange system. The decision model for COLREGs/STM integration procedure is presented in the way which enables suggestion on appropriate COLREG rule application in advance. Further system development is proposed as well, such as machine learning algorithms in COLREGs/STM integration, with the function of reducing the risks of marine accidents and increasing safety at sea.

Keywords

STM, ship collisions, COLREGs, human factor

1 INTRODUCTION

Maritime transport is the principal mode of transport for international trade and the global economy, with more than 90 % of traded goods carried by sea[1]. In pace with the increasing market and the related increase in maritime transport, the risk of marine accidents is increasing as well. To reduce the risk of accidents and increase safety at sea, the shipping industry is constantly searching for new solutions, one of them being STM system.

In 2012, with the European project Monalisa 2.0[2], an extension of the initial Monalisa project, the idea of STM was born. STM is a concept developed by the Swedish Maritime Administration with a set of systems and services similar to air traffic management. The idea is to share information between all stakeholders, making shipping a more efficient, safe, and environmentally friendly sector, which are the main goals of the STM. The STM services allow personnel on-board and ashore to support decisions for safe navigation and operation based on real-time data. One of the most significant services of the system is ship-to-ship route exchange. The route exchange gives the Officer Of the Watch (OOW) the possibility to foresee potentially dangerous situations and plan the ship's movement. Despite all available modern technology and advances in the shipping industry, collisions at sea caused by human error continue to occur.

The proposed paper deals with a question concerning human error in implementation of rules for ship collision avoidance which are given by the Convention of the International Regulations for Preventing Collisions at Sea (COLREGs). Analysis of marine accidents shows that wrong interpretation and lack of knowledge of the collision regulations are some of the most common reasons leading to ship collisions. This research aims to propose a decision-making model for COLREGs/ STM integration as a new potential STM service, in order to reduce the risk of this kind of human error.

The first part of this paper deals with the background and the main problem which are presented in the way of analysing ship collisions and determining which kind of human error considerably leads to them. The methods and a decision-making model that is suggested for the integration of COLREGs and the STM system are presented in the consequent chapter, together with systematic procedures that enable suggestions on particular COLREGs rule. The last part discusses the idea of the COLREGs/STM integration concept. The paper concludes with aiming for a safer navigation, reducing the risk of collision, as well as other sub-focus areas regarding machine learning technology implementation in the navigation and collision avoidance tasks.

2 BACKGROUND

There are many causes in the maritime traffic that could lead to accidents with catastrophic consequences. The biggest cause of all maritime accidents is human error, with an estimate from 75 to 96 %[3]. Human error is often described as an incorrect decision or improperly performed action. It implies the fact that crew members need to be well trained and alert to dangerous situations at every moment.

Some of the most significant causes of human error at sea are[4]:

- Inexperience, and lack of training
- Poor decision making and/or negligence
- Long hours, lack of sleep leading to fatigue
- Long voyages, extended time at sea
- Personal relationships between personnel aboard
- Reckless behaviour, including substance abuse
- Work pressure and duty-related stress

According to the European Maritime Safety Agency (EMSA), in the period from 2014 to 2019, loss of propulsion power was the most frequent type of accident, followed by contact, collision, and grounding.

Table 1 Number of accidents in the period from 2014. to 2019[5].

	2014	2015	2016	2017	2018	2019	Total
Capsizing/Listing	11	15	8	15	18	17	**84**
Collision	332	293	317	292	279	256	**1769**
Contact	390	402	357	420	379	320	**2268**
Damage/loss of equipment	287	361	356	310	341	297	**1952**
Fire/Explosion	160	173	131	133	133	124	**854**
Flooding/Foundering	60	56	44	62	35	46	**303**
Grounding/Stranding	325	329	290	292	301	228	**1765**
Hull failure	6	15	22	5	5	4	**57**
Loss of control - Other	1	1	12	4	6	0	**24**
Loss of control – Loss of containment	76	61	69	67	67	45	**385**
Loss of control – Loss of directional control	78	92	83	111	75	77	**516**
Loss of control – Loss of electrical power	61	45	47	65	59	59	**336**
Loss of control – Loss of propulsion power	373	373	469	504	552	615	**2286**
Missing	0	0	1	1	1	2	**5**
Total	**2160**	**2216**	**2206**	**2281**	**2251**	**2090**	**13204**

Source: EMSA, Annual Overview of Marine Casualties and Incidents 2020 publication

By distribution of fatalities, collisions were the leading type, with more than 30 % in the period from 2014 to 2019[5]. Researches states that wrong interpretation and lack of knowledge of the COLREGs rules are some of the common reasons for collisions. The survey conducted among seafarers showed that 50 % of seafarers either ignored or disregarded the rules, whereas 90 % of them mentioned that their poor knowledge of the COLREGs, as well as lack of education, are the main reasons for that behavior[6]. By recognizing this issue, the European Union approved the project called "*Avoiding Collision at Sea*" (ACTs), funded by the "Leonardo da Vinci" program[7]. Research results conducted within the project showed that the most common reason for ship collision is the disregard for COLREGs. As part of the research, the questionnaire was conducted between 1498 seafarers and 288 non-professionals (mostly maritime faculty students) to see which parts of the rules were misunderstood, and what the main issue regarding the rules was. The results of the questionnaire showed a lack of understanding and knowledge of the rules.

In one of the studies, the understanding of the rules among secondary maritime school students was analysed[8]. The survey results showed a lack of understanding of the basic COLREGs rules. Students from maritime universities who had no navigation experience, but had gained knowledge of the rules during studying, answered correctly on 59 % of the rules. The results of the research among seafarers and students raise concern about the lack of knowledge, misunderstanding, and ignorance of the rules for avoiding collisions at sea.

The following table displays some examples of maritime accidents that have led to collisions because of non-compliance with COLREGs. Accidents were analysed from investigation reports of the Marine Accident Investigation Branch (MAIB).

Table 2 Examples of collisions regarding non-compliance with COLREGs[9]

VESSEL'S NAME	TYPE	INJURIES/ FATALITIES	DAMAGE/ ENVIRONMENTAL IMPACT	RELATED COLREGs RULES
Cosco Hong Kong & Zhe Ling Yu Yun 135	Container Ship Fishing Vessel	No injuries 11 Fatalities	No damage Vessel lost	Rules 2, 5, 6, 8, 13, 15, 16, 17, 34
Alam Pintar & Etoile des Ondes	Bulk Carrier Fishing Vessel	No injuries 1 Fatality, 3 cases of hypothermia	Minor damage to the bow Vessel lost	Rules 3, 13, 16, 26
Strilmøy & Harvester and Ocean Harvest	Supply Vessel Fishing Vessel	No injuries No injuries	Bulbous bow holed Vessel lost	Rules 5, 6, 7, 8, 17, 19
Homeland & Scottish Viking	Fishing Vessel Ro-ro Passenger	1 Fatality No injuries	Total loss Damage to the midship section	Rules 2, 5, 7, 8, 15, 16, 17, 34
Scot Isles & Wadi Halfa	General cargo Vessel Bulk Carrier	No injuries No injuries	Damage to the hull Damage to the hull	Rules 5, 7, 8, 10, 15, 16, 17
Seagate & Timor Stream	Bulk Carrier Cargo Ship	No injuries No injuries	Pollution No damage	Rules 2, 5, 7, 8, 13, 15, 16, 17
Stena Feronia & Union Moon	Ro-ro Passenger General cargo Vessel	No injuries No injuries	Damage to the port side Damage to the bow	Rules 2, 8, 15, 16, 17, 34

Source: Marine Accident Investigation Branch (MAIB)

It should be noted that the above-mentioned accidents happened during good visibility and that the main cause for the accidents was non-compliance with the COLREGs rules, especially referring to *Part B Steering and sailing rules*. The data shows that accidents at sea, that occur as a cause of non-compliance with COLREGs, can have huge consequences for the marine environment and human life.

In addition, the number of collisions at sea also occurs due to misunderstandings between officers and a lack of English language skills[10], and it can be considered as human error. In certain cases, before implementing collision avoidance, OOW reach for a VHF radio to establish contact and mutually agree on an appropriate action. This is most often made by unconfident officers who can, through long communication over the VHF radio, reduce the possibility of timely and effective corrective action. A representative example is the case of collision linked to inappropriate VHF usage between an LNG carrier and a VLCC in the channel of Fujairah in March 2019[11], resulting in damage to the hulls of both vessels. In the reports of the Maritime and Coastguard Agency (MCA) it was stated that "*Although the use of a VHF radio may be justified on occasion in collision avoidance, the provisions of the Collision Regulations should remain uppermost, as misunderstandings can arise even where the language of communication is not a problem*". It is clear that the use of a VHF radio is a preferable instrument for collision avoidance, but the application of COLREGs rules should come first.

Some of the authors state that reducing human error can be achieved in several ways, one of them being the installation of safety warning devices, such as sensors and alarms, to detect problems and signal indicating that corrective action is needed. This is to a certain extent related to e-navigation[12], defined *''…the harmonized collection, integration, exchange, presentation, and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment.''*[13]

Nowadays, there is a growing number of research and discussions about Maritime Autonomous Surface Ships (MASS) which is expected to reduce human errors on-board and increase safety at sea. The future of MASS is inevitable, but the question of the implementation of COLREGS in the autonomous service raises serious issues. A significant amount of research has been focussed on the technological possibilities of collision avoidance for autonomous ships. In the paper[14] the authors proposed a set of solutions for collision avoidance with two layers:

- the collision avoidance decision-making model and

- the path planning.

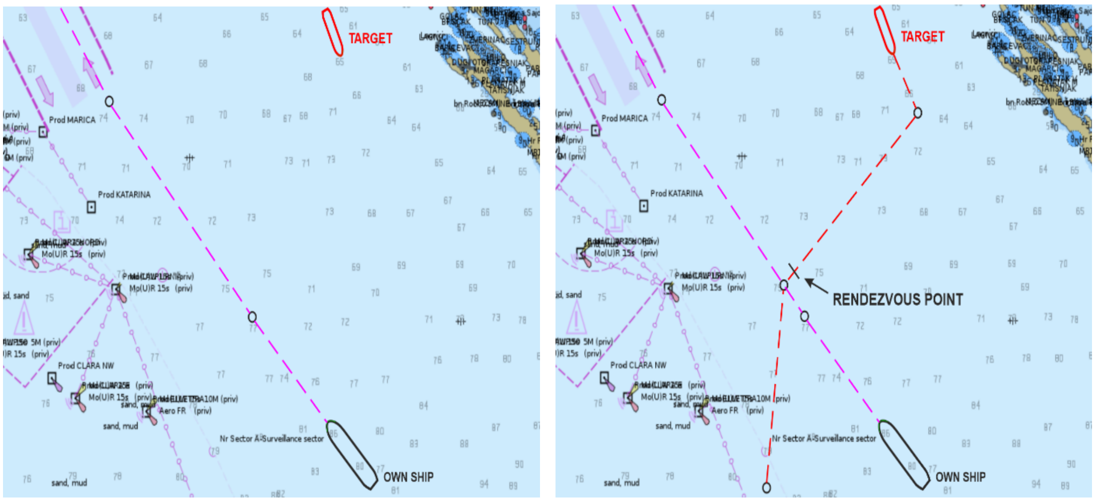
The decision-making model is presented as a stand-on and gives way ship option, while path planning is described using the Artificial Potential Field model. The decision-making system is often used in scientific research as a solution when it comes to collision avoidance of marine vessel navigation based on COLREGs rules and regulations. In another study[15] authors presented a fuzzy-logic decision-making system to facilitate collision avoidance. Implementation of COLREGs in decision-making systems is also presented as a decision tree method which is a predictive machine-learning technique that is used for both classification and regression (CART) models[16]. To create a model, the authors needed to prepare the number and importance of decision attributes and decision classes. Objects were classified into two decision classes: give way and stand-on vessel. Since all manned ships are obliged to behave in accordance with COLREGs rules, it is imperative to find an algorithm or some other solution that will work the same with autonomous (unmanned) ships. Some of the authors consider it necessary to make new recommendations for amendments to the COLREGs collision avoidance protocols in order to make them as accessible as possible for autonomous ships[17].

Past researches have been based on the practical implementation of COLREGs by the OOW and path planning in unmanned and manned vessel navigation, but none on the option of proposing which rules should be applied in specific situation. Based on these assumptions, this paper presents the possibility to reduce the number of collisions at sea with the collaboration of e-navigation.

3 METHODS

Ship-to-ship route exchange represents one of the possibilities of the STM system, which gives option to OOW to foresee possible dangers and plan his movement in advance. This information is transferred via the Automatic Identification System (AIS) between ships and displays the route segment consisting of the next seven waypoints of the monitored route with a rendezvous information layer that predicts a meeting point[18].

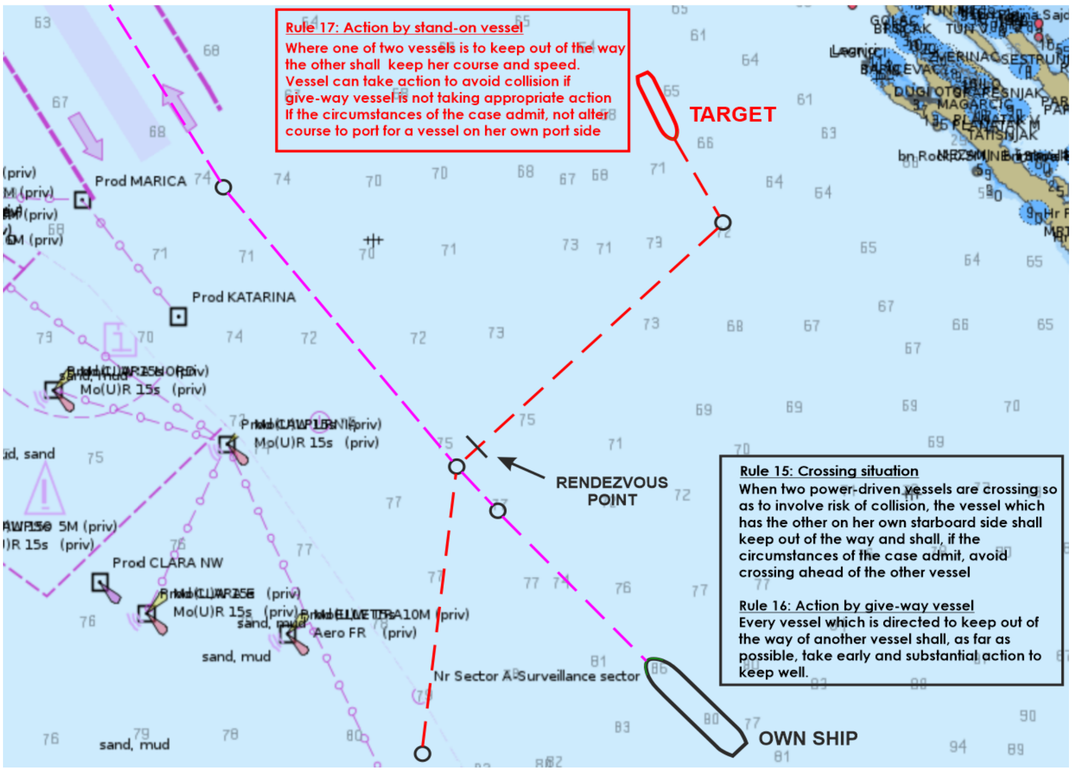
Figure 1 STM system (Ship-to-ship route exchange – right picture)



Source: Made by authors

There is a possibility of integrating COLREGs rules into STM based on route exchange and prediction of approaching ship as a decision-making model. The incorporation of rules into the system is conceived in a way that OOW offers suggestions on appropriate COLREGs rule application in advance. Therefore, in case of approaching a target (*Figure 1),* one can optionally choose a proposed suggestion on how to behave according to the Collision Regulations. In case of a possible collision risk, the panel gives the suggestion "COLREGs" tab that OOW can and does not have to select. After selecting an option, a window with the corresponding rule at the given moment will open. (*Figure 2*). The suggestion is also given to the other ship (target) with appropriate COLREGs rule in the same procedure described for own ship. Since STM is transmitted via AIS it is possible to receive information in a ship-to-ship zone (horizontal range about 40 nautical miles)[19].

Figure 2 Suggestion on appropriate COLREGs rule application

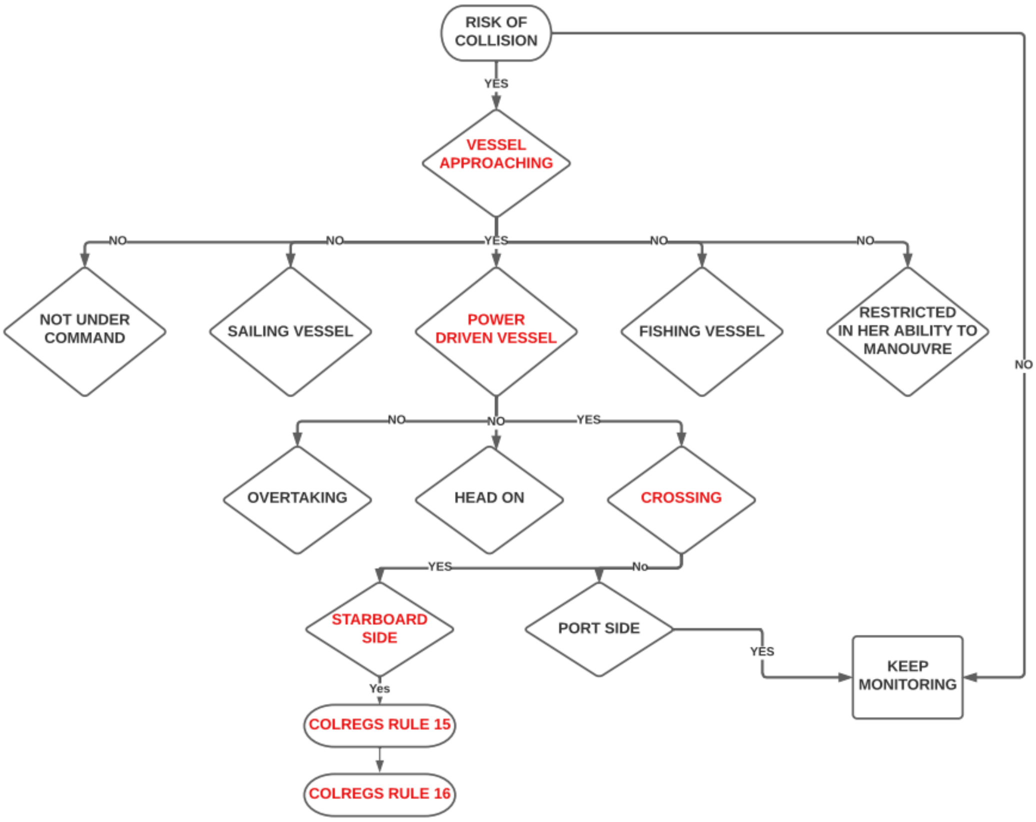


Source: Made by authors

The suggestion is also given to the other ship (target) with appropriate COLREGs rule in the same procedure described for own ship. This possibility is intended to comply with COLREGs rules *Part B Steering and sailing rules* apropos rules when they are in sight of each other (Rule #11 – Rule #18). This feature can also help the OOW as a reminder of who is in a particular situation Give-Way and who is a Stand-On vessel (*Rule 18 - Responsibilities between vessels*). In addition to COLREGs rule B, if the navigational status of another ship on AIS is correct, it may also comply with COLREGs rules *Part C: Lights and shapes*.

The concept of the integration procedure which enables suggestion of appropriate COLREGs rules is presented as a flowchart decision-making model (*Figure 3 Example of a Flowchart decision-making model)*.

Figure 3 Example of a Flowchart decision-making model



Source: Made by authors

The first step begins with determining whether the risk of a collision exists, based on a ship-to-ship route exchange (STM) and determining a meeting point. If there is no risk, the algorithm "monitors" the data continuously to prevent the risk occurrence. If there is a risk, the algorithm determines the type of the target approaching the ship. Since the STM system receives AIS data from the surrounding ships, the algorithm determines who is the Give-way, and who is the Stand-on vessel, respectively. In the above example, the approaching target is a power-driven vessel. The algorithm then determines the direction from which the target is coming. In the case of a crossing situation from the starboard side, the algorithm decides and determines that it is a case of COLREGs regulation No. 15 "Crossing situation" and No. 16 "Action by give-way vessel" and the suggestion is given to the OOW on proper action instantly, as per COLREGs regulation. Afterward, the OOW decides whether to use the suggestion or not.

For the development of the COLREGs/STM integration concept, the decision tree represents a sound method for the decision-making model creation. Considering its predictive features based on Classification and Regression Trees (CART) logic, as well as considering the concise nature of COLREGs, the structure of the tree can be properly built. There need to be predefined inputs that will make the root nodes, internal nodes, and leaf nodes of the decision tree. It all starts with the root node, or in the case of the example above, the risk of collision. The root node is then followed by the internal node and the leaf node. The internal node acts as the decision-making mode, while the leaf nodes of the tree contain an output variable that is used to make a prediction.

In the case of two vessels approaching with a risk of collision, objects are classified into two decision classes: give way and stand on vessel objects. Furthermore, the objects are classified with the output of yes/no data, leading to the final COLREGs rule proposal (leaf node) which becomes visible to the user (OOW).

Although conceptual, the proposed model has a considerable potential to facilitate OOWs' navigational tasks and to clarify ambiguous situations in terms of decision support.

4. DISCUSSION

Rule 5 of the COLREGs regulation clearly states that "*Every vessel shall at all times maintain a proper look-out by sight and hearing as well as by* ***all available means*** *appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and or the risk of collision*"[13]. Available means include technology installed in vessels to aid navigation and reduce the risk of collisions at sea which would certainly include the idea of integration of COLREGs/STM.

The biggest advantage of this feature is its ease of use. At contrary, the proposed model may be a problem in multi-ship encounter situations with more complex traffic situations. The idea is that the algorithm in that situation determines and gives an optimal solution (suggestion) of what to do according to the priorities of the target. The problem may also appear if the crew of the other ship forgets to change the navigational status on the AIS. This can lead to giving false suggestions to the OOW in case of Part C of the rules. This problem could be solved by "asking" the OOW before the ship-to-ship route exchange whether all AIS data is up-to-date and ready for exchange, thus reminding officers of the update of their navigational status. All these observations have to be considered in the further development of the proposed integration concept.

The idea of the COLREG/STM integration is conceived only as a proposal or a reminder of the rules. In any case OOW has the overall responsibility for navigation decisions and suggestions do not release OOW responsibility of keeping watchkeeping duties appropriately as well as doing appropriate collision activities in accordance with COLREG.

5. CONCLUSION

With increasing market and related increase in maritime transport and traffic, the risk of collisions at sea in the future is expected to rise. Despite continuous advances in technology in the shipping industry, ship collisions still occur with emphasis on the human factor as the main cause. Analysis of the data has shown that wrong interpretation and lack of knowledge of COLREGs rules are one of the main causes of collisions at sea and it is necessary to find ways to reduce them. The shipping industry is increasingly turning to machine learning technology for new possibilities. Machine learning technology nowadays has the potential to improve shipping operations and reduce the risk of marine accidents and increase safety at sea. The authors believe that by incorporating the rules (COLREGs) into the already existing way of exchanging the route (STM), with implementing dedicated machine learning algorithm can reduce the risk of collisions and near-miss situations.

The proposed rudimentary model based on Classification and Regression Trees represents a simple yet powerful approach to predicting errors and oversights which could potentially lead to unwanted situations. The presented study was based on a specific scenario and the employment of specific COLREG rules. The development and validation of a comprehensive algorithm together with the engagement of other related external factors remains a matter of further work. Also, the adaptation of the algorithm to more complex situations and particular areas represents a reasonable continuation of the research.

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