TRANSNAV
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 12
Number 2
June 2018

DOI: 10.12716/1001.12.02.20

Situation Awareness for Navigation Safety Control

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ABSTRACT: Situation awareness is the key element of the decision-making process. In navigation safety domain, monitoring, control, assessment of dangerous situations, support of operators of decision-making support system should be implemented in real time. In this paper we present the problem of situation awareness applied to navigation safety control. The paper considers existing models of situation awareness and ontology-based approach for maritime situation awareness. We introduce the situation concept using infons. Finally, we give an example how use these methods for design and creation of decision-support system for navigation safety control.

1 INTRODUCTION

In recent years, the interest in the issue of safety had improved considerably around the world. Continuous growth of threats from terrorism, organized crime, illicit drug trafficking, mass immigration and cyberattacks leads inescapably to a demand for constant monitoring for safety of territories and peoples. For monitoring and safety management rigorous methods, new modern technological solutions and corresponding organizational and human resources are needed. Also, we need a new decision support systems that will allow to integrate information and knowledge about the environment in an united information field and to perform joint decision-making for hazard prevention. The major goal of these systems is collection and processing of data from different heterogeneous and highly dynamic information sources. The main problem related with collection and processing of a large volumes of data is an information system's overload. This problem can be solved by identifying the content relevance of a concrete information source. The second problem is connected to analysis and classification of danger situations that influence safety, to generation of concrete solutions and of responses to them. It should be noted that the technology of situation awareness is a key to decision support system in safety domain. This technology allows to support decision makers by means of fusion of all available information, to allocate information more relevant for decision making process and to recognize potentially dangerous and significant situations.

Considering the maritime domain, millions of vessels follow a predetermined course every day. Having analyzed the reports of the marine insurers about maritime incidents, the most cases have happened not in the open sea but near the coasts, close to rivers and canals, where we have the shallow water and heavy vessel traffic. Usually, the pirate attack also occurs in the territorial waters near coasts. The majority of the nautical errors relate to grounding, striking of underwater formations and barriers near coast lines. In 70 to 80 % of cases, the cause of incidents are not technical fault or damage, but the human errors [1]. An inadequate assessment of the situation is the most common reason of making the wrong decision. Therefore, the continuous analysis of current situations and assessment of their influence on the whole maritime situation is needed.

Safe navigation implies collection, processing and identification of relevance of information, obtained from heterogeneous sources. The information sources for dangerous situation awareness can be: AIS, radar data, information about presence of navigational hazards, closed areas, ice and hydro meteorological situations. It should be noted that the information volume increase considerably in heavy vessel traffic areas, in narrow waters and ports. Thus, the critical information could be missed and importance of the available information could be incorrectly evaluated. Ultimately, it leads to the wrong assessment of the dangerous situation. It is worth pointing out that the capacities of the operator on assessment of the current situation are very limited, particularly in the case of the volume of acquired information. The operator can not collect, analyze and interpret this inhomogeneous information quickly and efficiently. For this reason it is necessary to develop new methods and technologies that will help operators in processes of collection, correct processing, situation awareness and interpretation of results.

The major goal of this paper is the expansion of the classical situation theory for maritime safety and description of the principles of organization of collaborative decision making system for maritime safety. Also, we present a new method of situation awareness for maritime domain. This method allows to describe different maritime situations such as vessel collisions, ecological dangers, piracy, navigation under very difficult conditions (ice conditions, meteorological conditions, shallows) in terms of the infons theory.

2 ONTOLOGY FOR NAVIGATION SAFETY DOMAIN

Initial data for maritime situation awareness process is information about vessels, sea objects and environment surrounding them. These data are compiled from different sensors (mechanical, natural) and provide information about properties and characteristics of monitored vessels and others sea objects. The ontology of knowledge representation about maritime objects needs to be developed for realization of the formal approach of data collection from sensors, which monitor environment. The ontology includes information about objects and relations between them, reflects any valid object changes and also measures their impact on the current situation. In addition, the ontology must be complete for realization of the real decision-making system in navigation safety domain.

The notion "ontology" had first been proposed by R. Goclenius and used to refer to the branch of philosophy that studies the fundamental basis of existence. Different notions of ontology in computer science are given in [2] among which we can be emphasize the notion of T.Gruber: "An ontology is an explicit specification of a conceptualization" [3].

The ontology creation process for any system includes:

- definition of the subject domain and ontology size;
- consideration of variants of recurrent-use of the existing ontology;
- listing of important concepts in ontology;
- definition of classes and classes' hierarchy on the basis of "is-a" and "kind-of" relations;
- definition of class properties which are called slots;
- definition of the facet for slots.

The typical components of the ontology are the following:

1 Concept is the complete collection of different individuals that share the most common features which can be more or less significant. While developing ontology of subject domain, the definition of concepts' structure of subject domain and logical relations between them, their identification and formalization is being implemented. The final result of development of subject domain's ontology is a hierarchy of classes containing the concepts of the subject domain and relations between them.
   Each concept is characterized by volume and content. The volume and content of concept is two interrelated sides of concept. The volume is class of generalized objects in the concept, but content is collection of significant features by which the generalization and selection of these objects in this concept is made.
2 Relations integrate classes and describe them. The most common type of relation used in ontology is categories of relationships. This type of relations has several other names such as taxonomy relation, "is-a" relation, class-subclass, hyponym-hyperonym, subsumption relation, a-kind-of relation.
3 Axioms determine the conditions for correlation between categories and relations. They express obvious statements, which are connected concepts and relations. Axiom is a statement, which is entered in ontology performed, and another statement can be obtained from it. They allow to show the information which can not be reflected in ontology through creation of concept (class) hierarchy and different relations between concepts (classes). Axioms allow to take forward the reasoning within ontology. In addition, based on axioms, we can form new rules which allow to automatically add new contextual information into ontology. Axioms can constitute of limitations imposed on some relations and allow to create new statements.

In addition to major components listed above the ontology includes the instances that are concrete elements of some category.

The basic requirements for ontology of collaborative decision-making system for navigation safety domain according to [4] are:

- simplicity: statements and relations need to be simple to use;
- flexibility and scalability: the addition of new concepts and relations in ontology must be clear and accessible;

– universality: ontology should support the different kind of contextual information in navigation safety domain;
– expressivity: ontology should support the description of necessary number of attributes for contextual information in navigation safety domain.

The core of ontology for navigation safety domain is abstract class *Situation*. Subclasses of this class are *Goals*, *Objects* and *Relations*. Entities of the subclass *Objects* can be physical or abstract and can have characteristics (*Attributes*). They also can participate in relations. The class *Attributes* define specific object characteristics such as location, speed, course, vessel's name. The *PhysicalObject* subclass is a specific type of *Objects* subclass which is characterized by following attributes: speed, draught and location. *Relations* subclass define the relation between sets of *Objects*. For example, *inRangeOf*(X,Y) relation means that one instance of *PhysicalObject* X is within the range of second instance of *PhysicalObject* Y. An important aspect of *Attributes* and *Relations* classes is that they include two values which can be changed over time. Each of these classes is connected with *PropertyValues* class and is defined by two time dependent functions, the first characterizes the current value and the other characterizes the changing over time value. A new *PropertyValues* is generated for *Attributes* or *Relations* when *Event* comes on affecting *Attributes* or *Relations*. Therefore, the value of *Attributes* or *Relations* can be defined on request to *PropertyValues* at any time (current, past or future). *Event* contains information about environment obtained from different heterogeneous sources (sensors) at some point in time that influences specific *Attributes* and *Relations*. *Event* contains the specific entities, which signal changes of current situation and thus are the means by which the situation representation evolves.

3 SITUATION AWARENESS FOR NAVIGATION SAFETY DOMAIN

3.1 *Situation awareness*

In the early 1980s of XX century, the situation theory was developed by J.Barwise and J.Perry [5–7] and then was successfully extended by K.Devlin and D.Pospelov [8, 9]. The situation awareness term has many definitions and understandings. For the first time this definition had been introduced by M.Endsley. According to the classical definition, situation awareness is "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" [10]. This basic definition was added by C.Dominguez at al. [11] under which situation awareness includes the four components:
– information about the environment;
– integration of this information with internal knowledge of relevance for mental representation of this situation;
– application of this representation for future study of current situation in perception cycle;
– forecasting the future situations.

In this paper situation awareness is, therefore, understood to mean continuous obtaining of information about the environment from heterogeneous sources in order to provide safety, integrating of this information into knowledge about the current situation and analysis of their impact on safety, forecasting of future situations and assessment their influence on safety. The situation awareness process lies in understanding of surrounding environment and what is going on around for awareness of how information, situations and their impact influence on the concrete goals and tasks in the present and near future. Significant factors, that influences the on the correct and timely decision making in case of dangerous situations, is the availability of complete, accurate and relevant information to decision makers. However, the decision making process in real systems for the event of maritime dangerous developments is complicated by such specific factors as time limit for decision making, accuracy and relevant information limit, incorrect, unexpected and sudden-onset situations which change in real time.

One of the first model for situation awareness was proposed by M. Endsley [12] and includes three level of the information processing:
– Level 1 (Perception of elements in the environment) – perception of the current situation, its properties and dynamic development of elements, related to observed situation, in environment.
– Level 2 (Comprehension of the current situation) – synthesis of the disconnected elements of the situation received on the Level 1, comprehension and processing of information, integration of various heterogeneous data and determination of its significance for particular situation.
– Level 3 (Projection of the future status) – available prognosis of future actions and future situation development based on knowledge of situation status and its elements' behavior, for taking timely decisions on future actions.

Nevertheless, it should be noted that the problem integration of heterogeneous information into a single comprehensive picture of the environment at the semantic level of human comprehension and projection remains open.

3.2 *Situation awareness for safe navigation*

Maritime situation is, therefore, understood to represent a set of parameters which directly or indirectly, defined status of the monitored maritime object at the moment. Maritime situation awareness is an instrument for analysis of specific characteristics and parameters of the monitored maritime object for the purpose the obtained information about its current status and forecasting its status in the near future [14]. In turn, the term maritime situation management implies focused influence on navigation safety decision support system in order to improve the quality of decision making. This improvement is in large part attributable to the changing of properties, characteristics and parameters of the system.

Initial data for maritime situation awareness process are information about vessels (vessel type, draught, stability, floodability), location of areas with solid ice cover, hydrometeorological conditions, location of the closed areas for navigation, location of the environmentally vulnerable areas and others.

For situation awareness in navigation safety domain, it is necessary to have the following:
– information about environment: location of the neighboring vessels, relationship among vessel tracking management system and other vessels, hydrometeorological conditions, status of the marine environment, tide water, steams.
– information about technical and information tools of the vessel such as GPS, AIS, radar, gyro-compass, fathometer, indicator.
– information about spatial orientation: there should be real-time information about dangerous maritime situations.
– time management: it is necessary to have lead time for decision making in case of the dangerous maritime situation.

As can be seen from the above situation awareness for navigation safety implies efficient and sufficient assessment of the current situation as well as prompt forecast of evolution of this situation in the context of environment.

According to [13] the information about situation can be formalized in the terms of infons. Infon is defined as follows

$$\sigma_i = << R, a_1, ..., a_n, \varphi >>,$$

where R is n-place relation; $a_1, ..., a_n$ are objects appropriate for R, that is objects appropriate to the same types as given relation; φ is polarity of the infon. If $\varphi = 1$ then objects stand in the relation R, if $\varphi = 0$ — otherwise. If we apply operations of conjunction, disjunction and situation-bounded quantification to infon, it will allow us to fuse several simple infons into a compound infon. Relationships among situations and infons is called supports relationships. For given infon σ and situation s statement $s \models \sigma$ can be written, which means that situation s supports infon σ.

Distinctive feature of the navigation safety system is recognition of the situation types. System can recognize the various types of objects, various types of the relations, various types of activities, ect. The basic types for situation awareness are the following [8]: the type of a temporal location, the type of a spatial location, the type of an individual, the type of an *n*-place relation, the type on an infon, the type of a type, the type of a parameter, the type of a polarity.

For an object *x* and a type *T* can be written as:

$$x : T$$

that means that the object *x* is of type *T*.

It should be noted that decision for real problems of navigation safety is often made in complex and rapidly changing environment, thus, decision making under conditions of uncertainty becomes paramount importance. For example, the solution task of the navigation safety any activities can have a considerable effect on further development of the current situation.

Any collaboration decision-making system for navigation safety can be split into two subsystem:
– knowledge management subsystem;
– navigation safety subsystem.

Knowledge management subsystem is intended to manage the whole knowledge domain while safety subsystem is implemented for specific monitored object, in this case, for navigation safety. The main tasks of the knowledge management subsystem are the following:
– data analysis of monitored object: it carries out collection of primary data which are obtained from different heterogeneous sources (sensors, radars, etc.) and its transformation into ontological format;
– event management: it generates useful information for monitoring situation on the object in order to ensure safety. There are plan to provide the analysis of retrospective information about dangerous situations and current information about situation on the monitored object.

Navigation safety subsystem allows to:
– implement maritime situation analysis and realization of the most appropriate crisis scenario of current situation development (for example, vessels' collisions, maneuvering in cramped conditions);
– keep logs on the monitored object and give an alarm signal if necessary;
– provide retrospective information about dangerous situations on monitored object at the users' request.

Assessment of the dangerous maritime situations lies in recognition of the following potentially dangerous situations:
– rounding of closed zone for navigation;
– crossing of the border of traffic separation schemes;
– navigation hazards;
– shallow water;
– collision with other vessel;
– navigation in dangerous conditions (solid ice cover, storms, heavy swell, frog, etc.).

From this variety of situations for each object sets of parameters are formed that describe the level of danger for this object along predictable vessel's traffic. The whole information about navigation hazards, shallow water zones, closed zones for navigation, borders of traffic separation schemes collaborative decision making system in navigation safety domain can be obtain from Electronic Chart Display.

Currently, the existing Electronic Chart Display can be divided into three groups:
– electronic chart display and information system (ECDIS);
– electronic chart system (ECS);
– raster chart display system (RCDS).

Electronic chart display and information system is equivalent of the modern paper navigation charts within the requirement of the Regulation V/20 of SOLAS Convention [15]. ECDIS provide characteristics and parameters of chart objects such as guidance, dangers, isobaths, the prohibited and limited areas for navigation and details about the conditions along vessel's route for skippers at their request. In addition to the traditional tasks of ECDIS that include provisional and executive charting, correction of the current location, new ECDIS tasks are the assessment of navigation safety, correction of an electronic chart, organization of advance alarm etc. ECDIS displays accuracy cartographic data in real time in conjunction with current location of vessels obtained from DGPS, GPS. System also processes and reports information from other navigation sensors, for example, hyro-compass, lag, echo sounder, radar. Fig. 1 displays the major components of ECDIS.

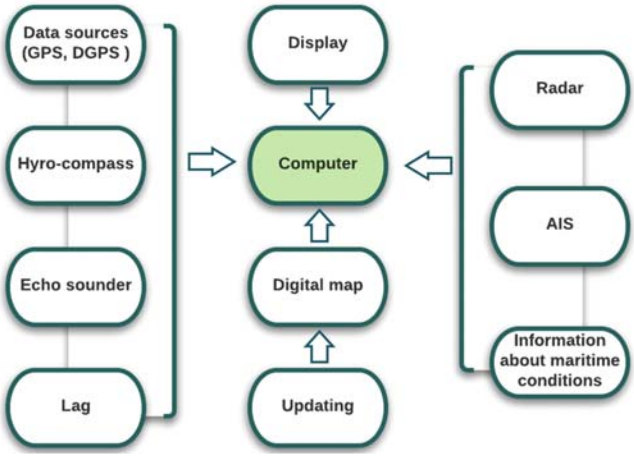

Figure 1. The major components of ECDIS.

4 CASE STUDY

The case study considered in this paper involves the following scenarios of dangerous maritime situations:

- navigation along the Northern Sea Route in complex ice situation;
- navigation in complex hydrometeorological conditions (heavy wind, frog);
- oil spill as a result of two oil tankers' collision.

The situation Navigation along the Northern Sea Route in complex ice situation is called *IceDangerVessel*. For this situation the following relations can be separated:

1 isNear(X, Y): it means the vessel is near an ice cover which influences the future safety of navigation with current values of speed, course and direction. In this relation, the first parameter X denotes an ice cover, and the second parameter Y denotes a vessel. For this relation infon can be written as:

$$IceDangerVessel \models \ll isNear, Ice, Vessel, 1 \gg$$

2 isClash(X, Y): it means collision of a vessel (Y) with solid ice cover (X). Infon for this relation can be written as:

$$IceDangerVessel \models \ll isClush, Ice, Vessel, 1 \gg$$

3 isThreat(X, Y): the occurrence of a given event suggests that the vessel (X) is shackled by the ice cover (Y) and can not proceed with navigation. Infon for this relation is:

$$IceDangerVessel \models \ll isThreat, Ice, Vessel, 1 \gg$$

4 isMoving(X): it points out a unary relation, where the single parameter X denotes a vessel in movement. The infon for this relation is the following:

$$IceDangerVessel \models \ll isMoving, Vessel, 1 \gg$$

Another graphical show of infons for *IceDangerVessel* situation is given on the Fig. 2.

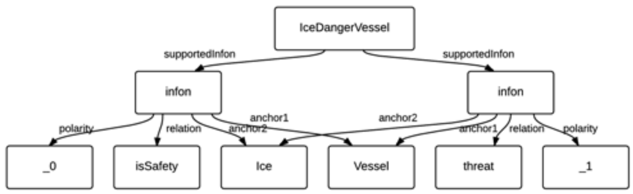

Figure 2. Graphical show for two infons of *IceDangerVessel* situation.

The situation Navigation in complex hydrometeorological conditions is called *WeatherDangerVessel*. This situation is akin to the situation *IceDangerVessel*. For this situation the following relations can be provided:

1 isWind(X,Y): it means that vessel (Y) move in severe storm conditions (X). Infon for this relation can be written as:

$$WeatherDangerVessel \models \ll isWind, Weather, Vessel, 1 \gg$$

2 isFog(X,Y): it points out a binary relation where the first parameter X is the current weather and the second parameter Y is the vessel. Here the vessel navigates in fog-bank conditions. The infon for this relation is:

$$WeatherDangerVessel \models \ll isFog, Weather, Vessel, 1 \gg$$

Fig. 3 shows different representation of infons for *WeatherDangerVessel* situation.

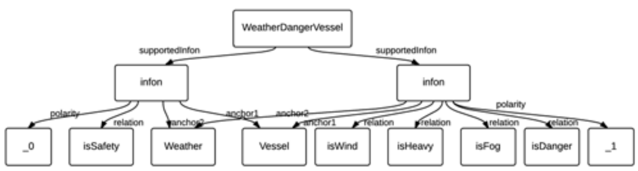

Figure 3. Graphical show of infons for *WeatherDangerVessel* situation.

The situation Oil spill as a result of two oil tankers' collision is called *OilSpillArea*. In case of this situation it is necessary to correct the planned route while taking into account assumed rounding the oil spill zone. The relation involved is:

1 isNear(X, Y): it means that the vessel X is near a zone of the two oil tankers' collision and it observes the oil spill. The navigation safety with current parameters (speed, course, direction) is

impossible. This relation points out binary relation, where the first parameter X denotes the vessel and the second parameter denotes the zone of the oil spill. The infon for this relation is:

$$OilSpillArea \models \ll isNear, Vessel, OilSpillArea, 1 \gg$$

For each infons mentioned above we can define rules which allow to describe the set of all dangerous navigation actions in collaborative decision-making system in navigation safety domain. For development of the rule base of collaborative decision-making system, it is necessary initially to define physical and abstract classes of ontology for navigation safety domain.

5 CONCLUSION

Onrush of information technologies and computer hardware, automation of different kinds of physical and mental human activity implies development of new information tools and technologies to help people. It should be note that situation theory for navigation safety presented in this paper is far from simple in terms of both understanding and realization. However, it is aimed at dealing with complex perceptual and cognitive problems. In any sphere of human activity the effectiveness of decision making in case of dangerous situations is directly related to analysis of environment, collection of the large volumes of data in near real-time. The modern decision support systems can exercise the computerized manipulation of large volume of data both on environment and on security for monitoring region. Vigorously developing of telecommunication systems, data transmission technologies allows to transfer these volumes nearly all over the world. Nowadays, nevertheless, the main problem remains providing precisely those data which are required users for effective decision making in current moment. The technology of maritime situation awareness allows to offer users all necessary information for navigation safety. This technology is a precursor of development of complete collaborative decision making system in navigation safety domain. The major goal of this system is navigation safety and exchange of data from different heterogeneous information sources between all participants in the decision making process. It may be useful to utilize the multi-agent architecture for modeling of the collaborative decision making system. Such architecture allows to make the system works on solution for problem in concrete subject domain and to increase the effectiveness of situation awareness by applying, for example, the theory of fuzzy sets for analysis of dangerous situations. Application of the situation theory and fuzzy methods of decision making in design of decision support systems allow:

- to improve the process of operative navigation safety;
- to monitor the most dangerous maritime situations;
- to share data between different participants of decision making process and navigation safety;
- to make decisions in navigation safety more deliberate and coherent.

Finally, it is appropriate to note that applying the situation theory should be a priority in research where the initial data flows are unstructured, have large volume and incorrect decision making leads to fatal consequences. Also, this theory permits the constant operative control for current situation and forecasting of the future situations taking into account the given information and knowledge.

ACKNOLEDGMENTS

This research was supported by the Russian Foundation for Basic Research (RFBR): grant № 18-07-01203 and was implemented within budget support of SRW SPIIRAS № 0073-2014-0005.

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