TRANSNAV
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 14
Number 2
June 2020

DOI: 10.12716/1001.14.02.18

Recommender System for Navigation Safety: Requirements and Methodology

N. Shilov
SPIIRAS, St.Petersburg, Russia

ABSTRACT: Low maneuverability of ships together with growing intensity of marine traffic result in new challenges related to navigation safety. This paper reports a research aimed at design of methodology of operation of recommender systems for navigation safety. First, a specification of requirements to systems of the considered class has been carried out. Based on these, the major principles of functioning of such systems have been defined. The principles were a basis for development of the mentioned above methodology, which is based on the usage of context patterns and characterized by the presence of feedback to update the system's knowledge base.

1 INTRODUCTION

Currently, in a number of cities of the Russian Federation large projects are going on related to the construction, modernization and expansion of seaports. The development of the shipping industry is one of the key directions of the economy development in the country. However, it entails problems similar to road traffic management. Since the maneuverability of ships is significantly lower than that of the automobiles, and weather conditions have a considerably more significant impact, information support systems for decision-making in the navigation safety domain are paid significant attention. Currently, ships are equipped with sophisticated control systems, evaluating the location of ships around, as well as weather conditions. In the ports and places with particularly intensive marine traffic, centralized navigation management systems are used. However, integration and shared use of information about marine traffic and upcoming maneuvers of ships around to support decision-making when planning ship movement can significantly improve the navigation safety especially in places, which are not equipped with centralized navigation management systems.

Besides, today it is a recognized fact that the paradigm of information systems organization has changed. This is caused by development of such technologies as mobile Internet, knowledge processing automation (cloud computing, crowd sourcing, recommender systems), and the Internet of Things (recently expanded to the notion of the Internet of Everything – the Internet of physical objects, IT services and humans). World-leading consulting companies estimate the pace of the connection of new devices to the Internet as 5.5 million devices per day (in 2020 the Internet of Things will include 20.8 billion devices [1]), and the market volume for such systems by 2025 can exceed 20 trillion USD [2].

These facts confirm the relevance of the new research direction for tasks falling into the class of System- of-System engineering, since the amount of relationships types and relationships themselves greatly increases in such systems as well as opportunities for people and machines to benefit from such relationships and available data. This requires creation of new approaches, models, methods and technologies for the entire diversity of socio-cyber-physical systems (systems that tightly integrate physical world, IT, and humans) at all stages of their lifecycle, taking into account their complexity and dynamics caused by the variety of types of system resources and changing environmental conditions.

In this paper, a decision support system aimed at support of navigation safety is proposed, which can be considered as a typical example of a distributed socio-cyber-physical system operating in a dynamic environment. The paper is structured as follows. The next section presents the state-of-the-art in the considered and adjacent areas. It is followed by specification of requirements to the systems of the considered class. Then the principles of operation of such systems are defined based on the requirements. The methodology built upon the principles is presented in the next section. Finally, the main results are summarized in the conclusion.

2 STATE OF THE ART

The intensive development of navigation, including the Northern Sea Route, requires constant monitoring of the situation from sides of both ground services and ships themselves. As a result, it is necessary to process large volumes of heterogeneous data. Usually, monitoring systems collect information from various sources and display it on digital maps to facilitate the work of decision makers (in this paper, decisions stand for any actions affecting the development of the navigation situation), but in the era of Big Data this is not enough. Intelligent data analysis from heterogeneous sources is needed to support decision making at a new level in order to identify potentially dangerous situations.

Information support of decision-making for navigation safety can be implemented in a number of ways. In particular, it could be a centralized system managing marine traffic in a seaport and the adjacent water area [3], [4] or systems warning about possible emergency situations [5]–[7]. However, today there are no integrated decision support systems that could take into account the current situation and its possible development not only for generation of warnings in case of possible emergencies, but also for solving navigation problems.

Among the systems, which are close enough to the decision support systems in the area of navigation safety, one can refer to the information systems supporting the driver of motor vehicles, which have recently received a significant attention form the research community. Some of them are focused on improving driving safety through tracking the state of the driver and his/her actions. Others are aimed at supporting decision-making related to the convenience of the car usage (navigation, travel planning, searching for parking lots and sights, etc.). One of the first companies to offer automatic recognition of obstacles and collision avoidance was Mobileye [8]. This company offers a number of solutions aimed at interpreting the field of view received by various cameras and sensors to prevent collisions with animals, pedestrians, vehicles and other obstacles, as well as the recognition of road signs and traffic lights. Today there are quite a number of such solutions [9]. For example, HARMAN [10] offers virtual and augmented reality systems that allow the driver should "see" everything that surrounds the car in order to increase driving safety, as well as to perform such maneuvers as lane change and parking. Considering the different needs of different drivers, HARMAN solutions are aimed at providing information in an intuitive way, taking into account the current needs of the driver (for example, for local trips or for long journeys). Unfortunately, such systems cannot be "directly" used for navigation, because they are very strongly tied to the specific features of motor vehicles, however some of the approaches and technologies can still be very useful in this area.

Below, the existing methods and approaches aimed at solving separate tasks, which are parts of the proposed research topic are considered.

Since the system integrating information for decision-making in the area of navigation safety deals with dynamic environment, it has to be context-dependent, i.e. its work has to consider processing the context of the current situation [11]. Context-dependence will not only enable accounting for the updated information about the dynamically changing situation, but also reducing the search space for solutions due to the dropping off information that is irrelevant to a particular situation. In this case the context stands for all information describing the current situation [12]. Context management technology encompasses many processes and technologies that support information gathering, management, and publishing in any form. In context-dependent decision support based on the usage of ontology the information is usually presented in an ontological form. Ontology management, in turn, includes the processes of ontology creation through integration of fragments of existing ontologies, ontology maintenance, re-using, adapting, and evaluation of the ontology for its compliance with the tasks to be solved.

Integration of information from various sources is an integral part of distributed systems, that are the class of systems the considered system falls into. The problem of interoperability, i.e. the possibility of various systems and data sources to work jointly are usually divided into several levels [13]. The most common model includes 3 levels: basic interoperability, structural interoperability and semantic interoperability.

The level of basic (or functional,) interoperability allows the data transmitted by one system to be received by another system. This level, however, does not require that the system on the receiving side could interpret the data. Basic compatibility can be considered as the basis of the communication pyramid, offering the most basic data exchange services. To support the interoperability of the basic layer, infrastructure solutions are used along with various protocols and data transfer standards [14]–[16].

At the middle level, the structural (or syntactic) interoperability determines the format of data exchange that occurs between systems. This level is mainly focused on defining message standards for data transmission. In particular, structural compatibility defines the syntax for data exchange [17]–[19]. Since the content of a structured message cannot be standardized, a higher level of interoperability is required.

Semantic interoperability is at the top of the communication pyramid. This level is defined as the ability of the systems not only to share, but also to use the transmitted information. In this case, the structured message contains standardized coded data. This allows the receiving system to interpret the data [20].

In systems that include various independent elements, semantic interoperability is crucial to bridge the gap in terminology between them, as well as between data sources. To solve this problem, it is necessary to create a common dictionary that provides accurate and reliable communication between the elements of the systems. And if the interoperability at the first two levels today is usually successfully solved due to the existence of different standards, the problem of semantic interoperability must be solved in each specific case because it is impossible to define a single vocabulary for all existing information systems. As a rule, today, ontology management technologies are usually used to solve this problem [21], [22]. Ontologies are the most frequently used and time-tested tool to support semantic interoperability, representing a set of concepts of a certain problem area, as well as the relationship between them [23], [24]. Thus, in this research it was decided to use ontologies for semantic interoperability support within context-driven decision support systems in the field of navigation safety.

To increase the efficiency of processing incoming information, it is proposed to use methods of context management tied together with the ontological information representation. The context in this case refers to a fragment of the ontology of the problem area, including elements and relations between them related to the current task, as well as instances of ontology classes that have parameter values corresponding to the current situation [25].

3 SPECIFICATION OF REQUIREMENTS TO DECISION SUPPORT SYSTEMS FOR NAVIGATION SAFETY

Based on the carried out analysis of the problem domain, the following requirements to decision support systems for navigation safety have been specified:

- information acquisition from distributed heterogeneous sources,
- flexibility and scalability with regard to the types and quantity of information sources,
- responsiveness,
- availability of means ensuring interoperability of system elements,
- proactiveness,
- application of recommender system paradigm.

Below, each of the requirements is described in detail.

3.1 *Information acquisition from distributed heterogeneous sources*

Usually, navigation processes involve numerous participants, which are often independent on each other. These participants include ships, services that provide information about the weather, traffic on the waterways, port infrastructure, etc. This leads to the need to collect and analyze information from different owners, and, consequently, different formats and semantics.

3.2 *Flexibility and scalability with regard to the types and quantity of information sources*

This requirement in some extent follows from the previous one. Depending on how busy a particular area is and if it has developed navigation infrastructure, the number of information sources, their availability, and the availability of certain type of information may vary significantly. Decision support systems working in the area of the marine traffic safety must be adapted to various operating conditions without compromising the quality of information support.

3.3 *Responsiveness*

One of the characteristics of the navigation situation is its variability. As a result, decision support systems in the field of marine traffic safety must continuously track the changing situation and respond to changes, which can lead to dangerous situations.

3.4 *Availability of means ensuring interoperability of system elements*

Since, as already mentioned above, the operation of decision support systems in the area of marine traffic safety support, requires processing information from various independent sources, there is a problem of supporting interoperability, i.e. the possibility of interaction of the system elements. In other words, such a system should be able to extract information from various sources, process and integrate it.

3.5 *Proactiveness*

The dynamic development of the situation related to ship traffic, as well as the rather long response time of large ships to control actions require in advance implementation of actions aimed at preventing dangerous situations. In this regard, decision support systems in the field of marine safety should predict the development of the current situation and not only provide information at the user's request, but also behave proactively, i.e. they have to indicate the possibility of a dangerous situation occurrence and provide the information necessary for making a decision to prevent it.

3.6 *Application of recommender system paradigm*

As already mentioned, to ensure the safety of marine traffic, it is necessary to analyze large amounts of information and take into account many different factors, and it is not always possible for humans to do this. Thus, it is proposed that the operation of decision support systems in the field of marine safety should be based on the principles of recommender systems, which do not only deliver information necessary for decision-making, but also provide for a ranked list of preferred decisions. Currently, there are a large number of models aimed at predicting the development of the navigation situation, the use of which for testing various solutions can significantly improve the reliability of the proposed solutions, and, consequently, the level of marine safety. Existing approaches to decision support in the area of navigation safety are focused on providing information about the current situation and the application of the paradigm of recommender systems in this area is a new result.

4 PRINCIPLES OF BUILDING RECOMMENDER SYSTEMS FOR NAVIGATION SAFETY

Based on the above requirements, the following principles of building recommender systems for navigation safety have been defined:

- service oriented architecture,
- usage of ontologies for semantic interoperability support,
- application of context management techniques,
- application of context templates to identify potentially dangerous situations and self-learning.

The correspondence between requirements and principles fulfilling them is presented in Table 1. Below, each of the principles is described in detail.

Table 1. Correspondence between requirements to decision support systems for navigation safety and principles fulfilling them.

4.1 *Service Oriented Architecture*

Service-oriented architecture allows not only using external sources of information with the ability to connect and disconnect them, but also to scale and adapt the functionality of the system without affecting its other components by adding, eliminating or duplicating the corresponding services. This principle allows the system to meet the requirements of 1 and 2.

4.2 *Usage of Ontologies for Semantic Interoperability Support*

As a result of the analysis of the state of the art in this area, it was concluded that ontologies are the most promising apparatus for solving the problem of semantic interoperability supporting when dealing with heterogeneous independent information sources. However, the use of a single ontology within the system would be complicated due to the highly dynamic information environment (as the ship moves, the sources of information constantly change). It is proposed to solve this problem by fragmentation of ontologies into specialized fragments (aspects). Because of the aforementioned highly dynamic information environment and the independence of information sources, it is either necessary to include all possible terminologies into the ontology, which is impossible, or to match the existing ontology with the ontology of the new information source each time. However, since the manual ontology matching is a very time and labor consuming process, and the currently existing methods of automatic ontology matching are accurate only in narrow domains, the fragmentation of the ontology of the considered system into specialized aspects is seen as a logical and effective solution that allows usage of the automatic ontology matching methods. This principle makes it possible for the system to meet the requirements 1, 3 and 4. The use of multi-aspect ontologies to automate ontology matching within the interoperability support for distributed systems is a new result.

4.3 *Application of Context Management Techniques*

The methods of context management are focused on determining which information is relevant for the current task, and which is not. Thus, these methods allow, on the one hand, increasing the efficiency of the system (requirement 3) by processing only the information directly related to the current task, and on the other hand, increasing the reliability of its work by ensuring that all information related to the task is taken into account. This principle allows the system to meet requirement 3.

4.4 *Application of Context Templates to Identify Potentially Dangerous Situations and Self- Learning*

Context templates [26] are partially instantiated contexts of typical situations, for which it is known what actions are needed to be taken. The main feature of the following this principle when creating a system is the possibility of accumulating historical data about the situations that have arisen together with the actions taken, what allows further analysis. As a result of the analysis, it can be determined which characteristics are the most efficient for the given navigation situation and which of the actions taken have led to its positive resolution. Thus, decision support systems in the field of marine safety get the ability to self-train, i.e. to accumulate the history of typical situations (in the form of context templates) that can lead to dangerous situations, as well as actions to be taken to prevent the dangerous situation, that is, recommendations (requirements 5 and 6).

Table 1. Correspondence between requirements to decision support systems for navigation safety and principles fulfilling them.

Requirements	Principles: Information acquisition from distributed heterogeneous sources	Flexibility and scalability with regard to the types and quantity of information sources	Responsiveness	Availability of means ensuring interoperability of system elements	Proactiveness	Application of recommender system paradigm
Service oriented architecture	+	+				
Usage of ontologies for semantic interoperability support	+		+	+		
Application of context management techniques			+			
Application of context templates to identify potentially dangerous situations and self-learning					+	+

5 METHODOLOGY OF OPERATION OF RECOMMENDER SYSTEMS FOR NAVIGATION SAFETY

This section proposes an original methodology of operation of recommender systems for navigation safety based on the principles defined above and characterized by the presence of feedback to update the system's knowledge base. According to the proposed methodology, the operation of the considered system aimed at identifying the general preferences of user groups, taking into account their confidentiality, consists of the following steps (Fig. 1):

1 Search for available sources of information, establishing communication channels with them and ensuring semantic interoperability through matching the relevant aspects of the system ontology and ontologies of the information sources, which in turn are formed on the basis of the analysis of the message structures from the sources.
2 Collection of the information from sources, translating it to the terminology of the system, formation of the context of the current situation and storing it in the context database.
3 Comparison of the context of the current situation with known context patterns corresponding to potentially dangerous situations.
4 In the case of a detected correspondence between the current context and contexts stored in the context history together with actions undertaken is performed. Possible reasons for the development of the situation to a dangerous state are identified. On the basis of the discovered patterns, new patterns of contexts and corresponding actions are created for both actions leading to dangerous situations and leading to resolution of potentially dangerous situation.
5 In case of determining a dangerous situation, the user is offered a number of solutions (recommendations) aimed at reducing the degree of its danger, until a potentially safe situation is reached. The decisions made (actions undertaken) are also saved in the system's knowledge base.
6 If the current situation is safe, the system continues to monitor the decisions made (if any) and the current situation.

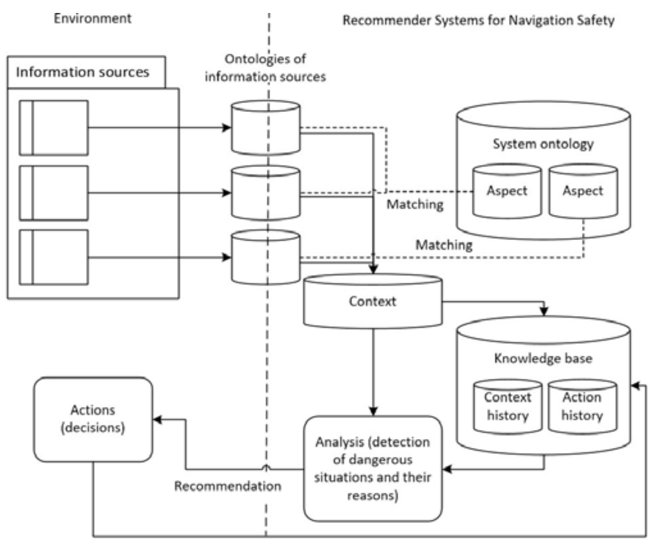

Figure 1. Generic scheme of operation of Recommender Systems for Navigation Safety.

6 CONCLUSION

The paper proposes a novel approach to building recommender systems for navigation safety. Based on the requirement specification major principles of operation of such systems have been identified including (i) information acquisition from distributed heterogeneous sources, (ii) flexibility and scalability with regard to the types and quantity of information sources, (iii) responsiveness, (iv) availability of means ensuring interoperability of system elements, (v) proactiveness, (vi) application of recommender system paradigm. The requirements have been used to define the methodology of the considered systems based on the usage of context patterns and characterized by the presence of feedback to update the system's knowledge base. The future work is aimed at prototyping of the approach in order to investigate the most appropriate solutions for particular aspects of the proposed methodology.

ACKNOWLEDGEMENTS

The reported study was funded by RFBR according to the research project № 18-07-01203 (state of the art analysis, specification of requirements to decision support systems for navigation safety, and the methodology of operation of the above systems) and by the State Research no. 0073-2019-0005 (the recommender system aspects and principles of building recommender systems for navigation safety).

REFERENCES

[1] R. van der Meulen, "Gartner Says 6.4 Billion Connected 'Things' Will Be in Use in 2016, Up 30 Percent From 2015," 2015. [Online]. Available: https://www.gartner.com/en/newsroom/press-releases/2015-11-10-gartner-says-6-billion-connected-things-will-be-in-use-in-2016-up-30- percent-from-2015. [Accessed: 26-Mar-2019].

[2] J. Manyika, M. Chui, J. Bughin, R. Dobbs, P. Bisson, and A. Marrs, "Disruptive technologies: Advances that will transform life, business, and the global economy," 2013.

[3] S. Y. Huang, W. J. Hsu, H. Fang, and T. Song, "MTSS -- A Marine Traffic Simulation System and Scenario Studies for a Major Hub Port," ACM Trans. Model. Comput. Simul., vol. 27, no. 1, pp. 1– 26, Aug. 2016.

[4] B. Dragović, E. Tzannatos, and N. K. Park, "Simulation modelling in ports and container terminals: literature overview and analysis by research field, application area and tool," Flex. Serv. Manuf. J., vol. 29, no. 1, pp. 4–34, Mar. 2017.

[5] S.-L. Kao, K.-Y. Chang, and T.-W. Hsu, "Fuzzy grounding alert system for vessel traffic service via 3D marine GIS," J. Mar. Sci. Technol., vol. 25, no. 2, pp. 186–195, 2017.

[6] E. Krishnamoorthy, S. Manikandan, M. M. Shalik, and M. Kumarasamy, "Border alert system and emergency contact for fisherman using GPS," Int. J. Res. Eng., vol. 4, no. 3, pp. 66–68, 2017.

[7] E. Pratiwi, K. B. Artana, and A. A. B. Dinariyana, "Fuzzy Inference System for Determining Collision Risk of Ship in Madura Strait Using Automatic Identification System," Int. J. Mar. Environ. Sci., vol. 11, no. 2, pp. 401–405, 2017.

[8] "Mobileye," 2019. [Online]. Available: https://www.mobileye.com/. [Accessed: 26-Mar-2019].

[9] A. Taramov and N. Shilov, "A systematic review of proactive driver support systems and underlying technologies," in 2017 20th Conference of Open Innovations Association (FRUCT), 2017, pp. 448– 459.

[10] Harman, "Advanced Driver Assistance Systems," 2019. [Online]. Available: https://car.harman.com/solutions/ advanced-driver-assistance-systems. [Accessed: 26-Mar- 2019].

[11] A. Smirnov, T. Levashova, N. Shilov, and A. Kashevnik, "Hybrid technology for self-organization of resources of pervasive environment for operational decision support," Int. J. Artif. Intell. Tools, vol. 19, no. 2, pp. 211–229, 2010.

[12] A. K. Dey, G. D. Abowd, and D. Salber, "A Conceptual Framework and a Toolkit for Supporting the Rapid Prototyping of Context-Aware Applications," Human–Computer Interact., vol. 16, no. 2–4, pp. 97–166, Dec. 2001.

[13] H. Dibowski, "Semantic interoperability evaluation model for devices in automation systems," in 2017 22nd IEEE International Conference on Emerging Technologies and Factory Automation (ETFA), 2017, pp. 1–6.

[14] P.-P. J. Beaujean, E. A. Carlson, J. Spruance, and D. Kriel, "HERMES - A high-speed acoustic modem for real-time transmission of uncompressed image and status transmission in port environment and very shallow water," in OCEANS 2008, 2008, pp. 1–9.

[15] D. Locke, "MQ Telemetry Transport (MQTT) V3.1 Protocol Specification," 2010.

[16] J. Rodríguez-Molina, B. Martínez, S. Bilbao, and T. Martín-Wanton, "Maritime Data Transfer Protocol (MDTP): A Proposal for a Data Transmission Protocol in Resource-Constrained Underwater Environments Involving Cyber-Physical Systems," Sensors, vol. 17, no. 6, p. 1330, Jun. 2017.

[17] W3C, "SOAP Version 1.2 Part 1: Messaging Framework (Second Edition)," W3C Recommendation, 2007. [Online]. Available: https://www.w3.org/TR/soap12/. [Accessed: 26-Mar-2019].

[18] W3C, "Extensible Markup Language (XML) 1.0 (Fifth Edition)," W3C Recommendation, 2008. [Online]. Available: https://www.w3.org/TR/xml/. [Accessed: 26-Mar-2019].

[19] ECMA-International, "The JSON Data Interchange Syntax," 2017. [Online]. Available: http://www.ecma-international.org/publications/files/ECMA-ST/ECMA-404.pdf. [Accessed: 26- Mar-2019].

[20] P. G. Larsen, J. Fitzgerald, J. Woodcock, R. Nilsson, C. Gamble, and S. Foster, "Towards Semantically Integrated Models and Tools for Cyber-Physical Systems Design," in ISoLA 2016: Leveraging Applications of Formal Methods, Verification and Validation: Discussion, Dissemination, Applications. Lecture Notes in Computer Science, Springer, 2016, pp. 171–186.

[21] G. De Giacomo, D. Lembo, M. Lenzerini, A. Poggi, and R. Rosati, "Using Ontologies for Semantic Data Integration," in A Comprehensive Guide Through the Italian Database Research Over the Last 25 Years. Studies in Big Data, Springer, 2018, pp. 187–202.

[22] Z. Wang, N. Chen, W. Zhang, F. Pu, and C. Du, "Semantic integration of wireless sensor networks into open geospatial consortium sensor observation service to access and share environmental monitoring systems," IET Softw., vol. 10, no. 2, pp. 45–53, Apr. 2016.

[23] F. Carrez, T. Elsaleh, D. Gomez, L. Sanchez, J. Lanza, and P. Grace, "A Reference Architecture for federating IoT infrastructures supporting semantic interoperability," in 2017 European Conference on Networks and Communications (EuCNC), 2017, pp. 1–6.

[24] A. Gyrard, S. K. Datta, and C. Bonnet, "A survey and analysis of ontology-based software tools for semantic interoperability in IoT and WoT landscapes," in 2018 IEEE 4th World Forum on Internet of Things (WF-IoT), 2018, pp. 86–91.

[25] K. Sandkuhl and A. Smirnov, "Context-oriented Knowledge Management in Production Networks," Appl. Comput. Syst., vol. 23, no. 2, pp. 81–89, Dec. 2018.

[26] A. Smirnov, K. Sandkuhl, N. Shilov, and N. Teslya, "Service Self-Contextualization in Cyber-Physical Systems based on Context Modeling and Context Variation," in Joint Proceedings of the BIR 2018 Short Papers, Workshops and Doctoral Consortium co-located with 17th International Conference Perspectives in Business Informatics Research (BIR 2018), 2018, pp. 94–105.