Decision Support System in Marine Navigation

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Abstract. The article presents basic functionalities of a navigational decision support system used in collision situations, illustrated with example performance of the NAVDEC system. Other similar systems have been characterized. The authors draw attention to the need to introduce legal regulations for the construction and operation of navigational decision support systems. The authors also attempt to outline directions of their development in the years to come in view of expected increase in number of unmanned and autonomous ships.

Keywords: Marine navigation · Decision support · Safety of navigation

1 Introduction

Increasing quantity and scope of information available on board a ship makes it easier for navigators to make a more complete situation analysis and assessment. At the same time, more data to be taken into account, with limited human perception, may hamper making decisions. Wrong decisions may result from fatigue or stress that lead to, inter alia, reduced mental toughness, lower personal safety, reduced self-esteem and situational awareness, disorders of leadership qualities, more time needed to make a decision and improper decisions [4].

Rapid progress in information and communication technologies facilitates finding new solutions. Decision support systems, functioning as an assistant/advisor, are a frequently proposed solution today. These systems analyze and assess a current situation and generate a solution recommended to the navigator. One should expect that the witnessed transformation of navigational information systems into decision support systems will allow us to reduce mistakes made by the humans, and consequently, reduce the number of accidents at sea.

On top of that, decision support systems may increase the efficiency of transport, as the proposed solutions are cost-effective, i.e. based on economic criteria. If we bear in mind sometimes huge losses caused by marine accidents, we can say these systems are important for assuring the safety of personnel, ship, cargo and environment.

This trend is also present in other modes of transport, including road transport. New solutions are dedicated to vehicle operators/drivers and traffic control centres. The scope and tools of decision support are obviously dependent on the specifics of transport mode, such as the characteristics of the operated vehicles and available infrastructure. The scale of applications is also essential, resulting from the purpose and availability of a given

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means of transport. It is particularly true for road transport, where solutions, so called assistants, are increasingly used for monitoring vehicle movement and, to some extent, taking over the control of the vehicle. The latter illustrates another trend, witnessed especially in air transport – development of autonomous vehicles. Unmanned remotely operated craft may be considered as a transitory stage. In both cases, for autonomous vehicles in particular, a decision support system seems necessary.

Traffic management systems also play a vital role [10]. Their number and areas of coverage are continually on the rise. In road transport, for instance, intelligent transport systems (ITS) have been implemented. Similar solutions have been used and systematically developed in shipping and aviation, known, respectively, as Vessel Traffic Service systems (VTS) and air traffic control (ATC) systems. It seems justified to employ decision support functions in these areas – generating solutions within traffic organization and management. It should be emphasized, however, that there are differences concerning the types and ranges of functionalities of decision support systems for sea-going vessels, airships or road vehicles as well as relevant traffic control centres.

The realization of decision support system requires various telematic solutions for the acquisition of information from different sources, data processing and transmission to traffic participants. Besides, these systems increasingly use methods and tools of knowledge engineering, including methods and tools of artificial intelligence: artificial neural networks, fuzzy logic, evolutionary algorithms, expert systems, approximate sets, knowledge bases etc. These tools allow us to provide technical systems, more specifically IT systems, with characteristics and abilities attributed to human intelligence, such as adaptation to substantial and unexpected changes, learning, autonomy and complexity [11].

As the indicated issues have a wide range, we will focus in this article on decision support systems for the navigator – operator of a sea-going vessel.

2 Areas of Decision Support at Sea

2.1 Standard and Emergency Situations at Sea

Making decisions in shipping can be considered from various perspectives: shipowner's, traffic service operators' controlling vessel traffic in approach channels and port waters, navigator's steering a ship and other traffic participants.

In the shipping context, decisions are related to the realization of specific transport tasks, including loading, voyage execution and unloading, with the vessel used for the carriage. Ship's operation, requiring constant maintenance activities, may be divided into standard (routine) and emergency situations. If we narrow down our considerations to voyage execution phase, decision making will cover various areas under the two categories of situations:

- standard situations:
  - open sea navigation – avoiding collisions and groundings, weather routing,
  - approach channel navigation – pilotage,
  - port manoeuvres – un/berthing, towing, turning;

- emergency situations [6]:
  - close quarters;
  - accidents involving personnel on board;
  - ship damage;
  - pollution;
  - assistance rendered to ships in distress;
  - other.

As far as information systems are concerned, decision support consists mainly in the automation of acquisition, processing and presentation of information. Decision support systems are expected to generate acceptable and optimal solutions, justify them and control process/es execution, using methods and tools for situation analysis and assessment, simulations and optimization. Such tasks are implemented by various methods and tools, including those for data integration, identification of dangerous situations and tools for communication with the system user.

2.2 Decision Support in Ship Conduct Process

The basic aim of navigation is the vessel's efficient and safe passage on an assumed trajectory. From this vantage point we can say that a navigational decision support system has to implement two basic tasks: conduct the vessel on an assumed trajectory and avoid collisions. The third phase to complete the voyage is to berth/unberth, which can include precise ship handling via dynamic positioning (DP), docking systems or pilot navigation systems.

The passage of the vessel from the port of departure to the port of destination requires acquisition, processing, analysis and use by the navigator of a large amount of information. The capacities of processing by a human are limited, which in turn affects the quality of decisions made. Wrong decisions made by navigators can result in collisions, particularly in areas with high traffic intensity, and consequently adversely affect the safety of people, vessel and the environment.

The decision support system carries out the task of steering a ship along a preset trajectory utilizing the data obtained from an Electronic Chart Display and Information System (ECDIS). Collision avoidance is based on information obtained from Automatic Radar Plotting Aid (ARPA) and Automatic Identification System (AIS) devices. The system, using the above information, works out alternative decisions for a given situation, which are in line with the specific character of an area and its restrictions on the one hand, and with the vessel traffic situation on the other hand. It may be said, therefore, that such a system should be capable of:

- assessing a navigational situation;
- indicating alternative decisions;
- proposing permissible and feasible decisions only;
- enabling the navigator to assess the decisions and to introduce additional assumptions.

Besides, such system should be a dialog system (question – answer – solution – decision), making it possible for the officer to update certain facts concerning the present situation of the ship. Therefore, problems could be solved in untypical situations (reduced visibility (fog signals) or in the night (ships' navigational lights). The major criterion for the system to be satisfied is that it should work in real time.

Berthing operation as well as DP require specific information. The main factor is precise positioning. But even a precise position is not enough if we do not know external factors which may affect our position, such as wind, waves, tide etc. Taking this into account, decision support system should:

– acquire, process, analyse and clearly present, on one display, information from DGNSS, anemometer etc.;
– present on the same display tools available for the operator, i.e. engine/engines, rudder/rudders, bow/stern thrusters etc.;
– "operate" between external factors and internal capabilities, i.e. provide the operator with solutions which enable him to perform tasks.

The major criterion for the system to be satisfied is that it should work in real time or even predict "behaviour" of own ship based on weather conditions and other factors.

3 Decision Support in Collision Situations

3.1 Existing System Functionalities

The navigational decision support system NAVDEC extends features of the ship navigational equipment [8]. It is an on-line system handled by the operator. The system records own ship parameters and the situation around the ship. The registered parameters are used for identification and assessment of the current navigational situation. The system works out and recommends solutions which assure the safe ship conduct. The system co-operates with standard equipment and systems installed on board, e.g. log, gyrocompass, Automatic Radar Plotting Aids (ARPA), Global Navigational Satellite System (GNSS), AIS (Automatic Identification System), Electronic Navigational Chart (ENC). The system performs information functions, similarly to the Electronic Chart Display and Information System (ECDIS). The information functions include presentation of bathymetric data from an electronic chart, an image of surface situation from a tracking radar, positional information from the AIS and GNSS receivers as well as calculation and presentation of targets movement parameters.

The correctness of situation identification and assessment as well as generated recommendations – recommended manoeuvers – depends on the accuracy of data used for these purposes. To improve the data quality used for calculations and presented to the operator. NAVDEC performs the fusion of own ship data and integration of data on targets from alternative sources. In the former case (fusion), measurements from a number of shipboard GNSS receivers are used to estimate more accurate own ship movement parameters, whereas in the latter the system integrates targets movement parameters delivered by alternative sources (ARPA, AIS).

A novel, important, functionality of NAVDEC is that it analyses and assesses the navigational situation in relation to all other or selected targets located within a distance pre-defined by the system operator. Normally this stage in the decision making process is performed by the navigator, because relevant regulations have to be taken into account. With NAVDEC on board, the operator is advised by the system on the identification of an encounter situation in compliance with the Collision Regulations. Such information is especially helpful in heavy traffic.

Apart from intense vessel traffic areas, one-to-one ships encounter situations in the open sea may end in a collision. Such events are known, for example the collision between m/v Gotland Carolina and m/v Conti Harmony in 2009 [13]. In situations qualified as a collision situation, the navigator decides which safe manoeuvre should be performed. He determines what to do (alter course and/or speed) and how to do it (manoeuvre parameters): moment to begin the manoeuvres and values of course and/or speed alteration to pass the target at a preset range considered as safe. NAVDEC is the only tool worldwide capable of performing this function because it incorporates the Collision Regulations, principles of good sea practice, and criteria used by expert navigators. The system calculates and offers on demand alternative solutions. Additionally, the system justifies the proposed manoeuvre. This function refers to all or selected targets.

3.2 New/Planned System Functionalities

NAVDEC system was installed on 12 ships of eight different shipowners. based on the feedback received from end users, the following functionalities are planned to be developed:

1. recommended save ship trajectory for an anticollision manoeuvre according to user defied criteria;
2. alternative ship trajectories calculated using additional (other) optimisation methods;
3. considering bathymetry when planning an anticollision manoeuvre;
4. automatic communication system for exchanging collision related messages and negotiation of anticollision manoeuvre;
5. taking into account wind direction when planning anticollision manoeuvre (version for sailors);
6. planning last minute manoeuvre (situation where a collision cannot be avoided by manoeuvre of one vessel only).

   These features greatly enhance the system capabilities.

4 NAVDEC - Examples of Use

4.1 Multi Ship Encounter Situation

The following figures present examples of NAVDEC use during a pilot test at sea on m/f Wolin, which belongs to Unity Line, the biggest Polish ferry operator. In Fig. 1 our vessel (5) is heading approx. NNW direction. There are 4 dangerous targets on her starboard side. According to the Collision Regulations [1] (1), our vessel is a give-way vessel. That is why the system suggests a new course (2), which enables it to pass all targets within a presumed distance, the closest point of approach (CPA) (7). Data of a selected target are displayed in (3), while the solution how to safely pass the target is in (4). The rosette (6) presents all solutions, which fulfils navigator requirements, for all targets within 8 Nm (in this particular case).

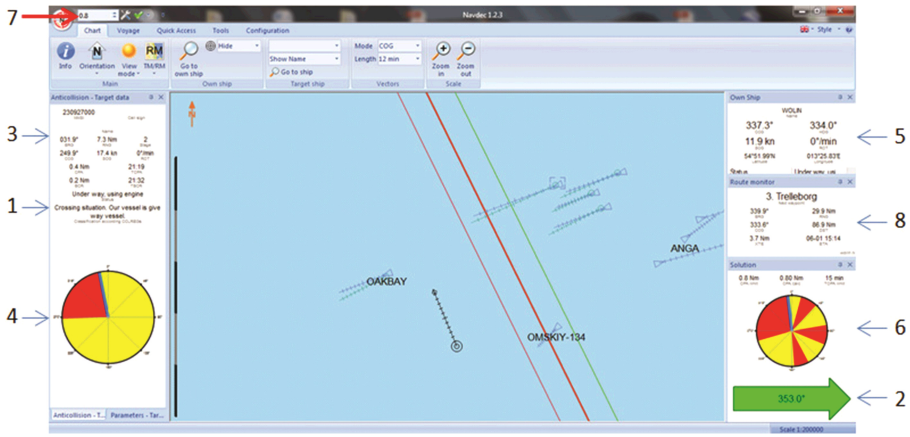

Fig. 1. Screenshot from the NAVDEC pilot test at sea on the m/f Wolin, showing main components [own study] (Color figure online)

NAVDEC uses navigation system data to provide fast and accurate options to the OOW (officer of the watch), including the most important variables to be considered:

1. Classification of encounter situation according to COLREGs (“**crossing situation**”, “**head on situation**” or “**overtaking**”) and which vessel is “***stand-on***” (has right of way) and which is “**give-way**” (must let the other vessel or vessels pass first),
2. Optimal course to avoid collision,
3. Target data,
4. Solutions for selected target,
5. Own vessel data: destination, distance to go, ETA, etc.,
6. Solutions how to pass all targets at predetermined distance from our vessel,
7. Assumed safe CPA,
8. Planned route.

When own vessel is a give-way vessel in relation to at least one target, NAVDEC displays a compass rosette with solutions (6), with red sectors indicating collision risk and yellow sectors indicating safe courses (respectively black and bright areas on figure) on which the vessel will pass other targets with predetermined CPA or larger distance. Displayed below the rosette is the optimal course requiring smallest deviation from current course: the green arrow (dark on figure) indicates starboard turn, a red arrow, not shown, a port turn.

Figure 2 presents another important functionality of NAVDEC. It is warning function connected with encounter parameters i.e. CPA and TCPA. Navigator can determine which targets will be considered as Dangerous Targets. In this particular situation, CPA limit was set up on 0.8 Nm and TCPA limit is 15 min and encounter parameters in relation to m/v Seagard are 0.6 Nm and 14 min. This is why tringle marking target “Seagard” changed colour to red (the oval on figure).

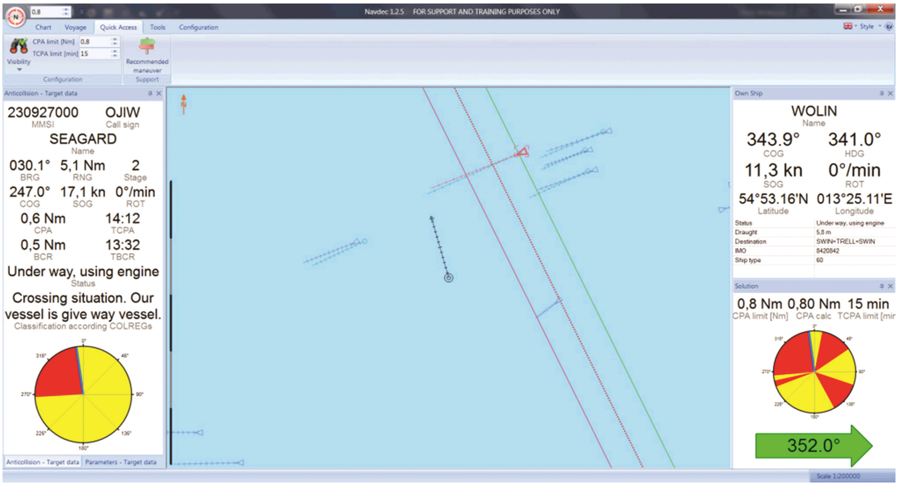

Fig. 2. Dangerous target [own study] (Color figure online)

In Fig. 3 another functionality of system is presented. After alteration course to starboard by m/f Wolin, present CPA to m/v Seagard is 0.8 Nm and is equal to CPA limit

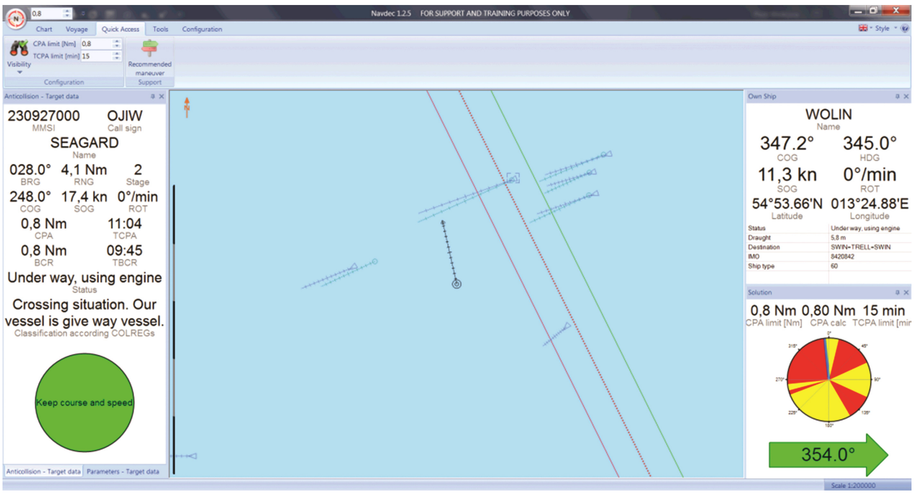

Fig. 3. Keep course and speed in relation to selected vessel [own study] (Color figure online)

set up by navigator. System still classifies encounter situation according to COLREGs, but rosette with solution changed colour to green (dark on figure). Additionally information "Keep course and speed" appeared. It means that by keeping current parameters we will pass m/v Seagard at least on minimum required CPA.

There is no risk of collision for m/f Wolin in situation presented in Fig. 4. CPA in relation to all targets is bigger than minimum required by navigator. In case it is smaller, then TCPA is already negative, which means that vessels passed by.

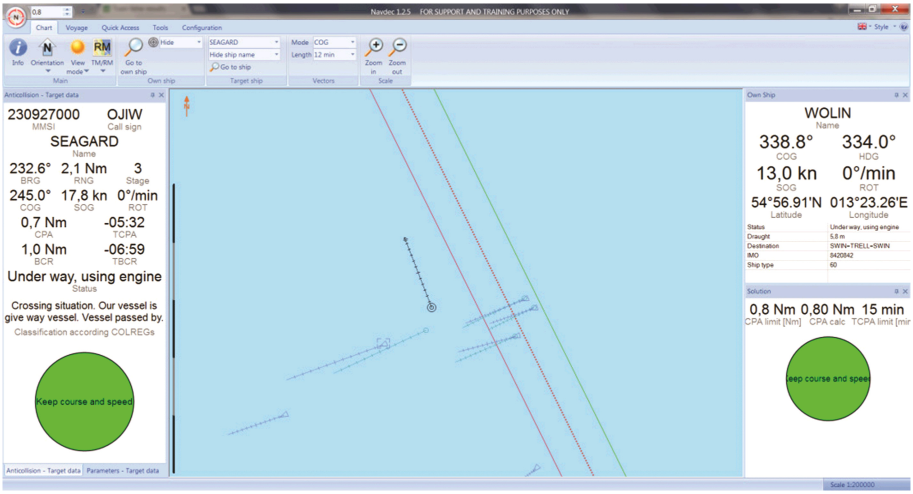

Fig. 4. Keep course and speed [own study] (Color figure online)

In situation presented above, both rosettes with solutions are green (dark on figure), which means that it is safe to keep course and speed until next encounter situation, which will be signalled by red-yellow rosette.

4.2 Multi Ship Encounters – Other Examples

The following two figures present m/f Wolin in three different encounter situations. In Fig. 5, southbound m/f Wolin met m/v Shetland Cement on opposite course. NAVDEC correctly classified that encounter as a head-on situation. In this case both vessels are obliged, according to the COLREGs, to alter course to starboard.

Figure 6 presents how the system utilises specific data from AIS, i.e. navigational status. Rule 18 of COLREGs "Responsibilities between vessels" is fully implemented in the NAVDEC system. It means that not only the positions, courses and speeds (like in ARPA) are taken into account in assessing encounter situation. In this specific case, the Arkona is a vessel engaged in fishing. The present CPA equals 5.7 Nm and is bigger than CPA limit preset by navigator. This is why the individual rosette (on the left) is green, which means that no action is required to pass the selected target at the preset CPA or farther.

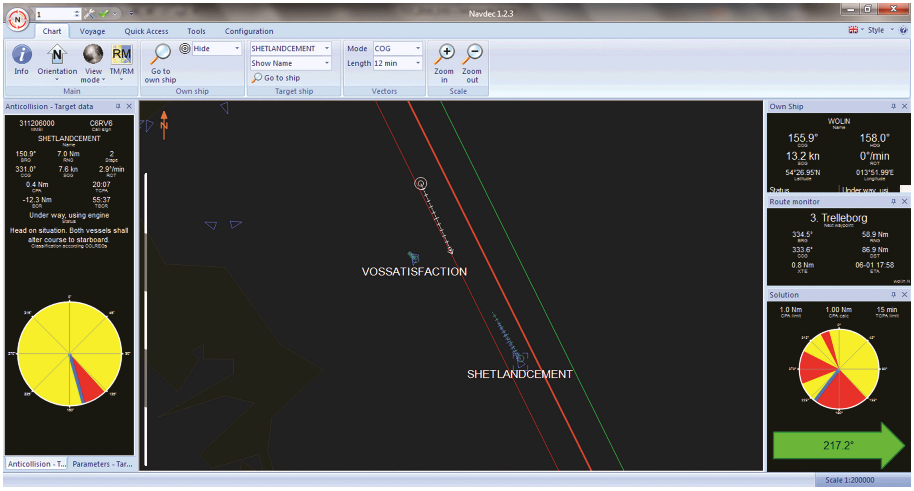

Fig. 5. A head-on situation [own study] (Color figure online)

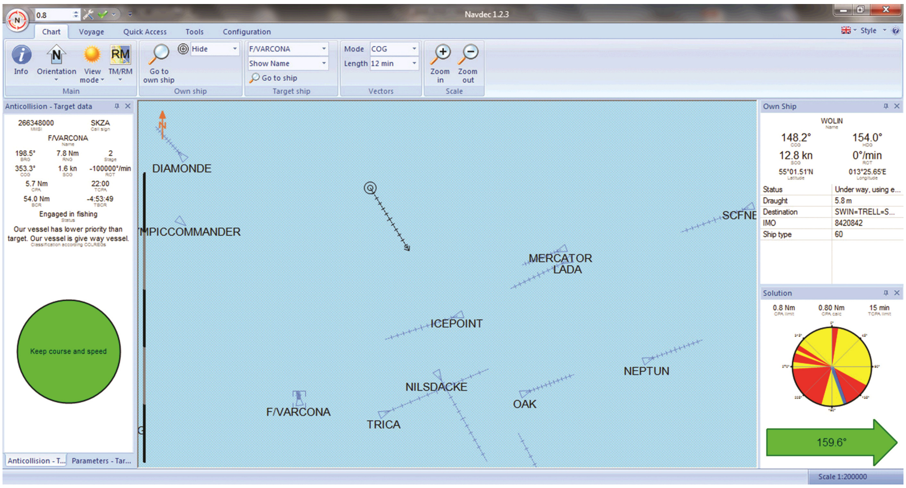

Fig. 6. Encounter situation with a fishing vessel [own study] (Color figure online)

5 Other NDSs on Ships

5.1 Totem Plus Decision Support Tool

The TOTEM DECISION SUPPORT TOOL [12] analyses target data and advises officers what action to take. Target CPA data are taken into account. If required, a “Course To Steer” is displayed to the officer (Fig. 7). It is based on analysis of data from nearby vessels, their CPA and TCPA, and the status based on the COLREGS. All the information is calculated automatically and is refreshed after a new message arrives [13].

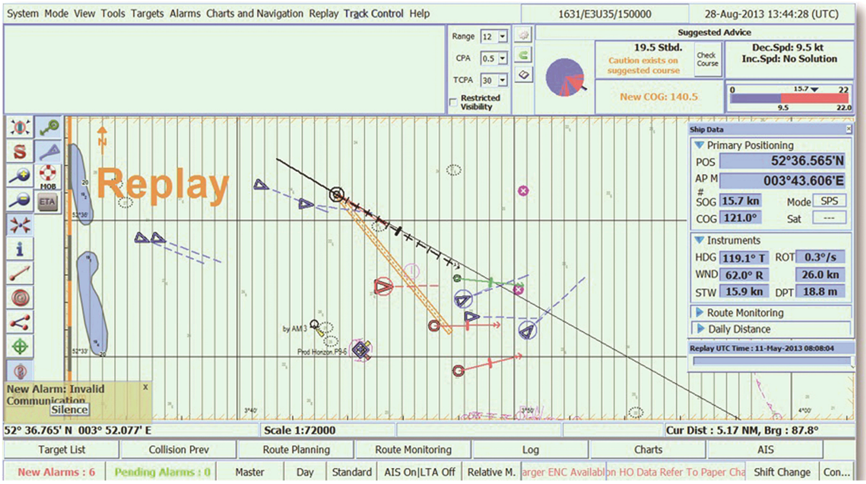

Fig. 7. Screenshot of Decision Support Tool [12] (Color figure online)

To present advice, AIS and ARPA targets within the required distance are constantly analysed. The Alert Radius, with a default value of 12 miles, (high seas) may be modified by the navigator. It also applies to the CPA, which is set by default to 0.4 mile, but can also be set by the operator according to the specific circumstances. Other parameters for instance Minimal Distance, have default values that only the Master can modify. Minimal values to be chosen are limited by specific vessel parameters such as ship's length and turning radius. Table 1 illustrates a system configuration [13].

Table 1. Example minimal values in the Decision Support Tool [11]

No	Parameter	Default value	Who can change
1	Minimum CPA allowed	0.4 mile	Watch officer
2	Alert radius	12 miles	Watch officer
3	Action time	20 min	Master
4	Vessel crossing from port - warning distance	20 min	Master
5	Vessel crossing from port - action distance	3 miles	Master
6	Vessel overtaking - warning distance	2.5 miles	Master
7	Vessel overtaking - action distance	1 mile	Master

In addition to the a/m information, the system displays an alert for "Approaching from Port" situations or "Overtaking" situations. In such cases, no advice is given as the ship is required by the COLREGS to keep her course and speed and the other vessel should take action, too. Once the approaching ship is closer than the defined distance, the system advises the officer to give such ships a warning signal. If the "give-way" ship is closer than the limit set for action - Action Distance - information on a new course to avoid collision will be given in accordance with the COLREGS [12].

5.2 Hyundai Intelligent Collision Avoidance Support System (HiCASS)

The system was developed to verify the model for use as a technological factor of e-navigation [3, 5, 9]. The system utilizes AIS information from vessels and establishes the risk of collision between own and another vessel as well as that between two other ships. The result of assessment, i.e. information on the degree of collision risk, is categorized by ship and by water area. The AIS Pilot plug is used to obtain AIS information from other vessels, which is transferred to the program using wireless communication. Where Wi-Fi is available, the navigator will be capable of using the program in a remote setting. The system display is presented in Fig. 8 [3].

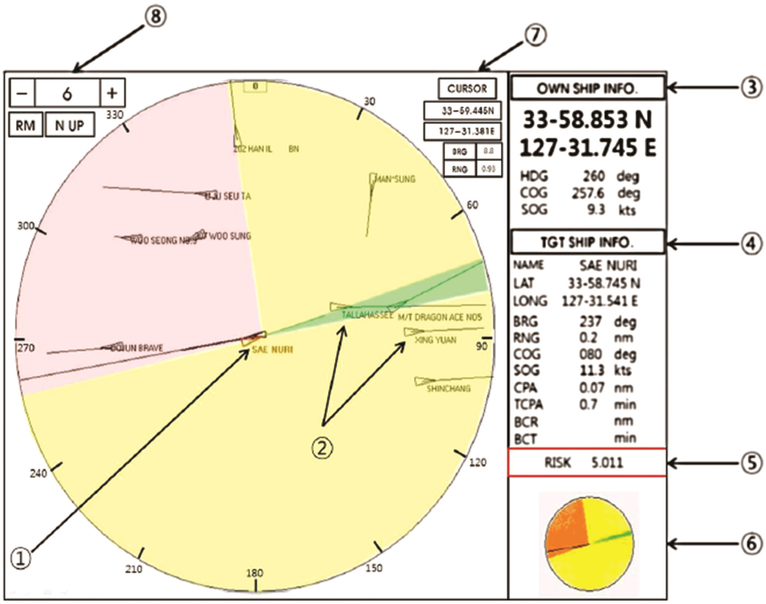

Fig. 8. Screenshot of HiCASS [3] (Color figure online)

The system display is similar to that of the radar and it can verify the degree of danger using a color code. Table 2 presents the functionalities of HiCASS [3].

The system marks vessels with a collision risk of 5.0 and above, which indicates a dangerous situation, with a line for clear identification. It also calculates the degree of risk of collision with any other vessel located around own ship. When risk is below 5.0, the degree of risk is displayed on the screen with a proper color code to indicate the level of risk [3].

Table 2. Functionalities of HiCASS [3]

No	Name	Description
1	Own vessel	Own vessel is always displayed on the center
2	Other vessel	Information of other vessels is collected from AIS
3	Own vessel data	Information of own ship including GPS position, heading, COG, SOG is displayed
4	Other vessel data	Information of other vessel including name, GPS position, relative heading/distance, COG, SOG, CPA, TCPA, BCR, BCT is displayed
5	Degree of risk	The degree of risk of collision is displayed by the Model
6	Degree of risk around the area	Degree of risk around own ship is displayed through color code (1–4 green, 4–5 yellow, 5–7 red)
7	Cursor information	Displays relative heading/distance of the other vessel from the mouse cursor's position and own ship
8	Monitor calibration	Scale of monitor, direction of stern, rearrangement of other vessel's information

5.3 Challenges

The present technological development opens opportunities for building more advanced navigational systems and extending their applicability. These systems perform information functions and, increasingly, decision support functions. The test results concerning the navigational decision support system NAVDEC and analysis of similar existing or designed systems lead to a number of challenges that emerge before researchers and designers [2, 7].

The complexity and diversity of probable navigational situations impose a large number of factors to be considered before the generation of suggested solutions/decisions. This also refers to navigation in restricted waters, where navigator uses criteria of situation analysis and assessment.

To implement a system with such characteristics as adaptation, learning, autonomy and complexity it seems purposeful to continue and extend the use of artificial intelligence methods and tools.

Existing or designed navigational decision support systems assist the navigator mainly in standard situations. Decision support in emergency situations is often more difficult. This explains the lack or limited scope of use of decision support systems in emergency situations. Relevant solutions basically include procedures (scenarios) for previously defined cases of emergency.

Other challenges concern accuracy, validity, credibility of information, increased availability, reliability and security of the system. This entails the use of various navigational systems and equipment for assuring system redundancy and diversity. Hence, the implementation of such systems requires that relevant performance standards should be defined. The lack of standards concerning the requirements for services offered and failure to assure a specified quality level of the final product may even lead to the reduction of navigation safety.

The development of unmanned and autonomous ships observed particularly in air transport lets us conclude that also the shipping industry will witness a gradual growth of this type of craft. As a result, it may become necessary to build systems of traffic control and management and develop instruments for enforcing relevant regulations. A larger number of unmanned and autonomous vessels may in the future call for regulatory changes, which in the case of maritime transport will affect Collision Regulations, now in force for over 100 years.

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