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Decision Support in Collision Situations at Sea

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The known navigational systems in use perform information functions and as such are helpful in the process of safe conduct of a vessel. One of the ways to assist in reducing the number of marine accidents is the development of systems which perform decision support functions, i.e. automatically generate solutions to collision situations. The use of information (and communication) technologies including knowledge engineering allows the generation of proposals for anti-collision manoeuvres taking into account the COLREGs. Demand for further enhancement of navigational safety by limiting human errors has initiated a trend to convert navigational information systems into decision support systems. The implementation of decision support systems will potentially reduce the number of human errors, which translates into a reduction of accidents at sea and their adverse consequences. This paper presents a summary of the research to date on the navigational decision support system NAVDEC. The system has been positively verified in laboratory conditions and in field tests – on a motor ferry and a sailing ship. Challenges associated with the development and implementation of such systems are outlined.

KEYWORDS

1. Navigation. 2. Collision avoidance. 3. Decision support system.

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1. INTRODUCTION. Efforts to ensure the safety of people, ships, cargo and the marine environment and to enhance the effectiveness of transport services in maritime shipping are increasingly important. Advancements in Information Technology (IT) and Information and Communication Technology (ICT) create new opportunities for constructing navigational systems with new functionalities, which facilitate decision making on ships and in land-based centres. This mainly refers to information systems supporting decisions on a ship in motion. The concept of e-navigation developed at the International Maritime Organization (IMO) forum responds to the demand for decision support. It aims at determining development directions and scope of future navigational systems, and specifying requirements and performance standards for these systems.

It seems that e-navigation should comprise a new class of navigational systems – navigational decision support systems, able to analyse a ship's situation and automatically generate a decision or decisions aimed at collision avoidance.

2. IT AND ICT IN NAVIGATION

2.1. *Decision making processes in marine navigation.* The decision making process can be divided into stages that have to be properly executed for the decision to be the right one and for the action taken to be effective: information acquisition, analysis of situation, making a decision and taking action. If we consider decision making as a continuous process in ship conduct, we should add another stage - monitoring of decision execution results, as this will provide a basis for modifying the decision or making a new one (Figure 1). The process is also referred to as control.

The correctness of a decision depends on such factors as the scope and quality of information, knowledge, experience and skills of decision makers and how well they know the problem (task) to be solved.

Various levels of navigational decision making, or control, can be distinguished.

1. The ship: ship's master is responsible for safe execution of the sea voyage; the primary duty of the navigator conducting the ship is to execute a sea voyage in compliance with the owners' orders / guidelines, observing the principles of safe navigation, regulations in force, and following instructions and advice of Vessel Traffic Services (VTS) operators.
2. Ashore – Vessel Traffic Services: VTS personnel, responsible for vessel traffic management within approach channels, harbour waters and inland waterways, have a number of tasks: assistance in collision avoidance, vessel traffic control, minimisation of waiting times to enter or depart from the port.
3. Land – ship owner / operator: from ship operator's perspective, vessel traffic control is aimed at optimal employment of the fleet for the execution of contractual transport services.

Decision making processes can also be analysed for various time spans of vessel movement control as:

1. Voyage planning; goals: safety and efficiency,
2. Operational; changing the movement parameters determined as in point 1; goal: preventing and avoiding collision,
3. Machinery maintenance (engine, rudder); goals: safety and efficiency.

Although some of the mentioned processes or their stages take place automatically, humans still make crucial decisions, particularly those concerning navigational safety. Information and communication technologies (IT and ICT) are increasingly used for supporting various stages of decision making processes (Hwang, 2002).

2.2. *Information systems supporting navigational decision making.* An information system is defined using the input-process-output components. Information resources at the input (data) are acquired from the environment or internal generators, while output information resources (information/data) are delivered to the environment or to other internal systems. Basic functions of information systems include measurement, registration, transmission, gathering, storage, retrieval, presentation and distribution.

Navigational equipment and systems used on ships and in shore- and land-based centres support decision makers at each or some decision making stages. These are monitoring of navigational systems and devices (information acquisition, monitoring),

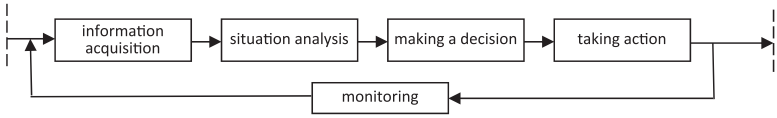

Figure 1. Stages of the decision making process.

acquisition, processing, integration, distribution, presentation of information, analysis of situation and situation prediction.

The ship's bridge of today is equipped with a number of devices and systems intended to assist officers of the watch to navigate safely. In collision situations the Automatic Radar Plotting Aid (ARPA) comes to the navigator's assistance. Apart from classical methods still in use, satellite navigation is becoming increasingly important, based on Global Navigation Satellite Systems (GNSS). The Automatic Identification System (AIS) provides automatic data exchange between ships, used for collision avoidance, ship identification by other ships and shore-based systems supervising vessel traffic. The Electronic Chart Display and Information System (ECDIS) is a navigational information system that combined with some backup devices is considered as an equivalent to updated navigational charts. ECDIS has an extended list of functions and warnings and has a capability to integrate data with those from ARPA and AIS (Weintrit, 2009).

Apart from the above, a number of special systems may be found on the bridge: Pilot Navigation Systems (PNS) (for restricted waters), Dynamic Positioning Systems (DP) (for precise automatic or manual ship handling), docking systems (for safe berthing and unberthing operations, particularly for ships carrying dangerous goods), Weather Routing Systems (for optimising ocean voyage routes based on present and forecast weather data, taking into account ship's speed and manoeuvring characteristics).

Vessel Traffic Services (VTS) systems are information systems at shore-based centres supervising and controlling vessel traffic. These systems provide three types of services essential from the viewpoint of vessel traffic management: information, navigational assistance and vessel traffic organisation. VTS facilities include radar equipment and systems, Global Navigation Satellite Systems (GNSS), ECDIS and AIS. To enhance the efficiency of VTS systems, they are additionally fitted with management modules, supporting the operator in decision making (Vessel Traffic Management Systems - VTMS). VTMS combine information, navigational assistance and vessel traffic organisation functions of the VTS.

The European Union (EU) Vessel Traffic Monitoring and Information System (EU VTMIS) has the widest coverage. Its primary functions are collecting data and offering them to the users, competent administrative bodies of states using the system, authorised local organisations in these states and other authorised organisations. The system is built on systems operated in EU member states: Ship Reporting System (SRS), AIS, Maritime Assistance Systems (MAS), VTS, database systems (SafeSeaNet) and the Long Range Identification and Tracking System (LRIT).

2.3. *Emerging trends and current challenges.* Navigational systems presently operated in global shipping are mainly based on data processing, thus these systems perform mostly information functions and to this extent they support the process of safe vessel conduct. Information systems, however, do not offer the navigator/operator ready solutions to collision situations relative to all targets located in the vicinity of own ship. For that reason decision support is limited and so is the effectiveness of collision avoidance.

We should expect further development of the existing systems, extended with new functionalities, as well as the development of specialised navigational systems (Pilot Navigation Systems, Dynamic Positioning, Docking Systems, Weather Routing) and their integration with other shipboard systems. The prototype decision support system for sea-going vessels developed at the Maritime University of Szczecin, Poland, is an example of a new trend (Pietrzykowski et al., 2012).

Decision support systems, in addition to information functions, are capable of analysing and assessing variant solutions to a situation that requires a navigator's decision. Based on the defined decision maker's preferences, the system works out a recommended solution, or decision to be made. Decision support systems are generally equipped with statistical tools, and tools for system / process modelling, simulation and optimisation, which allow the user, among other functions, to test various scenarios. Knowledge engineering tools have become of interest in this context. Knowledge can be understood as a theoretical or practical understanding of a subject. Knowledge has a variety of forms: facts; rules; heuristics, general strategies of action or specific theories.

The use of knowledge is becoming more common. Various tools have been designed for knowledge representation: artificial neural networks, fuzzy logic, evolutionary algorithms, expert systems, approximate sets, knowledge bases etc. These tools, making up a group of computer methods that are generally referred to as methods of Artificial Intelligence (AI), can be used for designing systems which process data as well as knowledge. Such systems have qualities normally attributed to humans (Fabri and Kadrikamanathan, 2001): adaptation, learning, autonomy and complexity.

Adaptation means that the system is flexible when facing new, unknown situations. The ability to learn means that previously acquired knowledge can be utilised so that the system behaviour can be promptly modified without a need to re-estimate previous situations (Borkowski and Zwierzewicz, 2011; Borkowski, 2014; Gucma and Pietrzykowski, 2006; Stateczny and Kazimierski, 2008). Research in that direction is justified by the obvious need to design more efficient and more robust information systems where external (human) intervention is minimised even in the case of complex conditions.

In this connection, information systems tend to be transformed into decision support (information-decision) systems, which will offer broader scope of assistance in various areas of human activity. Marine navigation is one of the fields where fully functional decision support systems can effectively facilitate actions of personnel in charge (Pietrzykowski, 2010). A review of marine accident investigation boards' decisions confirms the fact that human errors are one of the main causes of accidents at sea (Kokotos and Linardatos, 2010; MAIB, 1999; Tzannatos and Kokotos, 2009).

For a few years research has been continued on methods and algorithms for decision support in marine navigation. They refer to various time spans and stages of decision support process (Pietrzykowski et al, 2014a; Stawicki, 2008; Szłapczyńska, 2013; Wang and Chin, 2016). Both classical and artificial intelligence methods are proposed. Relevant publications address such issues as criteria of situation analysis and assessment, including risk estimation. Their description, apart from traditional methods, makes use of methods based on fuzzy sets theory or neural networks (Gucma and

Pietrzykowski, 2006; Hansen et al., 2013; Hwang, 2002; Pietrzykowski and Uriasz, 2009).

Much consideration is also given to routing algorithms. The route choice problem is generally formulated as an optimisation problem, where essential steps include the choice of optimisation method, formulation of the objective function and constraints (Lisowski, 2013; Qingyang et al., 2014). Due to computing complexity of the problem, the proposed algorithms are genetic, evolutionary or even ant algorithms (Ming-Cheng and Chao-Kuang, 2010; Ming-Cheng et al., 2010; Śmierzchalski and Michalewicz, 2000; Śmierzchalski et al., 2013).

The problem of route choice aimed to avoid a collision is generally considered for encounter situations involving two ships. Increasingly more attention is paid to solutions for multiple ship encounters, an important issue in areas where vessel traffic is intense (Szłapczyński, 2011).

The route choice problems also refer to long time spans, weather routing, or much shorter periods, for performing just one manoeuvre, e.g. berthing.

The practical use of proposed theoretical solutions requires that additional specific factors be taken into account, including ship particulars, the environment, the operator, and principles of good sea practice. The solutions should be based on situation assessment and route choice criteria accepted by the navigator and take into account the regulations in force. Otherwise solutions proposed by the system will not be accepted and used. For this reason, before implementing new functionalities within navigational decision support systems they have to be verified in real conditions, which is a slow process. The use of decision support systems on ships and in land-based centres may enhance the safety of shipping.

As a result, navigational decision support systems draw more and more interest, and first solutions have already been revealed:

- Navigational Decision Support System NAVDEC - presented at an IMO forum (fifty-eighth session of the NAV Sub-Committee) in 2012 (Poland) and included in a document prepared for fifty-ninth session of that sub-committee) in 2013 (Poland) (NAV 59/INF.2, 2013),
- Collision Avoidance Decision Support System presented at an IMO forum (First session of the Navigation, Communications and Search and Rescue (NCSR) Sub-committee) in 2014 (Israel),
- Ship operator-centred collision prevention and alarm system, presented at an IMO forum (Second session of the NCSR Sub-committee) in 2015 (Republic of Korea) (NCSR 2/INF.10, 2015).

2.4. *E-navigation.* The e-navigation concept of wider use of ICT in maritime navigation was developed in the IMO forum. The definition in NCSR 1/6 (2014) defines that e-navigation is “the harmonized collection, integration, exchange, presentation and analysis of marine information on board 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”. The aim is to develop an overarching accurate, safe, secure and cost-effective system with the potential to provide global coverage for vessels of all sizes.

The Correspondence Group on e-navigation, established within the IMO, worked out a draft of an e-navigation strategy implementation plan, which was endorsed by

NCSR Sub-Committee 2014. Five prioritised e-navigation solutions are identified in the document (NCSR 1/6, 2014):

S1: improved, harmonised and user-friendly bridge design;

S2: means for standardised and automated reporting;

S3: improved reliability, resilience and integrity of bridge equipment and navigation information;

S4: integration and presentation of available information in graphical displays received via communications equipment; and

S9: improved communication of VTS Service Portfolio.

As mentioned in NCSR 1/6 (2014), solutions S2, S4 and S9 focus on efficient transfer of marine information and data between all appropriate users (ship-ship, ship-shore, shore-ship and shore-shore). Solutions S1 and S3 promote the workable and practical use of the information and data on board.

On the basis of specified sub-solutions the required regulatory framework and technical requirements for implementation (tasks) are formulated. They are, inter alia, Draft Guidelines on Human Centred Design (HCD), Guidelines on Usability Testing, Evaluation and Assessment (UTEA) and Guidelines on Software Quality Assurance (SQA) for e-navigation. These guidelines are identified as important for the future development and implementation of e-navigation.

HCD incorporates human factors-related knowledge and techniques to help meet user needs and safety requirements whereas UTEA uses methods that rely on including users to test the ability of systems to support user needs (NCSR 2/6, 2015). Particular emphasis is placed on means for standardised and automated reporting (data exchange and access) and integration and presentation of available information in graphical displays. All these activities will improve functionalities of navigation systems supporting decision making.

In the document NCSR 1/6 (2014, Annex page 2, paragraph 14), the steps concerning further development of e-navigation are formulated:

"… further e-navigation development will be a continuous process following user needs for additional functionalities of existing and possible future systems (e.g. implementation of on board and/or ashore navigational decision support systems)."

In case of expected rapid development of decision support systems the development of relevant guidelines and performance standards will be needed.

As mentioned in NCSR 1/6 (2014), communications are key for e-navigation. Any communications systems used must be able to deliver appropriate electronic information ship-to-ship, ship-to-shore, shore-to-ship and shore-to-shore regardless of the number and scope of information as well as of type of navigation system actually used.

At present the automation of marine communications is focused on typical exchanges of data from navigational equipment and systems on ships and in shore- and land-based centres (Pietrzykowski et al., 2013). The automation is now facilitated thanks to the standardisation of contents and formats of data (navigational, operating and others). As a result, the amount of available information is constantly rising. This, in turn, entails the necessity to integrate and select the information required in a particular situation.

The unequivocal interpretation of navigational information is of key significance. A number of standards for marine information exchange have been developed, some are underway. The standards are based on the relevant, systematically extended ontology. Work is in progress on the construction of navigational information ontology and representation, which will enable their automatic analysis and interpretation (Banaś et al., 2013; Pietrzykowski et al., 2014b, Wójcik et al., 2014).

3. NAVDEC - DECISION SUPPORT SYSTEM IN COLLISION SITUATIONS AT SEA

3.1. *The scope of decision support.* At present, sea-going ships and yachts do not carry a decision support system to aid them in collision situations, like that used in aviation Traffic Alert and Collision Avoidance System (TCAS).

In the Baltic Sea alone the last decade (2001–2010) witnessed as many as 348 collisions (HELCOM, 2010). An average cost of ship collision, taking account of the hull repair cost, (excluding the costs of medical care, lost cargo or environmental pollution) is one million USD (The Swedish Club, 2011). An average yearly sum of damages paid by insurers (hull and machinery) is about two billion USD. The average total yearly insurance premiums in maritime transport is approximately 37 billion USD.

Navigational systems currently installed in ships only have an information function. The NAVDEC system processes and integrates data from information systems and generates anti-collision manoeuvres to be executed.

Actions have already been taken at the International Maritime Organization forum, in the NAV Sub-committee in particular, aiming at gradual introduction (advised system – recommended system – mandatory system) of decision support systems on sea-going vessels. As a result, the Polish delegation successfully submitted in 2013 a document adopted as NAV 59 INF-2 (NAV 59/INF.2, 2013).

The NAVDEC system particularly supports the navigator in making the right decisions in a collision situation, and generally assists navigators in the process of safe ship conduct.

The system prevents navigators from making potentially critical errors when they are identifying a situation and when they are planning an anti-collision manoeuvre (80% of collisions occur due to human errors). To avoid a collision, NAVDEC generates manoeuvres quickly and effectively so that the own ship will pass other vessels at the distance pre-set by the user/navigator. When planning an anti-collision manoeuvre in relation to many vessels, the navigator requires much more time, a critical factor for the manoeuvre to be effective. In such situations, developing a manoeuvre that provides for safe passing distances to a few targets is practically unfeasible. The navigator plans and executes the manoeuvre in relation to the most dangerous target and then plans the manoeuvre for the next object. NAVDEC plans one manoeuvre for the navigator, which complies with COLREGs and enables the passing of all other targets at a pre-set Closest Point of Approach (CPA).

Solutions proposed by the system, together with their justifications, do not relieve navigators from responsibility, but help them to make the right decision. Its main areas of use include:

- Collision avoidance – shipboard decision support system installed on the navigational bridge of:
  - merchant vessels (sea-going and inland shipping),
  - leisure boats (e.g. sailing ships, motor yachts),
- Navigational decision support in collision situations – component of shore-based vessel traffic services systems (VTS, VTMS, VTMIS, RIS);
- Analysis and assessment of marine accidents at sea and on inland waterways – a system intended for experts working for maritime courts;
- Marine officer training centres offering courses in the Collision Regulations – a module of navigational simulators (e.g. ship-handling, ECDIS).

3.2. *New functionalities.* The developed system utilises systems commonly installed on ships and yachts, such as GPS, AIS, or ECDIS – the electronic chart display and information system that enables navigation of the ship, voyage planning and display on a single screen of data from navigational equipment (GPS, AIS, ARPA, log, gyrocompass).

The present version of the software does not require additional equipment. NAVDEC may operate as a separate system (this requires purchasing charts), or may be incorporated into the integrated navigational bridge system.

Compared to the existing systems, NAVDEC's novel functionalities include:

- Generation and display of new courses allowing the ship to pass other targets at a pre-set distance (Figure 2),
- Presentation of ship's status in the light of the International Collision Regulations, combined with the integrated data from ARPA and AIS (Figure 2),
- Generation of a solution accounting for a number of vessels in the vicinity (Figure 2).

Compared to ARPA, a system currently used on ships, calculating ship encounter parameters and thus allowing the navigator to work out an anti-collision manoeuvre, NAVDEC has the following advantages:

- It takes into account the Collision Regulations for good and poor visibility conditions,
- The generated manoeuvre also accounts for ships that are currently in the blind sector of the radar,
- The operator is immediately notified of a manoeuvre started by another vessel thanks to information on that vessel's rate of turn,
- It requires a few seconds to calculate encounter parameters, while ARPA, according to IMO's test scenarios, needs as long as three minutes for this procedure,
- The system is more accurate in calculating the encounter distance (distance measured by a radar is 30 m or 1% of its current range scale, whichever value is higher), for two reasons:
  1. It allows for ship's length,
  2. Uses GPS to determine positions and dedicated algorithms carrying out data fusion,
- Takes into account ships' sizes while planning an anti-collision manoeuvre,
- For own ship calculates new courses enabling passing other targets at a pre-set Closest Point of Approach (CPA).

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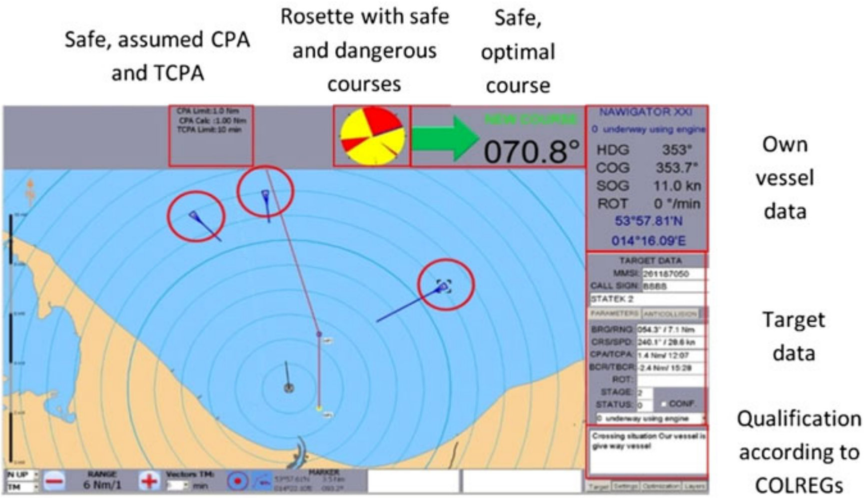

Figure 2. Graphical user interface of NAVDEC (Wołejsza 2013).

Users of the herein presented navigational decision support system NAVDEC confirm the usability of such systems on sea-going vessels.

3.3. *Tests.* Simulation studies of the NAVDEC system have been carried out in an area free of navigational dangers in four different scenarios in the Centre of Navigational Technologies, located in the Marine Traffic Engineering Centre at Maritime University of Szczecin. Results, in general, were positive. In detail, the system correctly calculates encounter parameters like CPA and Time to Closest Point of Approach (TCPA). Displayed parameters were each time compared to CPA and TCPA calculated by a simulator. The average difference in CPA was 36 metres and in TCPA 3 seconds. Moreover, the system correctly calculates new, safe courses which allow the passing of other targets at an assumed 1 NM distance. The passing distances, verified by the simulator, differed from the assumed ones by not more than 0·1 NM. The system presents the qualification of encounter situation according to the COLREGs separately for each selected target, and indicates the applicable rule. Moreover, NAVDEC displays the Recommended Trajectory i.e. route from present position to the next waypoint which allows passing other targets at an assumed CPA. Finally, the system is able to calculate sectors of recommended courses for at least 40 vessels in a pre-defined 5-second time period. These sectors are based on actual settings of CPA and TCPA, which are still the main parameters used during assessment of an encounter situation and COLREGSs for good and restricted visibility (Wołejsza et al., 2013). All vessels within the distance set up by the navigator, e.g. 8 NM, are calculated automatically. This means that additional action by the navigator is not required. The inclusion of water depth and other geographical environment factors is currently being developed and will be incorporated in the next version of NAVDEC.

The NAVDEC decision support system was also tested on *MV Hammonia Berolina*. The vessel sailed on a fixed route from Algeciras in Spain to West African ports: Lome, Onne, Douala, Tema, Takoradi and San Pedro.

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To verify the correctness of CPA and TCPA calculation, the results received from NAVDEC and a simulator (radar strings RATTM) were compared. A total of 1157 CPA and TCPA items were registered. 70% of CPA calculations by NAVDEC and ARPA were identical. Only in 1·5% cases (19) was the difference greater than 0·2 NM. All 19 cases were registered when a target ship started a manoeuvre. In the first phase of a manoeuvre (30 seconds) the difference ranged from 0·6 to 1·1 NM. At this time the difference in TCPA reached over 11 minutes. Later the CPA difference decreased back to the 0–0·1 NM range and remained as such until the end of the experiment. The results show that NAVDEC is more precise than ARPA, particularly when ships are manoeuvring. In the first phase of manoeuvres, CPA and TCPA presented by ARPA are useless and should not be considered while evaluating an encounter situation, as it could lead to a misjudgement. Moreover, NAVDEC informs the navigator that targets have started their manoeuvres. In such situations the target ship is flashing yellow. This function is not available in ARPA (Wołejsza, 2014).

4. AREAS OF USE

4.1. *Decision support on sea going vessel.* NAVDEC's main area of application is decision support on a sea-going vessel. Apart from real time use, the system can also be useful in marine officers' training, and in analyses and assessment of navigational accidents.

NAVDEC's basic functionalities will be presented through a simulation of a collision between the *MV Gotland Carolina* and the *MV Conti Harmony*. The simulation clearly illustrates the two extra applications of the system.

The collision under consideration occurred on 19 April 2008 at 0926 local time, 22 NM miles south of Ra's al Kuh (Iran) in daytime, in very good visibility. In the vicinity of the collision there were no navigational obstructions and dangers nor other ships that might have restricted possible anti-collision manoeuvres. Based on the data included in the report by the Danish Maritime Administration (DMA), a simulation was made to determine parameters of the encounter and to generate possible anti-collision manoeuvres at certain moments of time. The solution does not account for manoeuvring components (kinematic equations). Figure 3 presents a reconstructed situation at 0900 hrs. The range of courses that assure safe passing at the pre-set CPA or larger is marked yellow on the circle. The recommended manoeuvre is indicated as 'NEW COURSE' and enables the ships to pass each other at the assumed CPA. The speed range satisfying the assumed criteria is marked green, and proceeding at 'NEW SPEED' will result in the ships' distance during passing being equal to the assumed CPA. In open waters it is always recommended to avoid a collision using a course change only. A solution by speed alteration can be used in restricted waters, where course alteration is limited and the ship does not proceed at full sea speed. Additionally, the system generates a proposal of the safe trajectory for own ship (Figure 4).

The navigator or Master can set up minimum and maximum course alteration e.g. 15–90 degrees. In such cases, all solutions from other sectors will not be displayed. The presented solution takes into account all vessels within a pre-set distance of, say, 8 NM. So there is no risk that avoiding a collision with one target can create a collision situation with others. Time to the next waypoint can be checked in the Route Planning

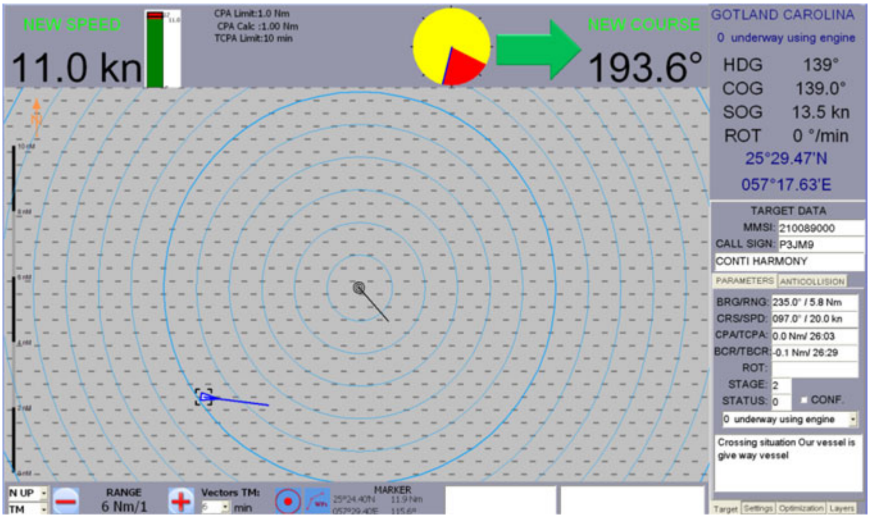

Figure 3. Ship encounter situation.

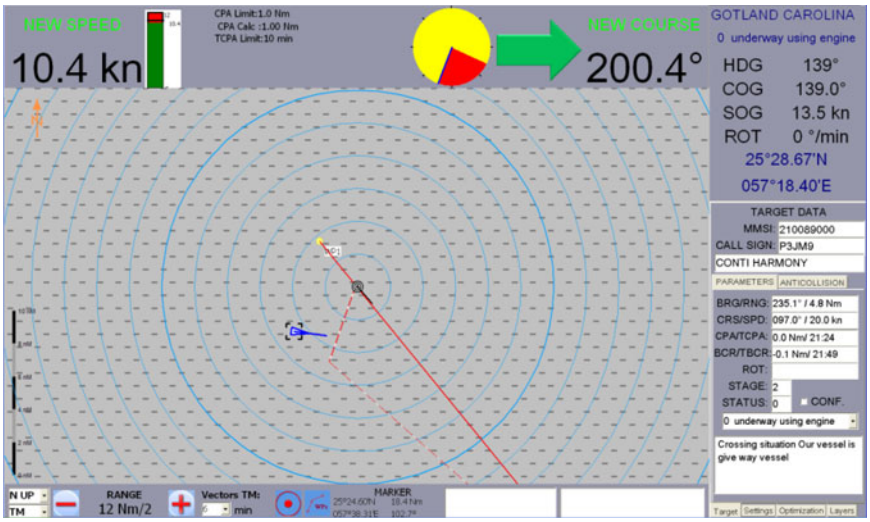

Figure 4. The recommended trajectory.

option. The turning way point is calculated under the assumption that all TCPA with other targets equal zero.

Anti-collision manoeuvres are calculated when our vessel has to give way to at least one other vessel. Relationships between the other vessels are not taken into account, but each change of their parameters is immediately noted and taken into account when calculating a new solution. Solutions are refreshed automatically after receiving a new message from AIS or ARPA. This means that each AIS or ARPA NMEA string

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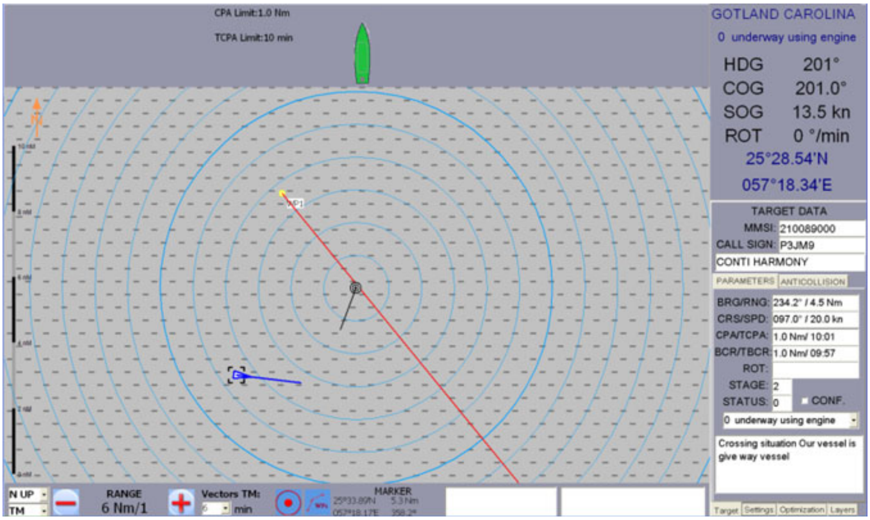

Figure 5. Situation after an anti-collision manoeuvre.

(using NMEA communication protocol) received by NAVDEC is carefully checked by the system. In case parameters of the target are changed, these are taken into account when planning the anti-collision manoeuvre.

When the recommended manoeuvre is performed by own (system operator's) ship, the system assesses the situation as safe (green ship contour – Figure 5), as all the criteria have been satisfied. At the same time, in line with the COLREGs, the situation remains qualified as before, so our (operator's) ship is still the give-way vessel.

If the navigator does not take a preventive action, the system will continue to work out manoeuvres to be performed. If a collision cannot be avoided by altering course to starboard, proposed course alterations to port will be displayed (Figure 6). In this particular situation the distance between vessels is only 1·3 NM. The dangerous target is on the starboard side of our vessel. These factors determine that it is already not possible to pass the target at the presumed distance of 1 NM by altering course to starboard. This is why the system suggested a change of course to port. In case of a multi-encounter situation, the recommended action will be the same. In case it is not possible to plan a manoeuvre to starboard in relation to at least one target (probably because of distance), the system will suggest an alteration to port.

At the time the ships come to a point where passing at distance of 1 NM will not be possible, the system automatically reduces the assumed CPA by half. The new CPA taken into account while generating an anti-collision manoeuvre is displayed at the top screen denoted by CPA Calc (Figure 7).

Failure to take a preventive action, which means failure to execute the action recommended by the system, will lead to a close quarters situation. Then only a concerted action by the two ships may save them from a collision (Figure 8).

4.2. *NAVDEC as an element of VTS.* The extension of information systems presently operated in VTS centres by adding the NAVDEC functionalities will enhance the scope of decision support offered by a shore-based centre (Figure 9). Such extension will include (Pietrzykowski et al., 2012):

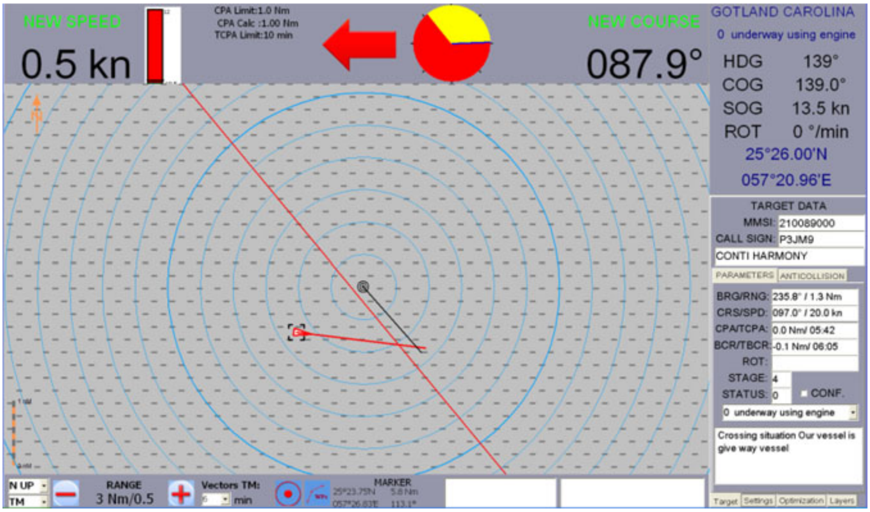

Figure 6. Solutions to the collision situation by course alteration to port.

- Fusion and integration of navigational data available on board and at a shore-based centre,
- Analysis and assessment of a navigational situation taking the Collision Regulations into account,
- Automatic generation of solutions to collision situations, using special computational algorithms, including optimisation algorithms,
- Explanation of the present navigational situation based on the navigational knowledge base (Collision Regulations, principles of good sea practice, criteria of navigational situation analysis and assessment used by expert navigators),
- Justification of the proposed manoeuvre.

Depending on the type and scope of information, decisions may be made under certainty, risk or uncertainty conditions.

If we consider the decision making process as an optimisation problem, it will be a problem of non-linear, multi-criterion, dynamic optimisation, in which some constraints, criteria and components of the objective function may be inaccurate – imprecise or uncertain (Pietrzykowski et al., 2014b; Pietrzykowski et al., 2010). One of the challenging tasks for system designers is the creation of relevant knowledge bases. Another major constraint is the time limit to generate a solution, a characteristic of real time systems. Therefore it is essential in creating a decision support system to specify or assure, respectively:

- Its range of operation,
- Conditions and restrictions,
- Method of information display (e.g. situation assessment, generated solutions and their justification, accuracy),
- Range and method of testing (verification and validation),
- Adequate software quality,
- System reliability, safety and security.

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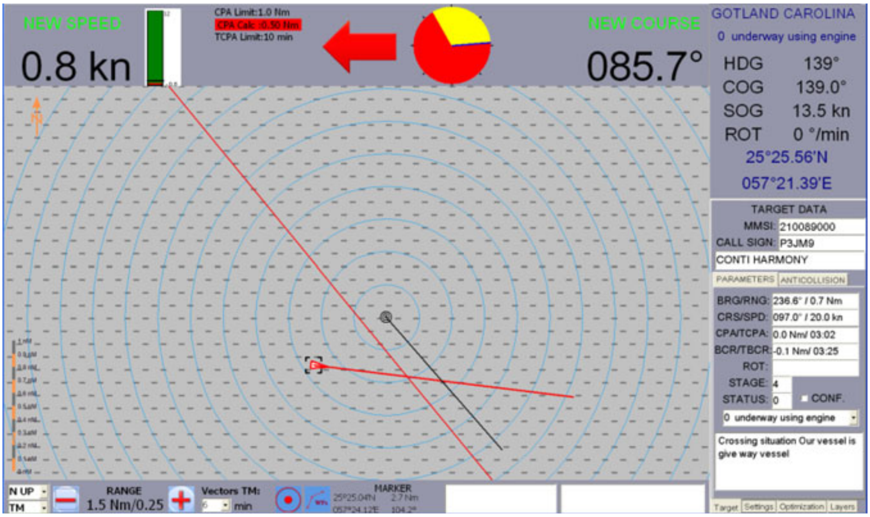

Figure 7. The manoeuvre generated after a reduction of the assumed CPA.

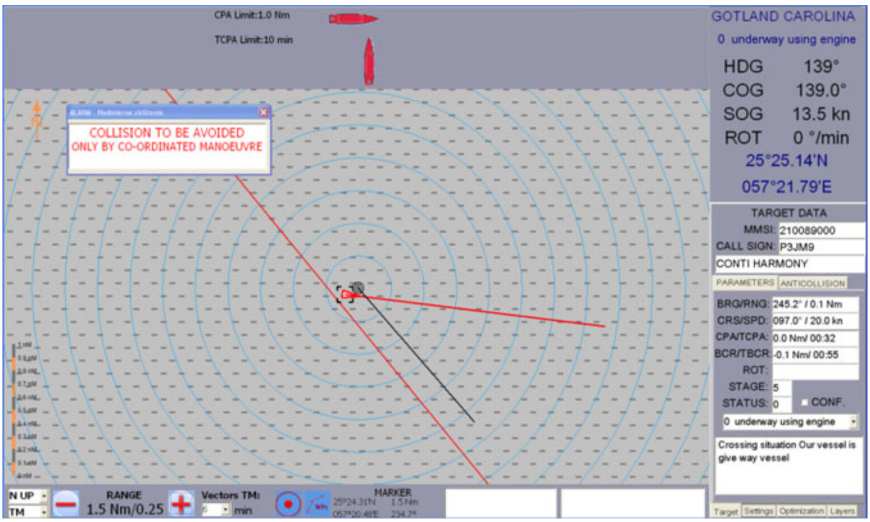

Figure 8. A close quarters situation.

On this basis, guidelines and performance standards for such systems can be developed.

At the fifty-ninth session of the NAV Sub-committee (NAV 59/INF.2, 2013) Poland presented the results of research into the construction of a navigational decision support system NAVDEC on a sea-going vessel, which may be implemented as an

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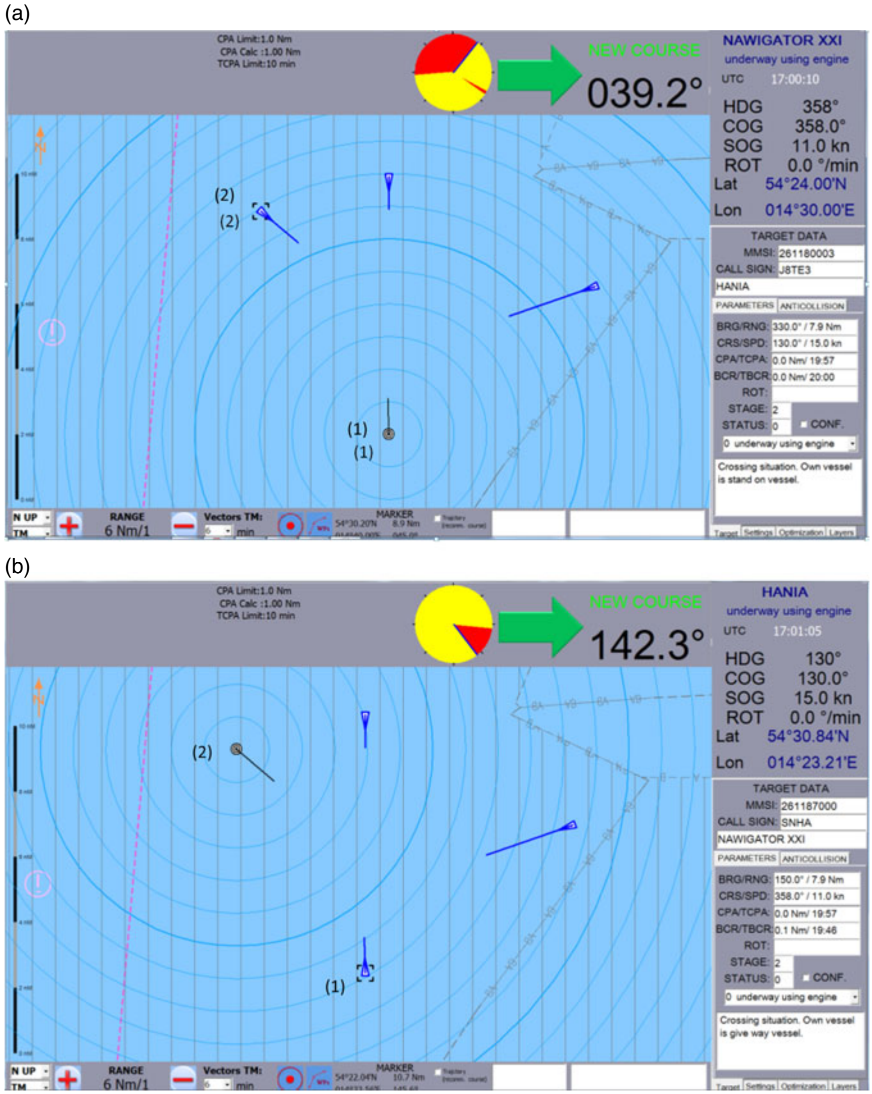

Figure 9. Navigational situation in the NAVDEC interface at a shore-based centre: a) viewpoint 1 - chosen ship *Nawigator XXI* (1); b) viewpoint 2 - chosen ship *Hania* (2)

anti-collision module in navigational systems, already installed on board the vessel or as a standalone computer system.

It was concluded that "Navigational Decision Support Systems, like other navigational systems, shall be liable to certification. This is a complex problem. It is necessary to prepare procedures and rules for the approval process as well as requirements and test methods. These shall take into account specifics of the system, its role in navigation processes and others. The issues such as responsibility, proper functioning and handling of the system shall also be taken into consideration."

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To this end initial proposals to be included in requirements for approval were formulated. The proposals referred to general operational requirements as well as proposed tests, test forms and test results. In addition to the mentioned IMO documents, these can be a starting point for the specification of requirements and performance standards for these systems. These actions may accelerate work on implementing and spreading decision support systems in the global fleet, enhance the safety of navigation and the effectiveness of maritime transport.

5. CONCLUSIONS. The development of IT and ICT is creating new opportunities for navigational systems, improved by adding new functionalities that support decision making on ships and in shore-based centres. Consequently, information systems tend to be transformed into decision support systems. The first such systems have already been designed, following user needs for additional functionalities, such as situation analysis and assessment accounting for the regulations in force and good sea practices, relevant criteria, and solutions being displayed to the operator.

The implementation of decision support systems can significantly reduce the number of human errors, which translates into the reduction of accidents at sea and their adverse consequences. The usability of navigational decision support systems on vessels has been confirmed by actual users of the NAVDEC system.

Therefore it seems justified to consider the place of navigational decision support systems in e-navigation, a new generation of systems capable of analysing the situation around the ship and automatically generating recommended decisions (solutions), for collision avoidance, and generally, safer and more efficient navigation.

In case of expected rapid development of decision support systems, the determination of their operational scope as well as development of relevant guidelines and performance standards will be needed.

Due to the complexity of such systems, resulting from a wide variety of decision situations, the number of decision-affecting factors and different criteria used by navigators, the development of guidelines and performance standards will take much effort and time. On the other hand, experience gained in the implementation of the ECDIS system and presently developed Guidelines on Human Centred Design, Guidelines on Usability Testing and Guidelines on Software Quality Assurance for e-navigation may accelerate the process.

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