Knowledge Representation in a Ship's Navigational Decision Support System

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ABSTRACT: Supporting the navigator in decision making processes may substantially contribute to the enhancement of the safety in sea transport. The navigational decision support system supplements the existing range of equipment and systems intended for sea-going ship conduct. One of the basic tasks of such systems is an analysis of a navigational situation and solving collision situations. A well functioning navigational decision support system should feature a decision-maker's (navigator's) knowledge representation. This refers to both explicit knowledge - procedural, declarative, heuristic, and tacit knowledge - empirical associations. The article presents assumptions of navigational knowledge base and its realization in the presently designed navigational decision support system.

1 NAVIGATIONAL KNOWLEDGE

1.1 Definitions

There is no consistent definition of both knowledge in general and navigational knowledge. It is assumed that knowledge is the total information about reality and the capability to use it.

Intuitively, knowledge is understood as the ability to behave in compliance with particular standards, norms, regulations and good sea practice.

Navigational knowledge, in turn, is to be understood as a set of data, facts, rules, procedures, strategies and theories combined with the capability of their interpretation and reasoning (Uriasz, 2008). This knowledge allows the navigator to fulfill the basic task of marine navigation, namely safe conduct of a ship from one point to another in any situation. This requirement also applies when the navigator's information is incomplete or unreliable.

1.2 Formal requirements

Navigational knowledge and associated competences are benchmarked and formally confirmed with IMO-approved certificates. The International Maritime Organization, aiming at the global assurance of the safety of navigation, sets forth minimum standards of professional competencies. These are contained in the STCW Convention and the relevant Code and constitute precise requirements for the competencies including the real knowledge and skills of seafarers and their task performance. The Convention in detail defines certain areas of knowledge, methods of its demonstration and assessment. The provisions of the Convention are periodically revised and updated.

The defined areas of navigator's competencies make up a formal description that contains information on the knowledge and its scope, its practical use and methods of performing certain tasks and methods of assessment.

1.3 Scope

Navigational knowledge can be considered from two perspectives: competencies and tasks.

The former refers to the range of knowledge for three levels as specified by the STCW Convention: management, operational and support. The Convention itself, defining minimum competence standards for performing various navigational tasks, specifies knowledge standards for seven functions. These are as follows:
− navigation,
− cargo handling and stowage,
− controlling the operation of the ship and care for persons on board),
− marine engineering,
− electrical, electronic and control engineering,
− maintenance and repair,
− radiocommunication.

The minimum scopes of knowledge are thus defined as necessary for the performance of these functions.

The latter perspective – task-based – simply results from the overall transport objective: carriage of cargo and people (voyage planning, loading, passage to the destination, unloading). To execute the above tasks one needs formalized i.e. acquired knowledge (defined, recognized facts, relationships, interrelations etc.) and, the most important, empirical association, that is knowledge acquired through practice and professional experience.

2 SYSTEM OF NAVIGATIONAL DECISION SUPPORT

2.1 *Assumptions*

The determination of navigators' competencies is strictly related with the assurance of minimum level of safety in shipping. However, satisfaction of these requirements does not eliminate the most common cause of marine accidents – human error. The construction of decision support systems broadens opportunities for the reduction of such errors. Apart from a proper situation display, the function of decision support systems is to automatically analyze and assess a situation and to work out (generate) manoeuvres recommended to the navigator for performance. One such solution comes from the Maritime University of Szczecin, where a navigational decision support system is being developed (Pietrzykowski et al. 2007).

The basic tasks for the system being designed include:

– automatic acquisition and distribution of navigational information,
– analysis of a navigational situation and avoidance of collision situations,
– interaction with the navigator.

The system should allow for the following tasks:
– signaling dangerous situations and the present level of navigational safety based on the criteria used by expert navigators,
– automatic determination of one or more manoeuvres and trajectories of ship movement in collision situations,
– possibility of explaining (justifying) of the proposed manoeuvre,
– display of a navigational situation clear for the navigator.

The navigational decision support system is intended as supplementary to the conventional shipboard equipment. Its correct operation depends on the compatibility with ship's devices and systems. The standard ship equipment includes: log, gyrocompass, radar, echosounder, ARPA (*Automatic Radar Plotting Aids*), GNSS (*Global Navigational Satellite System*), e.g. GPS (*Global Positioning System*), DGPS (*Differential Global Positioning System*), AIS – (*Automatic Identification System*), ECDIS (*Electronic Chart Display and Information System*), GMDSS – (*Global Maritime Distress and Safety System*).

There should be a possibility of adding navigational information from other sources, such as the Vessel Traffic Service (VTS).

The idea of constructing a navigational decision support system goes in line with current directions of developments in marine navigation, including e-navigation. As put in (IMO, NAV 53/13, 2007) E-navigation is the harmonized collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment". Therefore, navigational system of decision support will be a component of an e-navigation system.

2.2 *System architecture*

The system under design is one operating in real time. Its tasks include observation of the ship and the environment, registration of navigational information, its selection, retrieval, verification and processing. The navigator will be presented with the outcome of system processing – information such the identification and assessment of a navigational situation and suggested solutions (decisions) providing for safe navigation.

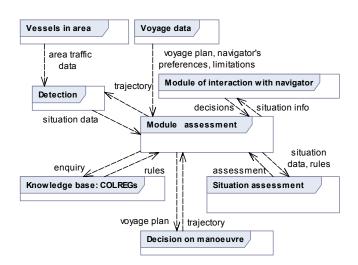The system's general architecture is shown in Figure 1 (Pietrzykowski et al. 2008).

Fig. 1. Architecture of the navigational support system on a sea going vessel

For the implementation of the tasks mentioned in section 2.1. we need to use the knowledge of expert navigators.

2.3 Object of implementation

The system prototype is being tested onboard the research/training vessel *Nawigator XXI*, operated by the Maritime University of Szczecin. Its basic parameters are as follows:
– length overall – 60.21 m,
– beam – 10.50 m,
– draft – 3.15 m,
– service speed – 13 knots.

The vessel has the following navigational equipment and systems :
– GPS:
  • CSI MiniMax (DGPS),
  • Koden KGP-913D,
  • Trimble NT200D (DGPS),
– gyro: Anschutz STD22,
– AIS: Nauticast X-Pack DS,
– radar/ARPA:
  • JMA 5300,
  • Kelvin Hughes NINAS 9000,
– ECDIS: -AG Neovo,
– echosounder: -Skipper GDS 101,
– log: Sperry SRD-421 S.

The ship's equipment provides navigational data needed by the navigator to make the right decisions. The data, after integration, make up a basis for the decision support system operation, i.e. analysis and assessment of a navigational situation and the suggestion which collision avoiding manoeuvre should be performed.

3 KNOWLEDGE IN THE NAVIGATIONAL DECISION SUPPORT SYSTEM

3.1 Types and scope of knowledge

The requirements for the scope of navigators' knowledge comprise procedural knowledge – procedures formulated by experts – and declarative knowledge – of descriptive nature, covering sets of facts, statements and rules.

Procedural knowledge, referring to the principles of behaviour, is mainly contained in all kinds of rules and regulations.

Declarative knowledge, acquired by navigators in the course of studies, training courses and on board ship service, is related with both analysis and assessment of situations and the principles of navigator's behavior.

Both procedural and declarative knowledge is based on theories of various fields and scientific disciplines, navigation in particular.

Taking the system assumptions into account (section 2.1) as well as knowledge standards which are to be fulfilled for various functions to be performed, as defined under the STCW Convention (section 1.3), we decided to limit the knowledge implement-

ed in the system to the function of navigation (problem 1). This knowledge includes two basic layers:
1) planning of a voyage route based on shipowner's shipping-related decisions – weather routing,

2) ship movement control accounting for the monitoring of the safety of navigation:

  – determination of safe course and speed for a present navigational situation bearing in mind the goals defined in layer 1,
  – performance of manoeuvres – rudder and engine settings according to the determined values of the course and speed.

The planning of voyage route is aimed at meeting shipowner's goals. Such planning has to take into consideration the present and forecast hydrological and meteorological conditions (access to weather information) and the knowledge in this respect. Also, the planning process is time-consuming as it requires a lot of calculations. Although it can be done onboard, the task is often ordered to specialized land-based centres. Therefore, we assumed that the planning task will be taken into consideration in further stages of development of the navigational decision support system.

Safe conduct of a vessel following the determined values of course and speed in a given navigational situation is the process that may be divided into several phases:
1 vessel detection and identification,
2 analysis and assessment of the situation,
3 defining the method of solving a collision situation – choice of a preventive manoeuvre – (manoeuvres of course and/or speed alteration),
4 determination of manoeuvre parameters, including the moment to start,
5 performance of a preventive (collision avoiding) manoeuvre,
6 monitoring of the ship conduct process.

The execution of the phases by a navigator requires that s/he has procedural and declarative knowledge as well as the knowledge resulting from the theories of scientific disciplines and fields making up the principles of navigation. The knowledge represented in the decision support system should assure that each stage of safe ship conduct is adequately performed. The implementation of this knowledge requires that its sources, methods of acquisition, representation and use are defined.

3.2 Sources of knowledge and methods of its acquisition

Sources of knowledge for a decision support system are scientific theories and declarative knowledge acquired by navigators during their studies, additional courses and sea service. These make up a basis for systematic principles of behaviour developed in the

form of regulations, recommendations and procedures (procedural knowledge).

Procedural knowledge is particularly useful for such aim as knowledge implementation in the decision support system (Pietrzykowski, 2004). Supplemented with methods, tools and techniques offered by scientific theories covering such areas as navigation, mechanics, hydrodynamics and control, it enables making right decisions to assure the safety of navigation. However, the complex character of systems and real processes and inaccuracies or imprecisions in their description make it necessary to take into consideration the knowledge resulting from navigators'experience (declarative knowledge). It mostly has a descriptive nature and is often expressed through sets of facts (premises and implications). In this approach the knowledge comes from expert navigators.

Procedural knowledge, among others, is contained in official regulations, such as the Collision Regulations or local regulations – in many cases these are very general and their scope of interpretation can be wide indeed. A valuable source of this knowledge are handbooks on seamanship or the theory of ship handling, including information, recommendations and procedures as well as interpretation of regulations prepared on the basis of long time sea service of mariners.

Navigators' declarative knowledge is more difficult to be put into a formal framework. Its main source are facts relating to a specific issue. Such facts are obtained by a variety of research methods:
–   field studies:
    •   observations (passive)
    •   experiments (active)
–   model-based research:
    •   physical (based on material models),
    •   mathematical.

Model-based research is particularly useful when combined with computer-aided simulation methods. The advantage of such research is due to difficulties of real field studies: high costs, limited possibility of registration of varied situations, while in the case of new projects there is no such possibility at all.

In knowledge acquisition, expert studies are an important option. Expert studies can be performed in the form of questionnaires or simulations with experts as participants.

The above mentioned methods have to be supplemented with analytical, statistical and artificial intelligence methods that are needed to identify relationships and dependencies in sets of facts collected by the methods in question. For this reason, artificial intelligence methods, tools and techniques are of particular interest: machine learning, artificial neural networks, fuzzy systems or evolutionary algorithms. These techniques allows to work out a representation of knowledge in the decision support system: directly (e.g. machine learning, artificial neural networks) or indirectly (fuzzy systems, evolutionary algorithms).

Various types of knowledge and the complexity of problems connected with its acquisition make it necessary to use a group or groups of methods.

The following sources and/or methods have been defined for each phase of safe vessel conduct (see section 3.2):

1) detection and identification of a vessel (including parameters of its movement):
    –   analytical methods (verification, selection and integration of navigational data),
    –   artificial intelligence methods (estimation of the state vector of another vessel)

2) situation analysis and assessment:
    –   analytical methods (algorithmization of COLREGs)
    –   analytical methods – closest point of approach (CPA) and time to CPA
    –   expert methods – questionnaires, and statistical methods (situation assessment criteria)
    –   simulation methods with experts' participation and statistical methods (situation assessment criteria)

3) pointing out the method for collision situation avoidance – choice of a preventive manoeuvre;
    –   analytical methods (algorithmization of COLREGs, classical optimization algorithms)
    –   artificial intelligence methods (fuzzy systems, genetic algorithms);

4) determination of manoeuvre parameters
    –   analytical methods (classical computational algorithms, including optimization algorithms)
    –   artificial intelligence methods (fuzzy systems, genetic algorithms)

5) performance of a preventive (anti-collision) manoeuvre
    –   analytical methods (classical control algorithms)
    –   artificial intelligence methods (fuzzy systems)

6) monitoring of ship conduct process:
    –   analytical methods (prediction of vessel movement).

The use of the above methods allows to acquire and implement (representation and use) of navigators' knowledge in the decision support system for safe vessel conduct.

4 REPRESENTATION AND USE OF KNOWLEGE IN THE DECISION SUPPORT SYSTEM

4.1 *Knowledge representation*

The acquired knowledge should be recorded in forms suitable to its purpose or method of utilization. The following methods of representation can be applied:

Database structures. Databases allow to gather sets of data and to record them in a specified manner for the adopted model. They enable efficient edition of data, their updating, archiving and further processing. Database applications in navigation get increasingly wider as information technologies are constantly being advanced. One such example is VDR, voyage data recording. Various facts of a given voyage may be used in the process of knowledge supplementing (situations and manoeuvres performed by navigators). Another example is the conception of WEND - Worldwide Electronic Navigational Chart Database (Hecht, 2007).

The electronic navigational chart represents a basic source of knowledge on a given water area and essentially complements the navigator's knowledge. Its database form enables a choice of the appropriate layers of vector data for the execution of navigational tasks (see 3.1)

Rules and decision trees. Rules represent the knowledge defining the conditions for assigning registered facts to distinguished classes: they define premises, implications and conclusions. Decision trees execute a similar task. They enable solving a classification problem for two or more classes.

Both rules and decision trees constitute such a form of knowledge that is well implemented in expert systems. Decision trees allow to describe the decision process – reasoning.

Decision tables. Another useful form of recording knowledge is its representation as logical decision tables. The table contains a description of a decision situation (DS), which is defined as a set of ordered threes:

$$\left(U_{dz}, H, f_u\right) \qquad (1)$$

where,
U_{dz} – set of possible actions,
H – set of possible results of actions,
f_u – utility function defined on the Cartesian product.

$$U_{dz} \times H$$

In marine navigation it is justified to use this method of knowledge representation, as it enables not only foreseeing the results of a particular decision but also, more importantly, adjusting the right actions to the planned result.

Neural networks. These are mathematical structures able to process signals. Their operation is based on the reproduction of processes taking place in brains of living organisms. In the construction of a neural network, one has to define the network structure, then to carry out the learning process resulting in the correct operation of the network, with a maximum adopted error. Neural networks find applications in approximation problems, image recognition, forecasts, selection, optimization etc.

Algorithms. An algorithm is a convenient and clear-cut method of knowledge recording. In fact, it is a detailed procedure for solving a problem. Recurrent algorithms in particular are very close to natural behaviour of the human being by allowing to present part of a problem instead of the whole. When in operation, the algorithm refers to itself until a solution to the problem is reached. Most problems in navigation are solved in a recurrent method, e.g. voyage planning and passage, planning and performance of a SAR operation, vessel detection and identification. Typical computational algorithms, including optimization algorithms, are an important group. They represent theoretical knowledge that allows to solve specific computation problems, e.g. determination of ships encounter parameters or parameters for performing a manoeuvre.

4.2 *Utilization of knowledge in the decision support system*

The system supporting navigator's decisions has to have the right scope of knowledge indispensable for its functioning. The knowledge recorded in the system will be represented in forms mentioned in section 4.1; these are in particular:

- database structures – in this form the system includes navigational cartographic information. The information, satisfying IHO standards, will make up a basis for presenting current navigational information. All manoeuvre recommendations will account for the vicinity of dangers to navigation.
- rules and decision trees – the navigator keeping a navigational watch does a number of actions: carries out observations, assesses present navigational situations, plans and performs manoeuvres. During these actions the navigator has to classify surrounding conditions and encounter situations by assigning them to various groups, which imply the application of different rules provided by internationally recognized collision regulations (COLREGs). The classification rules - principles used for this purpose in decision support systems may provide a relevant classification as well as contribute to the development of comparable criteria for classification used by navigators. This refers to special cases when the classification is based on incomplete or inaccurate information.
- decision tables – such record of knowledge will contain information on manoeuvres – their parameters, starting moment and effects. The navi-

gator will be left to decide on which manoeuvre to choose (its type and parameters).

– neural network – this will be used for the assessment of navigational safety in an encounter with other vessels; such assessment will take into account the parameters of vessels encountered. It allows to determine an area around the ship that should be maintained clear of other objects - ship domain (Pietrzykowski & Uriasz, 2009). The network will also be used for the determination of collision avoiding manoeuvres. As a universal approximating device, it will also be utilized in the process of state vector estimation of other vessels.

– algorithms – in the decision support system, among others, the interpretation of COLREGs is presented in the form of an algorithm. Based on recurrent algorithms, such operations as vessel acquisition or information decoding is executed. Complex computational algorithms have been used in the integration of navigational data from various shipboard devices and systems. Standard computational algorithms as well as complex optimization algorithms are used for selecting manoeuvres and their parameters.

5 CONCLUSIONS

As the types and scopes of navigators' knowledge and the methods of its acquisition and representation are varied, different forms were used for knowledge implementation and utilization in the decision support system.

The created knowledge base has a distributed nature. It includes the knowledge used in each stage of the process of navigation, or ship conduct.

The decentralized structure of the knowledge base make possible both supplements in terms of scope and representation forms. It can be complemented with navigators' knowledge in the area of voyage planning, and subsequently, it may cover the other six functions (apart from navigation) specified in STCW competence standards for enhanced performance of specific tasks.

REFERENCES

Hecht H. I, inni: *The WEND Concept for a Worldwide ENC Database – Past and Future?*, The International Hydrographic Review, Vol 8, No 2, 2007.

IMO, NAV 53/13. Development of an E-Navigation Strategy. Report of the Correspondence Group on enavigation, submitted by the United Kingdom. Sub-Committee on Safety of Navigation, International Maritime Organization, London, 20 April 2007.

Pietrzykowski Z., *Modeling of decision processes in sea-going ship movement control,* Maritime University of Szczecin, Series Study No 43, Szczecin 2004.

Pietrzykowski Z., Chomski J., Magaj J., Bąk A., Uriasz J., *Aims and tasks of the navigational support system on a sea going vessel,* Advanced in Transport Systems Telematics 2, Ed. J. Mikulski, Publisher Faculty of Transport, Silesian University, Katowice 2007.

Pietrzykowski Z., Magaj J., Chomski J., *Model of navigational decision support system on a sea-going vessel,* Scientific Journals, Maritime University of Szczecin No13(85), Szczecin, 2008.

Pietrzykowski Z., Uriasz J. ,*The ship domain – a criterion of navigational safety assessment in an open sea area*, Journal of Navigation, Vol. 62, 2009.

Uriasz J., *Navigational knowledge base*, Scientific Journals, Maritime University of Szczecin No13(85), Szczecin, 2008.