Scientific Journals
of the Maritime University of Szczecin

Zeszyty Naukowe
Akademii Morskiej w Szczecinie

2022, 69 (141), 91–97
ISSN 1733-8670 (Printed)
ISSN 2392-0378 (Online)
DOI: 10.17402/502

Received: 28.10.2021
Accepted: 09.12.2021
Published: 31.03.2022

Analysis of communication ontology between sea-going vessels in real collision situations

Paulina Hatłas-Sowińska[1]✉, Mirosław Wielgosz[2]

[1] https://orcid.org/0000-0002-5761-2994
[2] https://orcid.org/0000-0002-3113-5018

Maritime University of Szczecin, Faculty of Navigation
1–2 Wały Chrobrego St., 70-500 Szczecin, Poland
e-mail: [1]p.hatlas-sowinska@am.szczecin.pl, [2]m.wielgosz@am.szczecin.pl
✉ corresponding author

Keywords: navigation, e-communication, ontology, automation of communication, IT ontology, collision, marine accident

JEL Classification: C020, C63, N7

Abstract

This article explores the use of ontology for semi-automatic marine vessel navigation and ship-to-ship communication to mitigate collision risk. Semi-automatic vessel communication is a step towards automatic communication for autonomous ships. Examples of how such communication can be used is discussed, based on a comprehensive analysis of selected marine collisions, with particular attention to the communication conducted on ships. The effectiveness of such communication was assessed and compared. The suggested solutions are based on the review of official reports from accident investigations. The novelties of this work include original ontologies and interfaces. Through this work, it could be possible to fully automate communication processes between ships. In future work, the research results in this work will be used to create a system of automatic communications for manned and autonomous vessels.

Introduction

A basic marine navigation requirement is to ensure the safety of ships at sea by avoiding dangers during transit. One factor causing dangerous maritime transport situations is the lack of adequate communication between marine navigators. Specifically, the most common type of accidents are navigational accidents resulting from human error. In this sense, the 80-20 rule (Harrald et al., 1988) can be applied to shipping, where 80% of accidents are due to human error, and the other 20% are caused by technical failures. As it stands, the communication between current marine navigators is highly sensitive to errors. Modern communication systems do not fully protect ships from possible navigator mistakes, especially in a collision situation, as indicated by statistical data.

One of the basic conditions for making correct communication decisions is to possess all the necessary information (Pietrzykowski et al., 2016). Decision making in complex situations may require the collection of specific additional information and arrangements to be made between the parties concerned in a decision-making situation. This applies not only to social or social-technical systems, but increasingly to technical systems too. In the case of technical systems, as it stands most of the processes are controlled by humans. However, these systems are becoming more and more autonomous (e.g., unmanned, remotely controlled and autonomous aircraft or submarine vehicles).

The progress of autonomous marine transportation technology in the world has reached such a level of development that in some countries new legal acts are starting to be introduced (e.g., in Finland). Meanwhile, institutions in the UK are examining the benefits of artificial intelligence in transport (SAFETY4SEA, 2021).

The slower progress of artificial intelligence (AI) developments in the maritime industry is related, inter alia, to the complex problems of ship safety and security, and the need to combine different sets of data to fully exploit the advantages of AI. Specific problems that currently exist include navigating in difficult waters with dense vessel traffic, where access to up-to-date navigational information, including movement parameters of other ships is critical. A major obstacle may be the lack of access to the information necessary in a given situation, information overload leading to difficulties in its processing, and problems in communication between transport participants (mainly between ship navigators at sea). Communication problems vary, from the lack of information, messages being misunderstood or improperly formulated, to the misinterpretation of exchanged information. Therefore, automation becomes essential for the acquisition, selection, processing and presentation of navigational information as well as communication processes, which are carried out so far manually by navigators, and land-based vessel traffic center operators. One way to solve these problems is the use of ontology-based models. Ontology is a theory that systematically sorts collected data according to their classifications. Lexical analysis in ontology-based analysis brings tangible benefits and opportunities for expanding in any useful context of the development.

In the work of Pietrzykowski et al. (Pietrzykowski et al., 2011) a general concept for a communication system was proposed, which focused on the automation of data exchange in maritime transport. In this work, the intermediate step before achieving automatic communication was described as semi-automatic communication. To develop the automation of the mentioned processes, additional development of ontology-based analyses for navigation and communication is required.

State of the art – communication processes at sea

Communications currently taking place at sea are based on statutory (international conventions) requirements for ship equipment and personnel qualifications. Collision Regulations (COLREGs) have also been established as part of an international convention. Detailed procedures for intership communications are defined by the International Radio Regulations issued by the International Telecommunications Union. However, the communication process itself requires a wide analysis of the situations based on existing procedures and shipboard equipment and systems.

The COLREGs are designed to enable ships to make standard maneuvers, such as overtaking or passing, and collision avoiding maneuvers, without using voice communication and/or radio electronic communications (the latter should be effective without voice communication). For ships seeing each other, maneuvering, warning sounds, and light signals are permitted. However, the ambiguities and discrepancies in the interpretation of terms, such as the “safe distance”, “in good time”, “alter course to starboard” or interpretation of meeting situations (e.g. overtaking or crossing courses) have introduced the practice of verbal communication between navigators when ships meet.

The very high frequency (VHF) radio telephone is the preferred device for navigator verbal communication, with the generally used VHF channel 16 for distress, safety and calling, and subsequent change to a working channel. One disadvantage of this method of communication is that a vessel may be incorrectly identified or that the ship responding to the call is not the one being called. Another form of communication is Digital Selective Calling to transmit digital signals, which uses VHF channel 70, and then the ships change to a chosen voice channel. In both cases, the VHF channel depends on the height of the ships’ antennas, which in ship-to-ship communication averages 30 NM. Communications use ships’ unique Maritime Mobile Service Identity (MMSI) number, but it may be misinterpreted on the radar or ECDIS screen. However, in newer radars, this problem is not typically seen, given ARPA and ECDIS systems present automatic identification systems (AIS) in vessels.

Unambiguous communication is also possible using the AIS system, but it has a mini keypad using scrolling letters, which makes users reluctant to type on it. More convenient ECDIS keypads can be used if the AIS receiver is connected to it. Routine communication can be performed by a ship’s navigator if they possess the appropriate GMDSS operator certificate.

The communication process is divided into key elements consisting of the sender (or caller), the receiver, and the message. The process starts with the caller initiating the communication via coding the message for the receiver. Then, the communication channel is selected, to convey the message. Once the message reaches the receiver, the message is decoded. However, this last step depends on the perception capabilities of the receiver and it must be ensured that ship-to-ship communications are unambiguous and accurate. Thus, the sender must convey their messages in such a manner that the receiver will understand them unequivocally. To accomplish this, the communication process should follow a defined ontology-based model that describes concepts hierarchically, to determine the semantic relationships in the given field.

Research – application of ontology for a semi-automatic communication system

The concept of semi-automatic communication is understood as the exchange of queries, intentions, warnings, etc. by navigators using a user interface and using ontologies in this field. Ontology deals with the discovery and description of "what is it", in the form of a message, based on our minds and perceptions, written by the means of various symbols. It is ontology that allows us to formalize knowledge, and demonstrate clear-cut representations of the specific knowledge (Basser, 2004). It describes concepts hierarchically for the determination of semantic relationships in a given field. Ontology is characterized by a logic theory that introduces limitations to logic models. Some define it as conceptualization (Gruber, 2008).

Ontology, built for marine communication, is based on two planes: navigation ontology and communication ontology. The differentiation of these two ontologies is essential because they encompass completely different issues from different fields. Communication ontology runs via functions interpreting and generating messages. To visualize communications, interfaces are created.

Based on the definition of A. Meadche from 2002, ontology was written as formula (1), in which the set O defines the structure of concepts and relations between them:

$$O = \{O_k, O_n, f_g, \mathrm{rel}, A\} \tag{1}$$

where:

O_k – set of all concepts of the communication ontology,

O_n – set of all concepts of the navigation ontology,

f_g – generating functions,

rel – defined non-taxonomic relations between concepts,

A – set of axioms (selected axioms of the multiplicity theory).

The navigation ontology is built on specific marine vocabulary systematized to ensure its full clarity in message comprehension. The following classes are distinguished, based on the Standard Marine Communication Phrases (IMO, 2021): navigational information, maneuvers, events, wheel orders, engine orders, and objects, supplemented with the taxonomy of navigational information, based on (Kopacz, Morgaś & Urbański, 2014). These are the main classes, to which instances, or subclasses, are assigned, containing corresponding values (e.g. numbers). Communication ontology takes into account actual information acquisition and sharing processes and negotiations between traffic participants. It includes the type of message, (e.g., question, demand, answer), and defines its structure, featuring the heading and message body. These are needed for the unambiguous interpretation of messages. Ontology was built using the Protege program (Protégé, 2013). It presents the created structure of individual ontologies by defining the above classes of hierarchy (Figure 1).

The functions f and g are expressed by the formulas:

$$f : Y \times X \to K \qquad f(y_n, X_k) = K_i \tag{2}$$

$$g : K \to Y \times X \qquad g(K_i) = (y_n, X_k) \tag{3}$$

where:

$Y = \{y_1, y_2, ..., y_l\}$ – set of messages with the assigned category, $(l \in N)$,

$y_n \in Y$ – selected type with the message category assigned to it, $(1 \leq n \leq l)$,

$X = \{x_1, x_2, ..., x_m\}$ – set of navigational terms, $(m \in N)$,

$X_k = \{x_{k1}, x_{k2}, ..., x_{kj}\} \subset X$ – set of terms in k-th message,

k – numeral of the message sent $(k \in N)$,

K – set of messages,

K_i – i-th message from set K,

$K_i = \{s_{in}, s_{i1}, s_{i2}, ..., s_{ij}\}$ – individual words, used in the message, $(i, j, n \in N)$,

where:

s_{in} – n-th word in i-th message K_i from set Y,

s_{ij} – j-th word in i-th message K_i from set X.

Non-taxonomic relations between concepts are divided into relations in communication ontology and relations in navigation ontology. For a transmitted

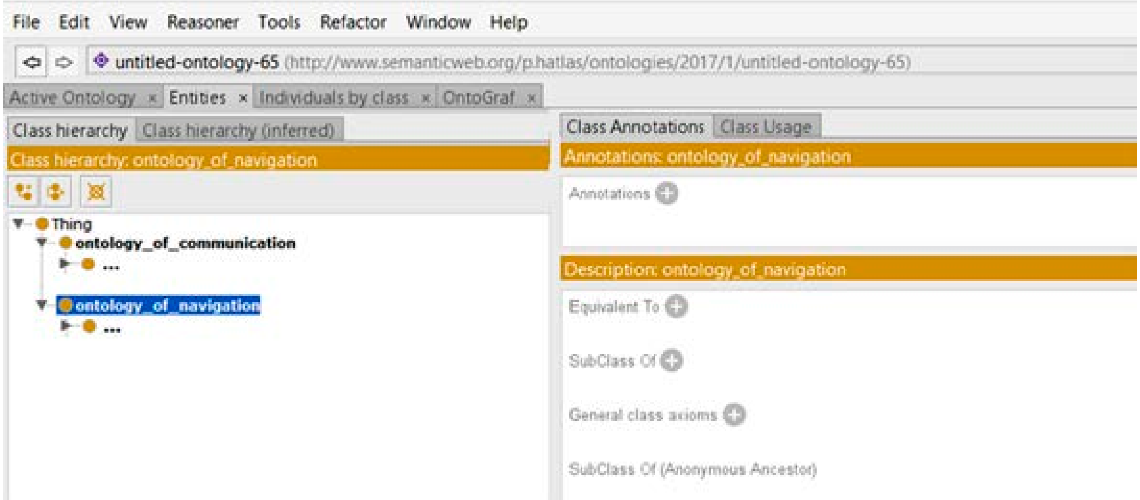


Figure 1. The ontology developed by the authors, presented in Protege v. 4.3 (fragment)

message to be unambiguous, relations are assigned in communication ontology: each type of message corresponds to one category. In navigation ontology, relations existing between navigational concepts have been created so that no contradictions occur in understanding these concepts.

The set of axioms contains selected axioms of the multiplicity theory: Zermelo-Fraenkel axioms, including the axiom of choice, enabling accurate subsets links from set X and similarly, from set Y.

The entire ontology can have an oval structure (Pietrzykowski et al., 2016), which is a natural manner for representing data hierarchy (physical and abstract objects, concepts, etc.). Trees, another form of ontology representation, facilitate and speed up search and work on sorted data; the tree trunk is the ontology, and the path is a series of branches stemming from the tree.

Research – examples of operation

An example of the ontology in use is presented below by examining the case of an actual ship collision, where official investigations have already been completed and official details of accident reports are available. The analyzed situation was carefully reproduced in the ECDIS simulator, taking into account ships sizes and types, movement parameters and hydrometeorological conditions.

The ECDIS simulator was extended with an AIS signal recorder developed at the Maritime University of Szczecin. During the research experiment, the verification of the interface performance, using simulated data from an AIS system was recorded to verify the conformity of the simulation with the contents of the official reports.

In the verification process for the functioning of communication and navigation ontologies, the above-mentioned station was connected with two standalone stations equipped with an interface for transmitting unambiguous ship-to-ship communications using the defined ontologies. The operators of the simulated ships and the connected ontology interfaces were experienced merchant ship officers. Selected accidents known from official reports were simulated and reproduced several times, then the navigators' actions were modified, based on the ontology.

Below is a description of the collision of the ships "Fu Shan Hai" and "Gdynia" (DMA, 2021).

The accident occurred on 31 May 2003 north of Bornholm Island (Baltic Sea) in daylight, with visibility above 10 NM (Figure 2). The distance from the scene to the nearest navigational hazard, a sand bar, was 3 NM. There were several fishing vessels whose movement parameters were not a direct collision hazard for either ship. The only signal transmitted

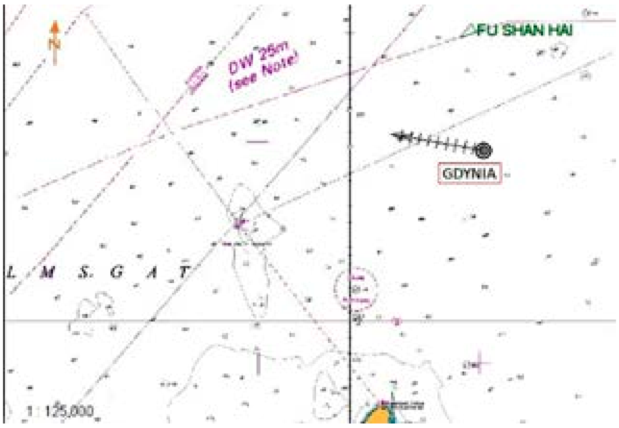


Figure 2. Initial settings of the ships: "Fu Shan Hai" and "Gdynia" in the ECDIS system

Table 1. Description of the collision of the ships "Fu Shan Hai" and "Gdynia", with ontological interpretation

Communication from the report	Analysis of the communication	The proposed communication
Messages, which did not prevent the ships from collision: **Gdynia**: At 1209: *I am altering course to starboard. The final course is ...'.*	– communication too late. – action too late. – correctly sent 5 short blasts at 1210. – Officer of m/s "Gdynia" waited too long to alter course to starboard.	The communication should have started at 1205 (due to the reduced distance to less than 3 NM) **Fu Shan Hai:** *What are your intentions?* **Gdynia:** *I intend to give way, altering course to starboard.*
Fu Shan Hai: At 1213: *I stopped my engine.*	– "Gdynia's" maneuver was not substantial (the OOW was not observing whether the maneuver was effective). – incorrect action (non-compliance with the regulation referring to the ship having the right of way, which should maintain its course and speed).	**Fu Shan Hai:** *Ok, I am standing on.* [Officer of m/s "Gdynia" should have monitored his maneuver and increased the course alteration – larger rudder angle to starboard, if not effective – reduce speed]. **Gdynia:** *Confirmed.* **Fu Shan Hai:** *Your action is not effective. I demand that you give me the right of way.* **Gdynia:** *Ok, I will turn more to starboard.* **Fu Shan Hai:** *It should have started maneuvering, due to the low value of CPA, turn to starboard.*

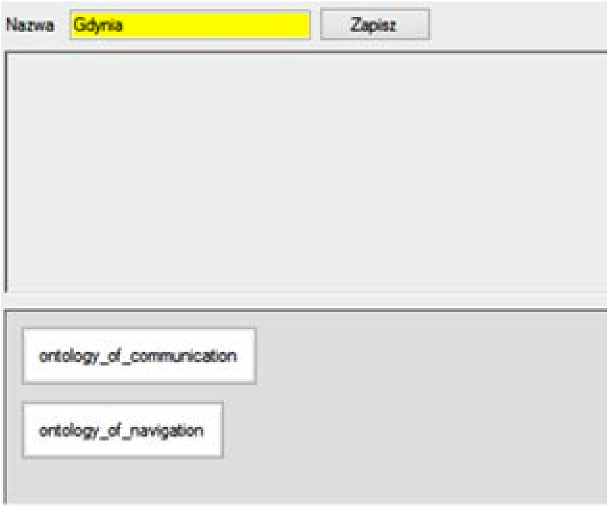
during the collision situation was five short blasts (doubt signal) from the "Fu Shan Hai". Table 1 presents the sequence of events, with the ontological record.

An example record of a message based on the ontology for the "Fu Shan Hai", is as follows:

- "Fu Shan Hai" – first message (K_1):
  $f(y_1, X_1) = K_1$, $y_1 = \{Q\_\text{intention.}\}$,
  $X_1 = \{\emptyset\}$,
  where: X_1 – empty set.
- "Gdynia" – first message (K_1):
  $f(y_1, X_1) = K_1$, $y_1 = \{T\_\text{information}\}$,
  $X_1 = \{x_{11}, x_{12}, x_{13}\}$,
  $X_1 = \{$(course), (alter course), (to starboard)$\}$,
  where:
  x_{11} = course, x_{12} = alter course,
  x_{13} = to starboard.
- "Fu Shan Hai" – second message (K_2):
  $f(y_2, X_2) = K_2$, $y_2 = \{A\_\text{information}\}$,
  $X_2 = \{x_{21}, x_{22}\}$,
  $X_2 = \{$(identification of situation), (keep the course and speed)$\}$,
  where:
  x_{21} = identification of situation,
  x_{22} = keep the course and speed.
- "Gdynia" – second message (K_2):
  $f(y_2, X_2) = K_2$, $y_2 = \{\text{Roger}\}$,
  $X_2 = \{\emptyset\}$,
  where: X_2 – empty set.
- "Fu Shan Hai" – third message (K_3):
  $f(y_3, X_3) = K_3$, $y_3 = \{T\_\text{demand}\}$,
  $X_3 = \{x_{31}, x_{32}\}$,
  $X_3 = \{$(identification of situation), (give way)$\}$,
  where:
  x_{31} = identification of situation,
  x_{32} = give way.
- "Gdynia" – third message (K_3):
  $f(y_3, X_3) = K_3$, $y_3 = \{\text{Roger}\}$,
  $X_3 = \{\emptyset\}$,
  where: X_3 – empty set.

Figure 3 presents a dialogue window for conversation between the ships "Fu Shan Hai" and "Gdynia" that took place through the installed interface.

Assessing the maneuvers, we can conclude that the actual actions and exchange of messages lacked



Nazwa Gdynia

Figure 3. The window of ontology-based dialogue

the control of the effectiveness of the maneuvers. The communication and actions of the two ships at an apparent close quarters situation were hesitant and incorrectly performed. Despite the evident guilt of the "Gdynia", which failed to give way appropriately (the maneuver was not substantial), the ship "Fu Shan Hai" acted against the COLREGs and stopped the engines, which eliminated the effect of "Gdynia's" maneuver and consequently led to the collision. It was also noted that the "Gdynia" failed to change speed.

Discussion – assessment of the effectiveness of the communication-based developed ontology

The latest methods in the field of communication are based on the introduction of intelligent conversational systems, i.e. computer programs designed to simulate an intelligent conversation through text or verbal methods (Inżynieria Wiedzy, 2018a,b). These programs are divided into two categories: Infobots – provide information in the form of a conversation on a given topic and Chatterbots – designed to talk on any topic. Examples of smart personal assistants are: Google Assistant, Siri, Alexa.

Semi-automatic communication is the transition stage to fully automatic communication. Future lines of research will focus on developing communication with more than two ships. The limitation at this point is priority definition (i.e., the importance of messages and the order in which they are sent). It was found in this article, assessing ontology effectiveness and operation, that criteria such as the clarity of communication, effectiveness and time of message transmission, reception and interpretation were all crucial. Firm improvements were observed in the clarity and the effectiveness of the communications, which would have resulted in the avoidance of the dangerous situation analyzed. It was observed that in the research experiment undertaken, participants had to be familiar with the ontology interface (system not currently used on ships), to shorten the time of message transmission. The reception and interpretation of the messages were not found to affect the length of communications. All analyzed collision situations were solved by keeping safe distances and correctly applying the COLREGs.

The dynamically developing IT industry introduces newer and newer communication proposals, in all areas of life (Rydzak, 2017). Communication interfaces have also been developed in industrial systems. In the field of transportation, where road transport has made the most advancements, results have not yet been disseminated and commercialized (PwC, 2019).

There are also no solutions for obtaining automatic communications through ontology. Therefore, the authors focused on developing semi- and fully-automatic communications based on the created communication and navigation ontologies.

Conclusions

This study has demonstrated the positive impact of ontology in the communication between ships. Additionally, it was demonstrated that the application of the relevant ontology for communication systems could lead to collision avoidance. However, the application of the proposed solutions is not limited to collision or close-quarter situations. Early communication, conducted as proposed in this study, will allow marine navigators to solve potentially dangerous situations, give them more time for analysis and situation development awareness, and will reduce the stress associated with last-minute maneuvers.

In this study, it was also found that the correct implementation of applicable Collision Regulations and navigational procedures would have been sufficient to avoid the collision cases considered. However, judging current practice and the number of collisions happening, it was found that at times they are not properly followed. Human errors are due to fatigue, rush, pressure on OOWs, lack of experience and poor knowledge of maritime English; the primarily standard maritime communication language. Automatic communication aims to increase the level of safety in maritime transport by improving communication systems.

References

1. Basser, A. (2004) *Ontology Engineering*. Newspaper IT 2 (21). pp. 42–47, 16.
2. DMA (2021) Danish Maritime Administration. *Casualty investigation reports*. [Online] Available from: http://www.dma.dk [Accessed: February 10, 2021].
3. Gruber, T. (2008) *Ontology. Entry in the Encyclopedia of Database Systems*. Ling Liu and M. Tamer Özsu (Eds.), Springer-Verlag.
4. Harrald, J.R., Mazzuchi, T.A., Spahn, J., van Dorp, R., Merrick, J., Shrestha, S. & Grabowski, M. (1998) Using System Simulation to Model the Impact of Human Error in a Maritime Risk Assessment. *Safety Science* 30, 1–2, pp. 235–247, doi: 10.1016/S0925-7535(98)00048-4.
5. IMO (2021) International Maritime Organization. Resolution A.918(22) IMO Standard Marine Communication Phrases. [Online] Available from: https://www.imo.org/en/OurWork/Safety/Pages/StandardMarineCommunicationPhrases.aspx [Accessed: May 22, 2021].

6. Inżynieria Wiedzy (2018a) *Istota, historia, ewolucja*. [Online] Available from: http://www.inzynieriawiedzy.pl/systemy-inteligentne/programy-konwersacyjne/istota-historia-ewolucja [Accessed: August 22, 2021].
7. Inżynieria Wiedzy (2018b) *Ontologie dostępne w internecie*. [Online] Available from: http://www.inzynieriawiedzy.pl/ontologie/dostepne-w-internecie [Accessed: August 22, 2021].
8. Kopacz, Z., Morgaś, W. & Urbański, J. (2014) *Information of maritime navigation: Its kinds, components and use*. Institute of Navigation and Hydrography, Naval University of Gdynia, Poland, pp. 53–60.
9. Pietrzykowski, Z., Hatłas, P, Wójcik, A. & Wołejsza, P. (2016) Subontology of communication in the automation of negotiating processes in maritime navigation. *Scientific Journals of the Maritime University of Szczecin, Zeszyty Naukowe Akademii Morskiej w Szczecinie* 46 (118), pp. 209–216, doi: 10.17402/139.
10. Pietrzykowski, Z., Hołowiński, G., Magaj, J. & Chomski, J. (2011) Automation of Message Interchange Process in Maritime Transport. *TransNav, International Journal on Marine Navigation and Safety of Sea Transportation* 5, 2, pp. 175–181.
11. Protégé (2013) *Protégé v. 4.3*. Stanford University, CA, USA.
12. PwC (2019) *Transport przyszłości. Raport o perspektywach rozwoju transportu drogowego w Polsce w latach 2020–2030.* [Online] Available from: https://www.pwc.pl/pl/pdf-nf/2019/raport-transport-przyszlosci-2019.pdf [Accessed: November 22, 2021].
13. Rydzak, W. (2017) The European Communication Monitor – the direction of change in company communication with stakeholders. *Zeszyty Naukowe Polskiego Towarzystwa Ekonomicznego w Zielonej Górze* 4, pp. 276–286.
14. SAFETY4SEA (2021) [Online] Available from: https://safety4sea.com/ [Accessed: June 20, 2021].

Cite as: Hatłas-Sowińska, P., Wielgosz, M. (2022) Analysis of communication ontology between sea-going vessels in real collision situations. *Scientific Journals of the Maritime University of Szczecin, Zeszyty Naukowe Akademii Morskiej w Szczecinie* 68 (140), 91–97.