Constructing Knowledge Maps for Situation Awareness of Maritime Autonomous Surface Ships

Rongxin Song, Eleonora Papadimitriou, Rudy Negenborn and Pieter van Gelder

November 3, 2022

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R Song[a*], Dr. E Papadimitriou[a], Prof. R R Negenborn[b], Prof. P H A J M van Gelder[a]

[a]*Safety and Security Science Group, Department of Values, Technology and Innovation, Delft University of Technology, The Netherlands;*

[b]*Department of Maritime and Transport Technology, Delft University of Technology, The Netherlands;*

*Corresponding author. Email: R.Song@tudelft.nl

Abstract

Many projects related to maritime autonomous surface ships (MASS) have been proceeding to date, which promotes the commercialization of MASS. It is anticipated that there will be ships with different degrees of autonomy coexisting in a waterborne transport system (WTS) in the near future, forming a mixed waterborne transport system (MWTS). To ensure navigational safety, the ship needs to be well aware of the situation in real time. As such, it is essential to unify the SA framework for MASS to eliminate the inconsistency with human operators. It is challenging but necessary for a MASS to accomplish the process of situation awareness involving perception, comprehension, and projection. Especially the part of comprehension is the core element that needs to be addressed well and enhanced further. One possible way to reach it is to integrate the information given by the perception layer, projection layer, as well as additional domain knowledge like navigational rules to conduct further analysis. Accordingly, the current paper proposes a method for knowledge integration of SA for the MASS. The method realizes four capabilities of SA to satisfy relevant requirements in maritime domain: a general map, risk assessment enrichment, temporal and dynamic features, as well as a supplement of domain knowledge. For that purpose, the paper takes two steps: (i) constructing a SA framework for MASS, in which the entities related to SA are classified to different categories. (ii) proposing an ontology-based SA comprehension model where the information of entities are integrated together and then the SA can be depicted for MASS in real time. A case study is provided to present how the model can be applied in maritime domain, in which a MASS is approaching a port executing its tasks. As a result, the proposed method can relate the information provided by both the perception and projection layers, and domain knowledge in the form of a knowledge graph to depict the real-time situation. The results show that the method is feasible to provide potentials to the MASS to be aware of the situation in real time considering domain knowledge. The method can be applied to MASS for the information fusion of situation awareness, which also can be supplied to Maritime Safety and Security (MSS) organizations such as Maritime Safety Administration or Coast Guard for traffic surveillance of WTS.

Keywords: MASS; MWTS; situation awareness; knowledge integration; ontology

1 Introduction

In recent years, there has been an increased interest in MASS that is anticipated to improve the safety and efficiency of WTS, work environment for seafarers (Wariishi, 2019), and reduce the number of accidents (de Vos et al., 2021). In order to promote the development of MASS, more time should be calculated to contend with social and technical factors that have thus far limited MASS reaching its full potential. According to existing research studies and documents issued by International Maritime Organization (IMO), MASS will go through four high-level stages of development: ship with automated processes and decision support, remotely controlled ship with seafarers on board, remotely controlled ship without seafarers on board, and fully autonomous ship, respectively. That means that several ships with different degrees of autonomy, such as manned ships, fully autonomous ships, and autonomous ships controlled by humans on board the ship or on shore remotely, will coexist in a scenario, constituting a new type of waterborne transport system, that is the MWTS. Meanwhile, several safety issues will emerge as well. For example, is a MASS capable to implement consistent actions, as would do a seafarer, in order

Authors' Biographies

Rongxin Song is PhD candidate with the Safety and Security Science Section of the Faculty of Technology, Policy, and Management, and a member of Researchlab Autonomous Shipping, TU Delft. He has a background of maritime technology and transport engineering , and is working on the interaction of human and maritime autonomous surface ships in a mixed waterborne transport system.

Dr. Eleonora Papadimitriou is Assistant Professor with the Safety and Security Science Section of the Faculty of Technology, Policy, and Management, TU Delft. Her research interests lie in transport safety, risk assessment and modelling, user behaviour with emphasis on vulnerable road users, infrastructure safety management and efficiency assessment.

Prof. Rudy R. Negenborn is full professor in Multi-Machine Operations & Logistics. He is head of the Section Transport Engineering & Logistics of Department Maritime & Transport Technology, and of the Researchlab Autonomous Shipping. His research interests include automatic control and coordination of transport technology (including autonomous vessels) in general, whereby he proposes multi-agent system and model predictive control approaches that benefit from real-time information availability and the potential of communication.

Prof. Pieter van Gelder is Professor of Safety Science at TU Delft. He is also head of the Safety and Security Science section and member of the MT of the Department of Values, Technology and Innovation. His research focuses on probability analysis and modelling conflicting values. Finally, he studies the impact of new threats (incl. urbanization, ageing, budget cuts, climate change) on safety and security, as well as the impact of new technologies (robotics, remote sensing, digitization, social media, artificial intelligence) on safety and security.

to avoid collision with a manned ship where MASS and manned ships interplay with each other? The reason of which is that either for a manned ship or a MASS, safety is the first concern that should be met. It is well established that the SA, one of the most important capabilities about safety for MASS, is essential to help MASS maintain a safe navigation state. Hence, there is an urgent demand to proceed with establishing the capability of SA for MASS.

The SA was proposed by Endsley in 1995 (Endsley, 1995). It is a model to describe "what is happening? what does it mean? what might happen next?". There are 3 layers within the SA to take on different tasks, including perception, comprehension, and projection. The SA model has been widely used in different fields, such as aviation (Carretta et al., 1996) (Chiappe et al., 2012), military (KAEMPF et al., 1996) and transportation (Golightly et al., 2010). Likewise, some studies in maritime domain also are carried out to apply the SA theory. A detailed comparison of some representative studies on situation awareness are conducted in table 1.(Glandrup, 2013) gives a method for building situation awareness. (Sharma et al., 2019) conducts an interview to sort out the necessary information for an seafarer in pilotage. (Sui et al., 2021) proposes a method based on complex network theory to assess the situation awareness. (Du et al., 2020) try to enable a ship the capability of obtaining the intention of the target ships surrounding her. (Huang et al., 2016) provides a method of velocity obstacle to assess the situation. Most of current studies on the SA in maritime domain, however, aimed at conventional ships. Few research focused on the improvement of the SA of MASS, such as (Zhou et al., 2019) tries to quantify the SA for a MASS. As we mentioned before, MWTS will arise in the near future with the development and commercialization of MASS. Therefore, the direction of inconsistency avoidance of situation awareness in a MWTS also needs to be focused on. In addition, as mentioned in (Glandrup, 2013), for human operators, different kinds of valuable information related to situation awareness need to be combined, including domain knowledge, sensors data, and the reasoning ability. Inspired by that work, we expect to propose a refined architecture of situation awareness for MASS by referencing the SA theory proposed by Endsley (1995) and the interview results of essential information of SA in Sharma et al. (2019).

Table 1: Overview of the literature comparison of situation awareness in maritime domain

Authors	**Method**	**SA subject**	**Application setting**	**Methods or model applied objects**
(Glandrup, 2013)	Reference to related domain	SA architecture	SA surveillance of WTS for MSS	Group of ships
(Porathe et al., 2014)	Interview	Requirement information	9 common scenarios	Remote MASS
(Huang et al., 2016)	Algorithm-based	SA comprehension and projection	Collision avoidance	MASS & Conventional ship
(Sharma et al., 2019)	Interview	Requirement information	SA in pilotage	MASS & Conventional ship
(Zhou et al., 2019)	Mathematical method	SA quantification	Ship in navigation	Remote MASS
(Du et al., 2020)	Algorithm-based	SA comprehension and projection	Collision avoidance	MASS & Conventional ship
(Sui et al., 2021)	Algorithm-based	SA comprehension and projection	SA surveillance of WTS for MSS	Conventional ship

Therefore, it is worth noting that the study on valuable information extraction related to SA for framework construction of SA aims to facilitate an advanced understanding about the current SA, which can avoid a redundant computation and get a SA graph efficiently and precisely for a MASS. For this purpose, some key problems need to be investigated, such as essential information extraction, refined SA framework building for MASS, etc. In order to reach these aims, the SA theory is introduced. In terms of our purpose, it is important to focus on the comprehension layer of SA, where sensors data, domain knowledge, such as International Regulations for Preventing Collisions at Sea (COLREGs), human experiences, etc., and correlations between them are crucial for a MASS to reach SA, especially in the MWTS. The aim of comprehension scheme enables the MASS to understand what the current situation is and know how to tackle such situation to avoid the inconsistency to the SA with human operators. The comprehension layer of the SA model plays the role of fusing information collected from perception layer and transmitting the elements of the SA to projection layer, which is needed to be investigated in depth. For a MASS, there could be many advanced equipment for an excellent perception, and numerous algorithms for projection. However, without a proper understanding of situation, the SA capability of a MASS is limited despite the advanced perception and projection capability available in the MASS. In contrast, if a MASS is aware adequately of its surroundings, it will be able to make rational and more correct decisions based on regulations and good seamanship. Thus, we propose a method to reach the goal, in which domain knowledge, sensors data, and correlations between them are obtained, calculated, related to be aware of situation sufficiently.

In this paper we focus on exactly refining the framework of the comprehension layer of SA for MASS and propose a proper method to apply the framework on a MASS, which is to empower in the MASS the capability of SA comprehension, in particular to avoid the inconsistency with a conventional ship in a MWTS.

In terms of the primary aims mentioned above, we would introduce a concept to reach this goal well – "SA map". SA map is the primary tool for completing the tasks of the comprehension layer of situation awareness, which is an approach to reach the goal by relating the information related to SA, which are gathered from different aspects.

After that, two questions can be formulated as follows:

(1) What should the capabilities be for the SA map to correspond to the requirements of the comprehension layer of situation awareness?

(2) How to enable the SA map with these capabilities?

To answer the research questions, what we first should do is to determine the content of the comprehension layer of SA. Furthermore, they should be extracted and modelled properly to make a good request to each other for situation comprehension. Finally, the situation can be depicted in the way that an autonomous ship should be aware of the situation.

The remainder of the paper is organised as follows. In Section 2, the key problems of the SA map are described, and desirable capabilities of the SA are introduced. In Section 3, we design a framework to reach the real-time situation awareness for MASS in its travel phases. In Section 4, we present an ontology model for SA map. Furthermore, in Section 5 a case study is given to display how the model works. Finally, in Section6, conclusions and further research are summarised.

2 Problem statement

In this paper, we propose an method to form a comprehension layer of SA for MASS to reach the awareness of situation in real time.

First of all, a novel framework for depicting the SA is given where we make explicit the elements of the SA. Furthermore, in order to enable MASS to formalize the SA map based on the framework, an ontology-based model is constructed. The overview of the SA process for our purpose can be seen in Figure 1 . Data produced by the multi-sensors system of MASS are the analysis premise of SA, including both static and dynamic data related to the perception layer of situation awareness. Furthermore, data are put into data processing and computing module to make further analysis based on risk assessment models and the other computation models such as for spatial topology relationship calculation for the projection layer of SA. Then, the data are extracted into different categories of knowledge, which are connected to each other by relationships into a knowledge graph. Finally, the comprehensive understanding of situation awareness can be expressed with the knowledge graph leveraging the functions of ontology such as reasoning and querying.

3 The framework of situation awareness

The SA is defined in (Endsley, 1995) as: the perception of environmental elements and events with respect to time or space, the comprehension of their meaning, and the projection of their future status. That is the reflection of static objects, dynamic objects, and their behaviours over time and space. In maritime domain, the SA for a MASS is similar with that. For a MASS in the navigation phase, the SA goal of which is to perceive, understand, and predict the status of both static and dynamic objects which have the potential to impact her safety or not in the current WTS. Accordingly, the MASS should be clear of the objects stated in the current WTS and perceive them sufficiently with its sensors equipped. After that, the MASS obtain the information from the perception layer and make a preliminary understanding about the situation with her domain knowledge. At the same time, the information from both the perception layer and comprehension layer are transmitted into the projection layer for prediction by computing the relationships with each other. Finally, the results of the projection layer are fed into the comprehension layer for a deep comprehension about the situation.

Some of the icons in the figure are sourced from Freepik.com

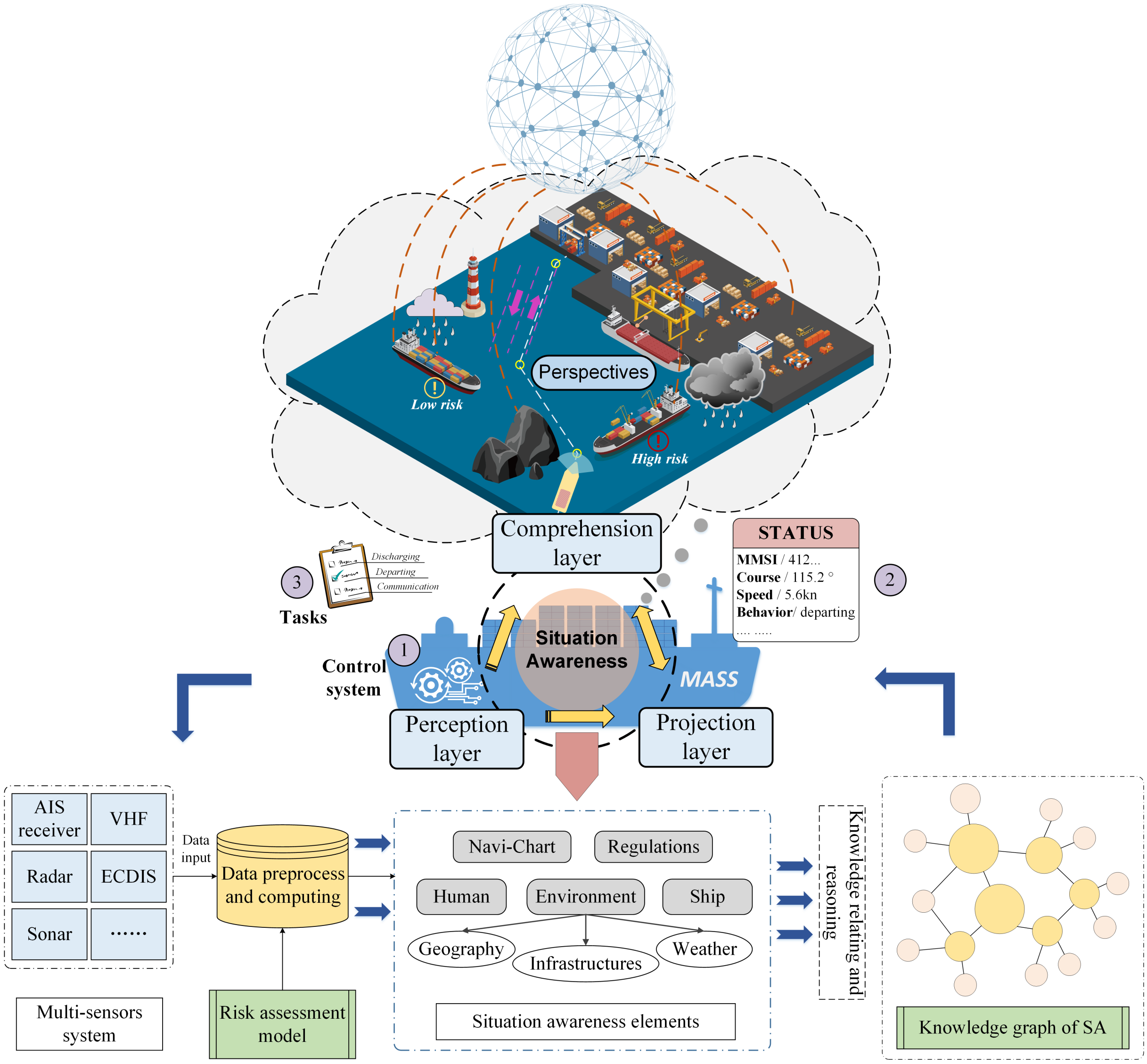

Figure 1: SA map created for MASS to realize the comprehension to situation awareness.

There are some results obtained from interview in (Sharma et al., 2019) related to SA for a ship operator in the pilotage, where the perception layer involves 5 components: ship status, equipment status, route plan, traffic and obstacles, and weather. Accordingly, some more advanced information are extracted in comprehension layer including ship and equipment, route, impact of events, and emergencies, and projection layer involving traffic and route, meteorological data. For a MASS being aware of situation, SA elements are similar with the SA requirements for human operators in the pilotage. Combined this work and SA theory, it can be summarized into 4 capabilities to reach them in the SA map that represents the comprehension layer, which are presented as follows:

- General map to guide ship navigation (ship and equipment status, route)
- Navigational risk assessment enrichment (impact of events)
- Temporal and dynamic (impact of events)
- Domain knowledge enabled (emergencies)

3.1 Definition of the SA in the waterborne transport system

For an explicit modelling of SA map, there is a strong need to distinguish the two terminologies: situation and scenario.

Definition 1: Situation is the evolution of the complete set of elements in a scenario for a certain time period.

Definition 2: Scenario refers to a perspective that the own ship perceives and the tasks to be accomplished at a time slice.

In a word, situation at a time slice is divided into two parts from the perspective of the own ship: the own ship and scenario that the own ship faces.

To obtain a comprehensive insight of situation awareness, MASS should analyse the entities impacting navigational safety located around or in a range of interplay. It is noteworthy that modelling the SA from a global view is unnecessary and impractical, because different awareness could be formed with the difference of the degrees of autonomy of ship and the ship types. Thus, a better standpoint is the own ship itself that the model really serve for. Accordingly, what we should do is to give a standard frame to formalize the process of the SA from the perspective of the own ship. For this purpose, we extract the elements of scenario and of the own ship, respectively.

By referencing the results of (Sharma et al., 2019), we extend and clarify them in more detail, which can be seen in Figure 1, to 9 expanded categories for *Scenario* shown in the dotted box labeled as ”Situation awareness elements”, and 3 categories for *OS* marked with purple circles around the ship.

3.2 Extracting scenario elements

3.2.1 Environment

Environment includes physical entities existing in the surroundings and affecting the navigation state of ships. Common entities are winds, wave, weather, etc. Specifically, it can be divided into 3 categories in maritime domain described as follows.

- Geography

  Geography entities refer to objects that exist in nature originally. For instance, islands, rocks, seabed, riverside, ocean hydrology (such as wave and current). They affect the navigation of ships by influencing their route planning, track keeping, etc.

- Infrastructures

  Infrastructure refers that the objects constructed by human for some purpose. There are many infrastructures in water traffic system encompassing beacon, berth equipment, buoys and so on.

- Weather

  It is very important to be aware of the accurate information of weather, which is closely related to navigation safety, especially visibility which can be impacted by fog, rain and snow. In particular, wind could affect the safety of ships even cause them to capsize instantly. For example, a ship called the ”Eastern Star” that is a river cruise ship, capsized during a thunderstorm in Jianli, Hubei Province (Zheng et al., 2016). The factor of wind plays a primary role in this disaster.

3.2.2 Surrounding Ships

As the main risky source of collision in the waterborne transport, the surrounding ship is one of the most critical factors that should be paid more attention. It is essential to identify the relationship stated in International Regulations for Preventing Collisions at Sea(COLREGs) between the own ship and the target ships from surrounding ships, such as head-on situation, crossing situation, and overtaking situation, according to which, the role of a ship being either a given-ship or a stand-on ship can be determined. However, it is not easy to justify it where some factors need to be considered, such as manoeuvrability (ship constrained by her draught, ship not under command, ship restricted in her ability to manoeuvre), visibility, ship type and so on. Therefore, acquiring the detailed information of target ships and also related information benefiting to deduce the encounter situation is necessary. The latter needs to integrate the evidence from other elements like environment and regulations. Then the actions of collision avoidance can be implemented by participants within the situation by their negotiation.

3.2.3 Human

Humans, as an important factor that cannot be ignored in the waterborne transport system (Ramos et al., 2018), include not only seafarers, VTS (Vessel Traffic Service) operators, but also the company managers, port workers, personnel of search and rescue and other services. The tasks to be completed by the ship always impacted by different human factors that are even more vital in the MWTS. For example, a ship being crossing into the bridge water areas could be impacted the factors from both the management of bridge and the surrounding ships manoeuvred by seafarers. In addition to the human categories mentioned above, there are also some leisure boats, such as sailing vessels, motorboats, water bikes, etc., which could cause some problems for autonomous vessels. Although they are limited by the navigable waterways, they also could make a mistake, for example by straying into the navigation area of a MASS, as the MASS cannot understand such anomalies if they rely only on COLREGs that doesn’t have sufficient regulations to separate commercial vessels from pleasure craft. Therefore, theses humans also need to be carefully considered in case an undesired situation arises.

3.2.4 Regulations

There are some regulations concerning the notifications of navigation in maritime, including COLREGs and local regulations, to guide the ship to sail in various areas. In addition, there are also suggestions of navigational methods made by services about routes designing for controller of the ship. For example, how to approach the port areas and cross the bridge water area safely. They exist with the form of documents which need to be converted by sophisticated human operators into machine-readable information, and then can be applied to ship navigation.

3.2.5 Navigation Chart

A navigation chart provides not only the entities of environment, but also virtual objects like fairway, anchorage, controlled area, etc. Those entities are designed for a certain purpose, such as safe navigation, functional areas and so on. Navigation chart is pretty important for a ship to sail safely and complete tasks efficiently. For a MASS, it is much more vital for its autonomous navigation as the main sensing source that provides most information involving physical and virtual entities which need to be computed then by MASS for a thorough awareness of situation. However, the chart also displays information with some icons or detailed data about those entities, which cannot be used directly to be aware of the situation for MASS. After receiving this information, MASS needs to further transform them to computable objects whose spatial relationships can be acquired conveniently according to spatial topology theories.

3.3 Own ship

The own ship is the initiator of situation awareness. A systematic structure analysis for MASS is important for the SA. According to the SA requirements and scenario elements divided before, we introduce three modules to illustrate available systems which will be called for in the process of the SA: control system, ship status, and task module.

3.3.1 Control system

Control system here refers to the module that is in charge of route designing, decision-making, and actions implementation. It takes over the control of MASS in most regular circumstances, while it transfers the responsibility of control to human operators on board or in Remote Control Centre (RCC) in some emergency situations.

3.3.2 Ship status

Ship status module plays the role of displaying the characteristics of MASS, including motion data and static data. For instance, identification information(ship name, call number, Maritime Mobile Service Identity number (MMSI)), course, speed, location, the number of crewmembers). Additionally, ship behaviour could also be involved in ship status such as the collision avoidance behaviours stated in COLREGs like overtaking another vessel.

3.3.3 Task

Task module takes charge of tasks information storage: 1) navigational information such as routes and waypoints; 2) communication tasks aiming to interact messages with services ashore or surrounding ships; 3) transportation information like cargo type, voyage details such as departure and arrival.

3.4 Functions formation of the SA

As mentioned before, the SA comprises three layers where various the SA tasks are completed. In particular, 4 functions are implemented in the process. For the first function, the spatial relationship calculation is the main task. Spatial relationship calculation involves the relationship between OS and each entity and between entities of current scenario. For this, we introduce two models here to reach this goal: relationship calculation between point, line and surface (Yuanqiao et al., 2021) (represented with STRR-15 in the following part) shown in Figure 2, and Region Connection Calculus model (Randell et al., 1992) for relationship calculation between surfaces, as can be seen in Figure 3 .

For the second function, risk assessment enrichment plays the role of projection of the SA. There have been several kinds of methods for assessing navigational risks, such as ship domain (Huang et al., 2020), collision risk index (CRI) combined both Distance to Closest Point of Approach (DCPA) and Time to CPA (TCPA) and so on. Those methods can be applied to measure risks required by COLREGs such as involve collision risks with, and further to support the SA.

Furthermore, the SA should be a temporal and dynamic process. Therefore, it is necessary to embed time feature in the SA. Once the function is given, MASS can depict a situation dynamically.

Finally, acquiring domain knowledge is supportive to be aware of situation, such as navigational rules - COLREGs, international or domestic law documents, etc. However, there are different regulations to be obeyed for MASS in different scenarios. Hence, an interface is left here to learn the domain knowledge to mingle well in the MWTS.

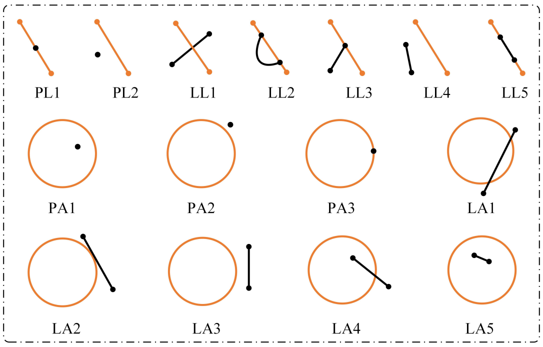

Figure 2: Spatial topology relation representation between point, line and surface.

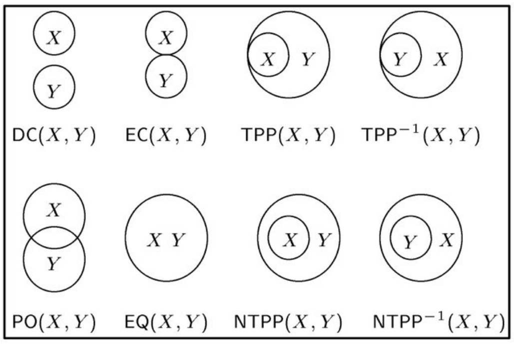

Figure 3: The spatial relationship between surfaces (RCC-8).

4 SA map construction

The primary aim of the SA map is to form a structural knowledge graph in which various objects and whose relationships with each other should be presented. Specifically, the work to construct a SA map includes several aspects: spatial topology relationship calculation, conflict identification based on risk assessment (obstacle including stationary and dynamic), and navigation conditions enrichment (sea condition, weather, navigation plan, traffic condition, policy, relationships obtained from above). The situation awareness comprehension layer can be reached by a MASS considering the knowledge from both perception layer and prediction layer.

In order to accomplish the work of semantic combination, we introduce a promising ontology where various real world scenarios can be represented. It includes different functions such as classes, properties and if-then rules to make up a structural knowledge graph. A network can be raised with different-sources of information by linking the relationship between each entity. The ontology is a method to present the knowledge in a certain domain with related properties and relationships between each other in the domain. Therefore, Ontology is supportive to form the SA map. In the end, a structural network combining those elements can be given for situation awareness.

4.1 Classes

Each element should be one of the classes of the SA map ontology. We use Protégé, a tool for ontology modelling, to construct the knowledge network. SA map contains two main classes: the SA and time. The SA class is divided into the own ship and the scenario, which is consistent with the framework of the SA that we construct and analyse before.

4.2 Object property

Object property is responsible of linking each class to form the whole network. By means of the function, the SA network can be formed by connecting each class that corresponds to the element of situation by their relationships. Afterwards, the network constitutes the situation that MASS is encountering where the inter-ship network(OS and surrounding ships), ship-environment network(OS/surrounding ships and environment), and physical-virtual scenario network(OS, scenario, navigation chart, and regulations) can be depicted and further queried.

4.3 Data property

Data property here is to represent detailed information of each instance, such as speed and course of the own ship, wave height, wind speed, the course of surrounding ships, the role of human operators like VTS operator, port scheduler, manager of ship company, etc.

5 Case study: SA map applied on a MASS approaching to a pier

To validate the feasibility of the SA model proposed, we select a travel phase of a MASS approaching from outside of a port to a pier as the case study to perform how the model works. In the case study, we assume that necessary information involving situation can be obtained from a sensors system, detained information of objects and relationships between one another can be seen in Table 2 and Figure 4.

A MASS called OS-MASS is approaching into the port along with the planned routes: route1, route 2, and route3. There are 3 waypoints for all the routes to change the route to sail along with: waypoint1, waypoint2, and waypoint3. In the process of the approaching, two power-driven vessels that are TS1 and TS2, respectively, are set individually to come up to encounter with OS-MASS by means of crossing situation and head-on situation. The

Table 2: Elements information of scenario around MASS at i^{th} time slice

Entity	Type	t_1 - Scenario$_1$		t_2 - Scenario$_2$	
		Attributes	**Relationship with OS**	**Attributes**	**Relationship with OS**
OS	Own ship	$\{p_1, v_1, course_1,$ MASS$\}$	–	$\{p_2, v_2, course_2,$ MASS$\}$	–
Current	Geography	$Current_1$: $\{V_{c1}, C_{c1}\}$	Active	$Current_2$: $\{V_{c2}, C_{c2}\}$	Active
Wave	Geography	$Wave_1$	Active	$Wave_2$	Active
Wind	Weather	$Wind_1$: $\{V_{w1}, C_{w1}\}$	Active	$Wind_2$: $\{V_{w2}, C_{w2}\}$	Active
Visibility	Weather	$Visibility_1$	$Scenario_1$ has $Visibility_1$	$Visibility_2$	$Scenario_2$ has $Visibility_2$
Temperature	Weather	$Temperature_2$	Active	$Temperature_2$	Active
Pier	Infrastructures	$Pier_1$	OS is PL2 $Pier_1$	$\{line_1$, 90, container quay$\}$	OS is PL2 $Pier_1$
Fairway	Navigation chart	$\{Polygon_2$, Fairway$\}$	OS PA2 Fairway	$\{Polygon_2$, Fairway$\}$	OS PA1 Fairway
Anchorage	Navigation chart	$\{Polygon_3$, Anchorage$\}$	OS PA2 Anchorage & Anchorage within $Scenario_1$	$\{Polygon_3$, Anchorage$\}$	OS PA2 Anchorage & Anchorage without $Scenario_2$
TS_1	Surrounding ships	$\{p_3, V_{TS1_1}, course_{TS1_1}$, power-driven vessel$\}$	OS is crossing with TS1	$\{p_4, V_{TS1_2}, course_{TS1_2}$, power-driven vessel$\}$	–
TS_2	Surrounding ships	$\{p_5, V_{TS2_1}, course_{TS2_1}$, power-driven vessel$\}$	–	$\{p_6, V_{TS2_2}, course_{TS2_2}$, power-driven vessel$\}$	OS is head on with TS_2
$Scenario_1$	Scenario	$polygon_4$	OS is within $scenario_1$	$polygon_4$	OS is without $scenario_1$
$Scenario_2$	Scenario	$polygon_5$	OS is without $scenario_2$	$polygon_5$	OS is within $scenario_2$

visibility for each vessel in the situation is set to be in sight of one another in the whole process. A rock is set as the obstacle, meanwhile fairway, and anchorage are given to show the attribute of general map of the SA map. In addition, the information of weather is also given to enrich the SA map in real time. Two time slices are set to show the temporal features of the SA. After adding these information to the ontology as instances and relationships, the real-time SA map can be displayed with an ontology network.

The results of the model can be shown in Figure 5, which can present various elements of the situation MASS encounters in t_1 and t_2, respectively. The instances are connected to their classes with solid arrow lines and related to each other with dotted arrow lines. By this way, the situation awareness information for a MASS at the two time slices can be related in the form of a knowledge map.

As for complicated statements of rules, such as COLREGs, Semantic Web Rule Language (SWRL) is an appropriate way to formalize them, which can transform human-readable rules to machine readable language. Therefore, the situation of collision avoidance for a MASS in terms of surrounding ships at t_1 and t_2 considering COLREGs can be expressed and deduced with SWRL. As can be seen in Figure 6 and Figure 7, the yellow part

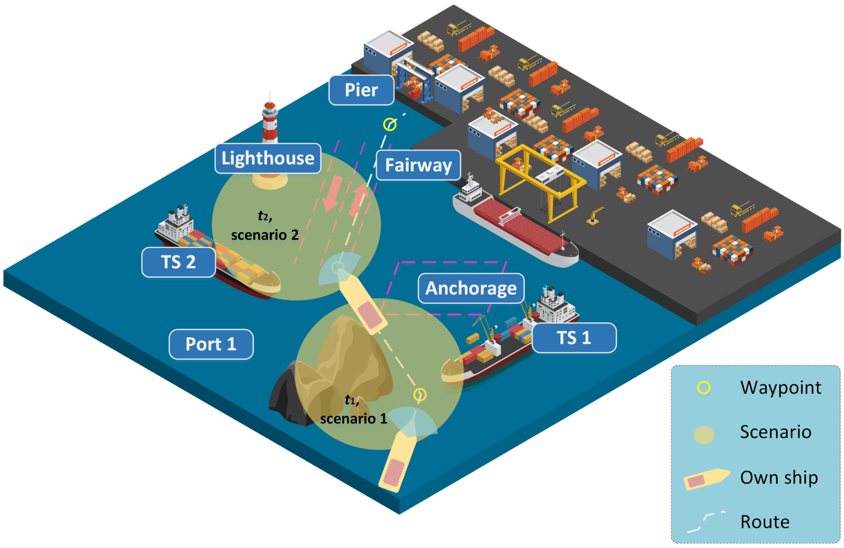

Figure 4: Experiment of MASS in port water areas.

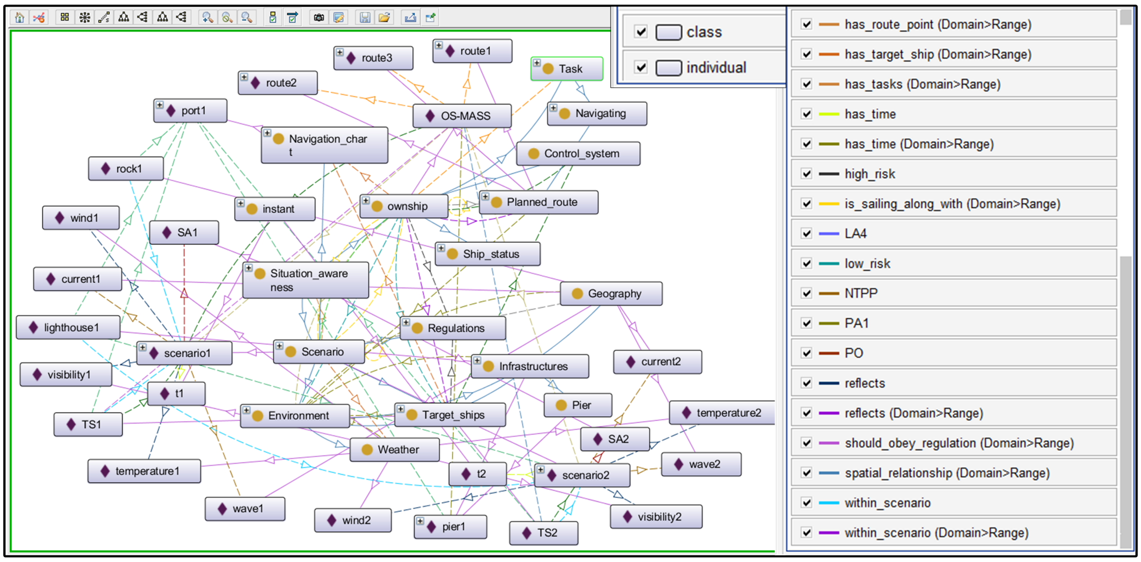

Figure 5: The display of the the general attributes of SA map at t_1 and t_2.

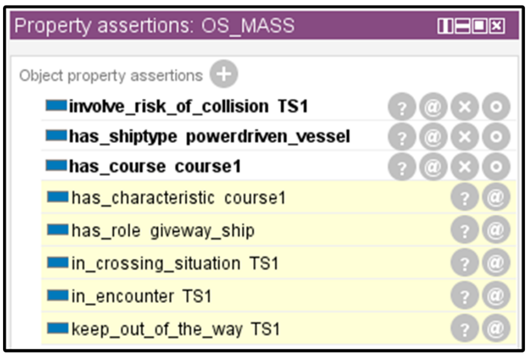

Figure 6: SA results of MASS in the case of avoiding collision with surrounding vessels at t_1 considering COLREGs.

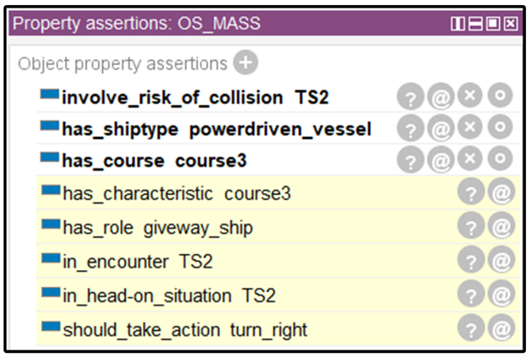

Figure 7: SA results of MASS in the case of avoiding collision with surrounding vessels at t_2 considering COLREGs.

presents what the relationships of the collision stated in COLREGs should be and what MASS can do to avoid the collision complying the COLREGs that have been stated in SWRL.

6 Conclusion and future research

In this paper, aiming to address the problem of the lack of the comprehension capability of situation awareness for MASS, we propose a framework to formulate the elements and process of SA for a MASS, called "SA map". It is applied to the MASS for SA driven by an ontology model where the capabilities proposed are embedded to realize the comprehension. MASS can be aware of situation in some extents by itself leveraging the SA model.

Compared with previous studies, the SA map model provides a refined framework to obtain the valuable information related to situation for a MASS to realize a great comprehension layer of SA. In addition, the approach to realize the framework is a knowledge-driven method that is more explainable for MASS than the methods used in previous studies.

However, there are also some work need to be improved further. We didn't consider the enrichment of risk assessment model and complex domain knowledge such as good seamanship, which should be integrated into the SA map model for further investigation of projection layer. Furthermore, how to do control for a MASS given sufficient knowledge in a MWTS is a problem that needs to be addressed.

Acknowledgements

This work was supported by China Scholarship Council under Grant 202106950002.

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