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Knowledge Base in the Interpretation Process of the Collision Regulations at Sea

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ABSTRACT: The article presents the problem of transforming knowledge contained in the provisions of the International Regulations for Preventing Collisions at Sea, and the so called good seamanship in computer applications. Some methods of knowledge representation in decision support in avoidance of collision situations are compared and examined. Acquisition, representation and sharing of knowledge are taken into consideration from the viewpoint of supplementing the knowledge database and computational complexity.

1 INTRODUCTION

Widely introduced on ships and land-based facilities, navigational information systems are designed to assist users in the decision-making process. Their main task is collecting and presenting information necessary for safe navigation. Currently available technologies give wider opportunities to assist navigators in interpretation of navigational situations and to generate suggestions of possible solutions. This is connected with the observed development of these information systems in the direction of decision support systems. These systems are based on the use of knowledge, which includes: the existing legal regulations, procedures of conduct, principles of good seamanship, navigational theories. The point is to appropriately acquire that knowledge and create its representation, which enables its efficient and effective use. The problem of decision support also applies to the interpretation of the navigational situation in accordance with the International Regulations for Preventing Collisions at Sea (COLREGS). Due to the fact that in certain areas local law may apply, it is also important to take it into account. Assuming that decision support also includes propositions of solutions (e.g., manoeuvres), a knowledge base should contain the principles of good seamanship.

The knowledge engineering is a branch of information technology which deals with issues of knowledge acquisition, representation and sharing. The methods and tools of this new discipline open way to the construction of systems facilitating the interpretation of the sea route regulations and the application of the principles of good seamanship. The knowledge base built in this way can be used as one of the expert system elements, which may be part of a larger decision support system.

2 ASSUMPTION

There are many methods of knowledge representation that can be used in the navigational decision support process. The most important are:

- decision trees, as a representation of possible paths of decision-making depending on the existing and changing conditions;
- logical rules, presented in a simple or complex form, contain the premises and conclusions resulting from them;
- frames that are the base of object-oriented representation of knowledge.

One of the main problems which appears during the design of the knowledge base consists in choosing the proper method of knowledge representation. The decision to choose the proper ways of reasoning is as important as the explanation method and future expansion of knowledge. The selection of these methods is strongly determined by the specificity of the application field, therefore it is important to identify assumptions for a knowledge base and further for an expert system.

The knowledge base should satisfy the following requirements:

- ability to reproduce and verify the rules arising from regulations contained in COLREGS;
- possibility of supplementing the knowledge with special regulations issued by competent authority;
- opportunity to submit informal knowledge contained in the principles of good seamanship;
- open database that allows easy expansion of knowledge;
- simple presentation of the knowledge stored in the database to make it understandable to people who are not systems designers, and easy to verify.

The expert system using the above knowledge base should satisfy the following requirements:

- generation of explicit answers resulting from the knowledge contained in the database;
- interpretation of COLREGS regulations and special rules;
- generation of proposals of actions to be taken arising from the principles of good seamanship;
- explanation of the system response by quoting relevant rules or principles.

An example of the implementation of COLREGS is, designed at the Maritime University of Szczecin, the knowledge base included in the Navigational Decision Support System (NDSS) (Pietrzykowski et al. 2009, Wołejsza 2005). The method of knowledge representation used in this system has a form of decision trees. They give a possibility of checking the subsequent conditions and, on that basis, determining the response of the system. Their main disadvantage is the difficulty of extension, which may cause considerable complexity of the system, and thus the difficulties in the verification of correctness and prolonged time to a response.

Knowledge representation based on logical rules (rule-based knowledge base) is open to change, enables easy verification of accumulated knowledge and makes it possible to offer explanations by simple methods. Due to data security and the systems application field, designers decided that the expert system based on this knowledge base would not be a self-learning system.

3 DECISION SUPPORT SYSTEMS

Knowledge bases are an integral part of decision support systems. According to the theory of information systems, it is possible to distinguish several classes:

- transaction systems, whose main task is to collect full information from trustworthy sources and through simple models to allow the basic analysis and compilation;
- management information systems, which aggregate data from other systems, among them transaction systems; they use cross trend analysis using equation models, that operate on deterministic data, but there may occur shortcomings and contradictions;
- decision support systems, which have an extended data analysis mechanism for probabilistic, often contradictory, incomplete and incorrect; when they assist the decision making process, they use knowledge bases, and optimization and simulation models;
- expert systems, built with the use of knowledge and skills of people who are experts in the appropriate field, which are given as logic and heuristic models;
- artificial intelligence systems, which use a wide range of artificial intelligence methods to perform modelling and analyses.

Because of the wide use of Decision Support Systems, in addition to the foregoing division, they can be characterized by taking into consideration many other factors and criteria. For example, the division can be based on decision-making model or decision-making process modelling (description, prescription). The division by type of controlled system or process comes down to the determination whether the model used is deterministic, statistical or fuzzy. The number of steps in decision-making process (in one step or in n steps), the number decision-makers involved in decision-making process (individual decision or group decision) and the time factor (how the time span is determined to take actions and decisions) are further factors. The next factor characterizing the decision support system is the manner it works – static, when it stops just after giving the answer or dynamic – system that at a given time discretization and at the occurrence of certain events (inputs) operates continuously and appropriately adapts to the existing conditions. Despite the divisions and classifications, which in fact may reflect many aspects, decision support systems, in general, deal with data acquisition, convert information into knowledge and generate answers (decisions) on the basis of the knowledge they comprise.

This division of classes also shows the evolution process of information systems from static to fully dynamic, managing the models in decision support systems (Pietrzykowski et al. 2007). It should also be noted that expert systems currently being developed and artificial intelligence systems are ranked as a subclass of decision support systems.

It is planned that the developed knowledge base will be an element of the system considered as an expert system. With its open formula, cooperation is also possible with the systems that belong to other classes.

4 EXPERT SYSTEMS

A typical expert system could be described as structure presented below:

- user interface – a module which is responsible for interaction between the system and the user (navigator). The module input allows user to ask questions and to specify additional information. The module also gathers input data from other systems. The module output provides the user with answers and explanations;
- knowledge base – data which are characterised by special structure adjusted to store logical rules. The rules are quickly searched for in accordance with given criteria;
- inference mechanism – main part of the system that is responsible for the process of solving the problem. To do so, the mechanism uses knowledge base, logical rules and additional information;
- explanation mechanism – part of the interface that provides the explanation and gives legitimacy for the system answer (decision) (Giarratano & Riley 2004, Jackson 1998).

The most important issues that shall be examined during the process of creating knowledge base of the expert system which offers COLREGS interpretation and gives solutions for aiding navigational decisions are:

- database structure definition;
- data acquisition.

Because the expert system with rule knowledge base is to be considered, specific problems that should be worked out are as follows:

- rules based on COLREGS and local laws or regulations;
- inference mechanisms that are supposed to seek proper rules and formulate conclusions;
- priorities mechanism that is responsible for building proper hierarchy of exact rules and regulations;
- working out the inference mechanism based on good seamanship procedures, that works simultaneously with the mechanism that considers COLREGS rules and local regulations.

5 KNOWLEDGE ACQUISITION

The rules stored in the knowledge base are derived from regulations provided in the COLREGS. The regulations were taken under examination that led to a set of logical rules. The connection between regulations and rules was taken into consideration in rules' notation. It is essential during the explanation process of the answer given by system. The operation of extracting data from special rules can be performed in the same way.

In case of extracting any informal knowledge that accounts for the principles of good seamanship, the process is more complex. For example, Jones or Cockroft diagrams which apply to restricted visibility situations can be treated as such source of knowledge. The knowledge itself must be then checked, verified and supplemented by experts - navigators.

6 SOLUTION

The knowledge base and the system that are proposed will contain a database divided into three parts that apply to:

- rules from COLLISION REGULATIONS,
- rules that concern the principles of good seamanship,
- additional rules that arise from special regulations. It is important to bear in mind that local rules have higher priority than general rules. Therefore, it is possible that some conflicts will occur and corresponding local and general rules may be contradictory.

Ultimately, the proposed expert system is expected to work as stand-alone module or as be a part of Navigational Decision Support System, developed at the Maritime University of Szczecin.

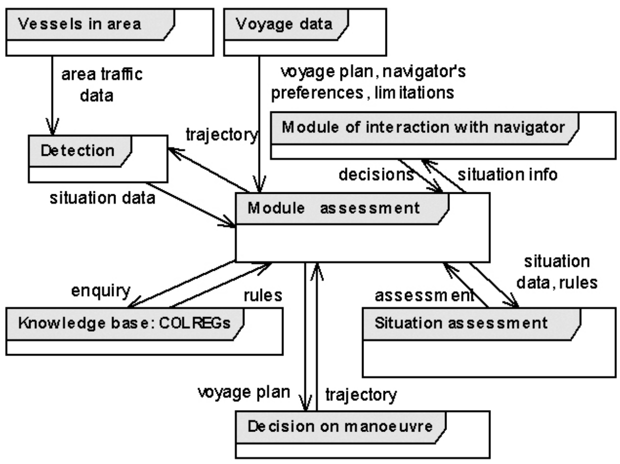

Figure 1. General architecture of navigational decision support system on a seagoing vessel (Pietrzykowski & Uriasz 2009)

The diagram above shows arrangement of the proposed system. It will replace the knowledge base module and take over its function and tasks (Fig.1).

Due to the fact that the knowledge base will be used for building the expert system and consequently it will operate in the decision support system, the following structure of the expert system is taken into consideration (Fig.2).

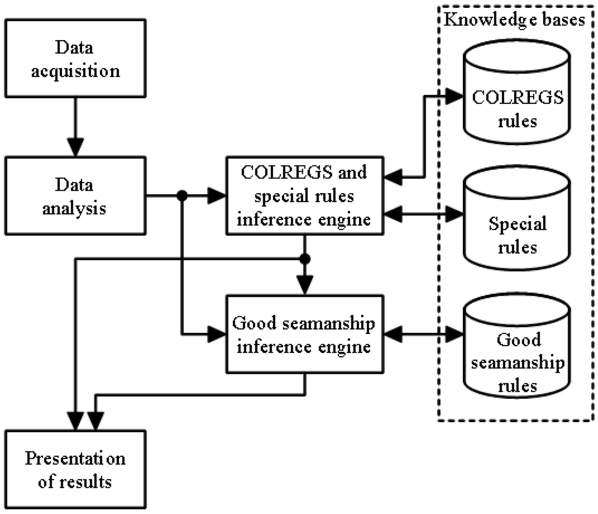

Figure 2. Structure of the proposed expert system.

The functions of the proposed expert system are:

- Data acquisition – the module that acquires data required for the system to work, such as: position, speed, navigational statuses, headings, relative bearings, aspects, weather conditions, etc.;
- Data analysis – the module that analyses acquired data, performs data standardization and calculates formulas and parameters to be used in inference mechanisms;
- COLREGS and special rules inference engine – inference mechanism which performs the interpretation of knowledge contained in the rules stored in knowledge bases; on the basis of data sent from ‘Data analysis’ module, optimal rules are selected – the rules that fit the examined situation. Then, the selected rules are used in forward chaining process and, consequently, the navigator is informed if the vessel is a give-way or stand-on one. In addition, the rules and special rules which are applicable at the moment will be presented.
- Good seamanship inference engine – inference mechanism running in parallel to the above mentioned one, using a knowledge base containing rules reflecting the principles of good seamanship; diagram of operation is very similar to the previous one, but the output gives a suggestion of conduct in a particular situation; the operation of this module is independent from the previous one, so it is possible to give suggestions for appropriate conduct in spite of an absence of priority such as manoeuvres resulting from the Cockcroft diagram for restricted visibility;
- Knowledge bases – set of knowledge bases containing rules resulting from the extraction of knowledge from COLREGS, local regulations and the rules of good seamanship, supplemented with links to relevant regulations and explanations;
- Presentation of results – this module prepares the information obtained from inference mechanisms for presentation and transfers them to the user interface.

Data needed to carry out the inference are derived from a host computer or directly from the navigation systems of the vessel. As assumed, the proposed system always includes all information available. If some data are required and are not among those transmitted, it may be necessary to refine data, taking place via the master system. Obtained data are processed in order to adapt them to the internal representation of knowledge present in the system. This processing is primarily responsible for standardization and for searching for contradictions (e.g., incompatibility of data obtained from different sources, taking into account malfunctions, measurement error or human factor). In the proposed system, input information is obtained in the form of vector data and it may contain contradictions that must be eliminate. The processed data are the basis for the inference process.

Inference mechanisms work with dedicated knowledge bases, which contain rules extracted from the COLREGS, local regulations (special rules) and rules of good seamanship, a transcript of the knowledge of expert navigators, supplemented by other sources of non-codified rules for determining the proper conduct in different situations. The method of writing the rules was adapted to the transferred input values obtained from the data analysis module, enabling the user to find them promptly.

For the storage of rules there is a dedicated database with appropriately designed structure. Defined in this structure are the tables for each set of rules and additional data used in the process for requesting and managing the work of the whole expert system. The first step in the process of inference is performed by a query to the appropriate tables, which results in a set of rules satisfying the conditions compatible with the existing navigational situation. Then, the provided rules of inference will be carried forward, resulting in the generation of a conclusion, passed to the module output.

Because there exist different sets of rules for the COLREGS (and local regulations) and the principles of good seamanship, two conclusions are obtained in parallel: on the right way with an indication of applicable regulation and rules, and the proposed procedure in the situation.

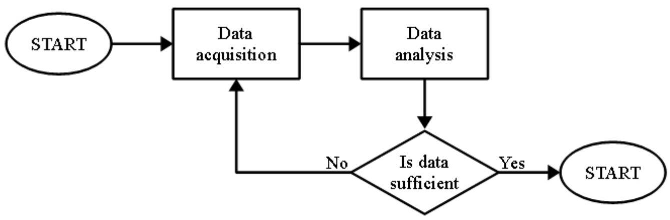

Figure 3. Functional diagram of data acquisition.

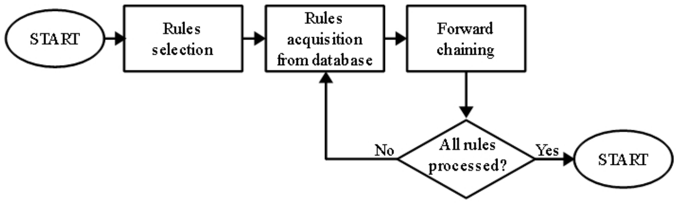

Figure 4. Functional diagram of the inference process.

The system operation is based on the following algorithm shown in Figures 3, 4:

1 Get input from the user interface and navigation equipment;
1 Adapt to the requirements of the input search rules;
2 Find rules matching the analysed situation in the respective knowledge bases;
3 If rules were found in the database with local regulations, they must be taken into account in decision making;
4 If rules were found in COLREGS, determine their hierarchy against the local regulations;
5 Decide on the basis of the rules contained in the databases of local and COLREGS;
6 If emergency arises resulting from the absence of rules and regulations of local COLREGS, acquire again data (clarify) (go to point 1). If the data cannot be refined, send information about the lack of data required to make a decision;
7 If the base of the principles of good seamanship contains rules for the situation, determine suggestions resulting from these rules;
8 Show the results of the expert system work.

Marine navigation equipment and systems on board are the source of input data for running the expert system based on the knowledge base. Where an ambiguous situation is identified, that may result from the inability to establish certain facts, a request will be made to supplement data, for example by a dialogue between system and navigator.

Rules in the knowledge base should be supplemented with additional information, such as the degree of validity of the a rules e.g. rules with the lowest degree of validity are used only to carry out the inference process, rules of higher degree will also appear on the screen as a warning, and a rule having the highest degree will additionally activate a sound alarm.

If the system has an additional knowledge base that contains rules based on local laws, it is possible to automatically take it into account when making a decision. The moment of inclusion or exclusion depends on the geographical position of the vessel obtained from navigational devices (e.g. GPS).

7 EXAMPLES

Below are examples of the proposed expert system functioning. The system receives selected input data and provides a response in the form of conclusions and explanations. The system response and risk of collision which is determined by the decision support system provides the basis for working out the manoeuvre according to COLREGS. The answer is preceded by an analysis of the rules contained in the knowledge base. Examples 1 to 4 are shown on figure 5.

1 Input data: restricted visibility = NO; Distance = 5Nm; Own priority (S1) = 6 (power-driven vessel); Other vessel's priority (S2) = 6; Relative bearing = 005° PS - Port Side; Aspect = 150° SS - Starboard Side; Own speed (V1) > Other vessel's speed (V2)
Conclusion: Give a way
Explanation: conclusion based on rule No. 13 of COLREGS – Overtaking.
2 Input data: restricted visibility = NO; Distance = 3Nm; Own priority = 6; Other vessel's priority = 6; Relative bearing = 100° SS; Aspect = 040° PS; Own speed < Other vessel's speed
Conclusion: Give a way
Explanation: conclusion based on rule No. 15 of COLREGS – Crossing situations.
3 Input data: restricted visibility = NO; Distance = 3Nm; Own priority = 6; Other vessel's priority = 6; Relative bearing = 003° SS; Aspect = 004° PS; Own speed ≈ Other vessel's speed
Conclusion: Head on vessels, Alter your curse to starboard
Explanation: conclusion based on rule No. 14 of COLREGS – Head-on situation.
4 Input data: restricted visibility = YES; Distance = 2Nm; Own priority = 6; Other vessel's priority = 6; Relative bearing = 010° SS; Aspect = 010° PS; Own speed ≈ Other vessel's speed
Conclusion: all actions should be taken to avoid collision – reduce your speed.
Explanation: conclusion based on rule No. 19 of COLREGS (all actions should be taken to avoid collision).
5 Input data: restricted visibility = NO; Distance = 10Nm; Own priority = 6; Other vessel's priority = 6; Own speed ≈ Other vessel's speed
Conclusion: none
Explanation: The distance is considered as safe.

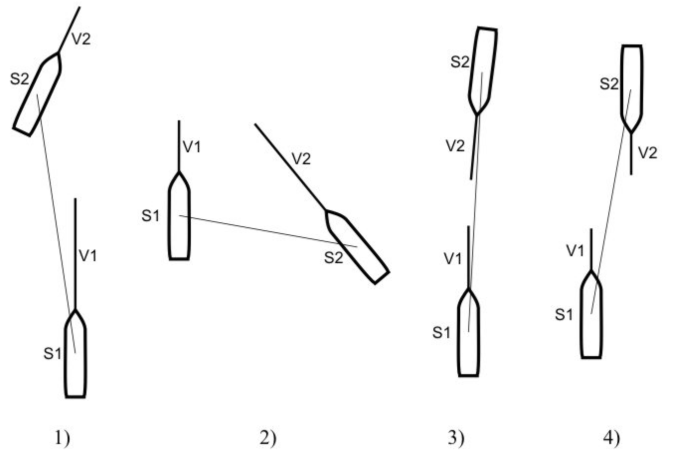

Figure 5. Examples of navigational situations.

Explanatory notes and assumptions applied to the above mentioned examples

- 8Nm is a distance assumed to be safe by the system and no actions need to be taken in navigational situation;
- Vessel's priorities gradation is adopted from simplified "privileged hierarchy" (Rymarz 1995).

8 SUMMARY

The construction of decision support systems can significantly expand the capabilities of navigational decision support systems. Their important element is the knowledge base, which may be a separate structure or part of expert systems. The effectiveness of decision support systems largely depends on the correctness of the knowledge base, its structure and mode of action.

The following assumptions and proposals of implementation have been presented:

1. To use an expert system as a sub module of decision support system;
2. To prepare a knowledge base based on rules;
3. To divide a database to 3 parts containing respectively COLREGS rules, special rules and principles of good seamanship rules to improve efficiency and to allow the knowledge to be updated.

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