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NAVIGATIONAL DECISION SUPPORT SYSTEMS IN MARITIME TRANSPORT

Abstract: Navigational equipment and systems installed on board ships and at land-based centres improve and automate the processes of navigational information acquisition, processing and presentation. These systems perform mainly information functions that enhance decision making processes. The growing range and amount of available information and the consequent difficulties in data processing and use make up a potential source of human errors, one of the main reasons behind marine accidents. Actions already undertaken aim at extending the existing navigational systems, or building new ones, where decision support functions will have a wider scope. This article will describe the present situation and directions of developing navigational systems in maritime transport.
Keywords: navigational safety, sea transport, decision support system

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 result in increasingly updated navigational equipment and systems implemented on board ships and in land-based centres. These new facilities, widely using advanced information technologies, support decision making processes. Basic functions of decision support systems include acquisition, storage, processing and presentation of navigational information.

As the user's needs are diverse in terms of scope and form of navigational information to be presented, dedicated systems are being created. These include, but are not limited to pilot navigational systems, docking systems, weather routing systems and dynamic positioning systems.

Available computing power continues to grow, consequently more and more complex computing methods and algorithms can be introduced, extending the range of functions of navigational systems presently in use. This refers to issues such as vessel movement predictions, generation of solutions to an existing situation with the justification of the solutions generated by the system. Developments we can observe tend to gradually transform navigational information systems into decision support system utilizing methods and tools of knowledge engineering.

2. DECISION PROCESSES IN MARITIME TRANSPORT

2.1. Areas of decision making in the maritime transport system

Maritime transport is a major link of the entire transport chain. Like in other modes of transport, transport service providers, apart from economic aspects, have to take into account the safety of people, means of transport (vessels), cargo and the environment. Maritime transport services are executed by the maritime transport system ($\mathbf{S}_{\mathbf{TM}}$) [7].

There are a number of factors that affect the quality, effectiveness and safety of marine traffic. These include the technical condition and equipment of sea-going ships and ports of call. Vessel traffic control understood as the organization of ship movement processes is another major factor. This issue can be considered in various control areas. Vessel traffic control from the shipowner's viewpoint aims to optimize transport service operations of its fleet. The operators responsible for the organization and supervision of vessel traffic within port approaches and basins are expected to efficiently handle ingoing and outgoing traffic: assist in collision avoidance, control movements of each ship, minimize their waiting times before arrival and departure. The navigator on watch has to execute a sea voyage according to shipowner's guidelines and, at the same time, observe the principles of safe navigation, regulations in force and instructions of land-based monitoring and control centres. Executing tasks in the above areas of control means making decisions. Once the tasks are identified, the respective areas of decision making can be defined. It will be noted that ranges of decision making in the three areas shown are partly overlapping.

Taking account of the scope of problem considered in this article (decision support in safe ship navigation), we will discuss vessel traffic control in two areas: vessel traffic organization and supervision and vessel conduct by the navigator.

2.2. Navigational decision processes

The scope of decision processes herein discussed will be narrowed to navigational issues of conducting the ship and assuring its navigational safety. The navigational decision making considered in this article comprises decisions made by land-based centres responsible for vessel traffic supervision and control and decisions taken on sea-going vessels.

The range and types of navigational decisions taken on board a ship result from the execution of the transport task – carriage of cargo and/or people.

Navigational decisions made on board and concerning safe ship movement control refer to various time ranges. Considering the specific character of navigation in restricted waters, approach channels and harbour basins in particular, we can distinguish a group of decision processes related to the ship movement control in these water areas. Decisions made relate to standard or emergency situations. On this basis, the following areas of decision making can be distinguished and the corresponding navigational decision processes:

- weather routing, where changes of weather conditions during the voyage are taken into account – strategic decisions,
- ship movement control (collision prevention and avoidance) – operational decisions,
- ship movement control in restricted areas, including port basins – operational decisions,
- ship movement control in emergency situations (rudder or propulsion damage, rescue operation, etc.) – operational decisions.

The vessel traffic service (VTS) system is understood as any system put into service by the authorities of a coastal state in order to provide for the safety of navigation, traffic efficiency and the environment protection. The basic functions of a VTS system are as follows [5]:

- organization of traffic in a fairway,
- traffic supervision and control,
- navigational assistance (information function),
- coordination of rescue operations in case of accidents and disasters,
- management and control of navigational systems operation,
- delivery of data for port and regional services and data storage for administrative, research and planning purposes.

Having considered the above functions (tasks) of the VTS system, we can identify areas of decision making and corresponding decision processes, which are: 1) planning – organization of vessel traffic, 2) solving collision situations (collision avoidance), 3) procedures in emergency situations.

The systems under consideration are to ensure the safety of vessel traffic and support the navigator steering a vessel. It is navigator's responsibility to handle his/her vessel safely throughout a voyage.

2.3. Navigational decision support systems

The development of information technologies has created opportunities for computer-based systems to be used in decision processes requiring a lot of data to be processed with the use of complex computing models. These systems are referred to as Decision Support Systems (DSS).

The characteristic feature of these systems is that model bases and knowledge bases are used in a number of decision tasks, such as analysis and assessment, inference, verification of decision effectiveness, optimization.

Taking into account the areas and ranges of navigational decisions made in land-based centres and on board ships (conf. sections 2.1 and 2.2), we may identify the following tasks that DSS has to execute:

- navigational information acquisition, integration and presentation through a user interface,
- monitoring, analysis and assessment of a navigational situation, including dangerous situation alarms and indication of current navigational safety level,

– prediction of a navigational situation,
– solving problems of collision and emergency situations by using relevant computing models,
– planning, coordination and supervision of vessel's movement (on board) and vessel traffic (land-based centre),
– justification of situation assessment results as well as solutions the system generates.

The navigational systems currently in use to a varying degree perform the above tasks. Some systems are used both at sea and on land. These are mostly information systems supporting decision processes comprising automatic acquisition, processing and presentation of navigational data and alarming when events defined as incorrect or dangerous occur.

3. Navigational systems in decision support processes

3.1. Shipboard navigational systems

Standard equipment of a merchant vessel, apart form such navigational devices as a log, gyrocompass, radar, echosounder, is composed of a number of systems which assist in making decisions on board. These include ARPA (Automatic Radar Plotting Aid), AIS – (Automatic Identification System), ECDIS (Electronic Chart Display and Information System), GNSS (Global Navigational Satellite System) – e.g. GPS (Global Positioning System).

ARPA is a computer assisted radar data processing system, which graphically presents a current situation. The basic functions of the systems are: automatic or manual acquisition of targets, true or relative motion radar presentation, digital read-out of acquired targets which provides course, speed, range, bearing, closest point of approach (CPA), signaling dangerous situations based on preset values of CPA and time to CPA (TCPA), the ability to perform trial maneuvers, including course and/or speed changes.

AIS has a capability of automatic exchange of data between ships used for collision avoidance and ship identification by land-based systems controlling vessel traffic. AIS functions include automatic and continuous transfer of ship's static and dynamic data with an adequate frequency of transmission. Examples of static data are the IMO number, ship's call sign and name, its parameters and type. Dynamic data include ship's position and movement parameters (course and speed). Additionally, voyage data is delivered (ship's draft, dangerous cargo, if carried, port of destination and estimated time of arrival – ETA) plus brief information relating to safety, updated as need arises.

ECDIS is a navigational information system which, combined with redundant devices, can be regarded as an equivalent of updated navigational charts. The system enables a presentation of selected data from built-in electronic navigational chart (ENC) together with positional information obtained from navigational devices. ECDIS-derived information integrates data from co-operating devices and systems, e.g. log, radar, ARPA, echosounder, GNSS, AIS and others. Its basic functions are as follows: display of all data found in an ENC necessary for safe and effective navigation, continuous plotting of ship's position, determination of ship's movement and target approach parameters, generation of alarms and warnings referring to the situation displayed or, in case of other equipment failure, route planning, track control and voyage recording.

The diversified needs of users necessitates construction of specialized navigational systems taking account of the specific tasks the navigator has to execute. Examples of such systems are pilot navigational systems, docking systems, weather routing systems and dynamic positioning systems.

3.2. Specialised decision support systems onboard sea going vessels

Weather routing systems. The purpose of weather routing (navigation) is the determination of an optimal route of an ocean-going vessel based on the present and predicted weather data, taking into account ship's speed and manoeuvring characteristics.

The ship's route is determined on such criteria as ship and cargo safety as well as economical criteria (e.g. voyage time, fuel consumption). Therefore, the optimization of a sea route depends to the group of multicriteria problems [9].

In case of commercial programs the basic goal of the system operation is to minimize the voyage time at given ship's boundary operating conditions, such as wind, waves, minimum approach to a tropical cyclone, etc., taking into consideration areas that are not available for navigation (ice fields, waters closed for navigation). Difficulties in defining the optimal voyage route are mainly due to limited reliability of hydro meteorological forecasts, long-term forecasts in particular, and to the fact that ship's speed characteristics have to be accurately specified.

Until recently, only land-based centres used such systems. At present, the number of those installed on board is growing. Examples of these systems are SPOS (Meteo Consult), Bon Voyage (Applied Weather Technologies) or Bridge (Weather News). They are also used for an analysis and verification after the sea voyage.

Pilot navigational systems. The pilot navigational systems are intended for navigating in restricted areas, often referred to as pilot navigation, which consists in three tasks that the system has to perform [1]: 1) planning a safe manoeuvre, 2) determination of a ship's position with a specific accuracy, 3) ship movement control enabling safe performance of a planned manoeuvre.

The need to build such systems results from the specific character of navigation in a restricted water area, e.g. fast changes of ship's position in relation to land objects, navigational obstructions and others. Examples of such systems are E-Sea Fix system (Aachus based Danish Marimatech) and the Pilot Navigation System (PNS) developed at the Maritime University of Szczecin (MUS).

Major features of the PNS developed at the Institute of Marine Traffic Engineering, MUS, are as follows:

- safety: independent sources of navigational information, waterline position, choice of navigational information presented to the navigator, manoeuvre prediction,
- effectiveness: increased effectiveness of services rendered to the ship in the port – cost reduction and capacity increase.

Characteristic features of navigational information presentation by the system, facilitating decisions made by the navigator, are: route-up orientation, one readable depth contour, basic information about aids to navigation, lack of topographic data, minimum of required navigational information [3]. The PNS was implemented in two versions: stationary (for sea ferries) and portable (for pilot navigation).

Docking systems. Docking systems are developed to assure the safety of the vessel, cargo and the marine environment during berthing and unberthing manoeuvres, particularly by ships carrying dangerous cargo (e.g. LNG) in heavy weather conditions [4]. These systems provide accurate data on ship's hull position and speed relative to the berth. The required accuracy can be obtained by using GNSS receivers working with an external source system such as the RTK system or by means of a measurement system mounted on the berth, e.g. a laser system.

Actual examples of this type of systems are SmartDock (Trelleborg Harbour Marine) and Maritech-made BAS (Berthing Aid System). Both systems feature a control unit located on the berth. The navigator on board uses a portable display.

Dynamic Positioning Systems (DP). DP systems are used for precise ship manoeuvring: maintaining ship's operating position; moving a ship to another position maintaining a specific low speed; controlling the position, speed and course during ship's operation.

Automatic positioning is based on reference systems, using electric power units, bow and stern thrusters, azimuth thrusters, the main propulsion and rudder, taking account of weather conditions. These systems have a variety of applications, e.g.: diving operations using floating divers' bases, works using submarine vehicles, pipe and cable laying or repair operations, precise dredging works, drilling using floating drilling rigs, special transshipment by offshore or shuttle tanker type vessels.

These systems have automatic or manual control options. Examples of DP systems include K-POS (Kongsberg Shipmedics), Mate DP (Marine Technologies) and NavDP (Navis in Control).

3.3. Navigational systems in land-based centres

Land-based centers directly responsible for vessel traffic monitoring and control are vessel traffic service centres (VTS). At present there are many VTS systems operating all over the world. They cover areas of heavy traffic and/or areas difficult for navigation. To increase the effectiveness of these information systems, management modules are added to support the operator in decision making (Vessel Traffic Management System VTMS). Attempts are made to merge individual VTS (or VTMS) systems into co-operating units so that larger traffic areas will be supervised and controlled (Vessel Traffic Management and Information System VTMIS).

The mentioned systems make use of specialized equipment and navigational systems which support the processes of information acquisition, processing and presentation.

Vessel traffic service systems were originally equipped with radar and ARPA systems also used on ships. At present VTS systems are specialized systems with functional capabilities of shipboard systems such as ARPA, ECDIS and AIS. VTMS systems combine three basic services of VTS: information, navigational assistance and traffic organization into one system of traffic management. The extended VTMS function basically refers to the management of the entire port complex. As far as VTMIS is concerned, additional functions result from an expanded traffic control area and inclusion of other maritime services. VTMIS is composed of [6]:

- Ship Reporting Systems (SRS),
- Maritime Assistance Services Systems (MAS) and associated places of refuge,
- Long Range Identification and Tracking System (LRIT),
- National Computer networks of Data Exchange (national SafeSeaNet systems).

3.4. Development directions of navigational decision support systems

One example of trends followed by navigational decision support systems used on ships is the prototype system developed at the Institute of Marine Navigation (MUS) [8]. The system is intended for navigation in open sea waters. Apart from functions typical of navigational information systems (ECDIS, ARPA), it has the following functions:

- analysis and assessment of a navigational situation, taking into account the mandatory Collision Regulations [2],
- prediction of a navigational situation,
- automatic generation of solutions to collision situations using special computational algorithms, including optimization algorithms.
- explanation of a 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 generated manoeuvre.

Work connected with the development of specialized navigational systems goes in two directions: improvement of the existing systems and the integration with other navigational systems.

As for weather routing systems, research concentrates on:

- seeking solutions using methods and tools of multicriteria optimization,
- application of adaptive models for the determination of ship's speed characteristics.
- integration with other navigational systems on board, particularly with ECDIS.

We should expect further advancements in navigational pilot systems. Their advancements will include decision models using optimization methods and tools. These will enable extending the scope of decision making in determining safe trajectories of ship movement in restricted areas, such as port approaches, fairways and port basins. Knowledge bases on safe manoeuvres in such areas may contribute to a significant progress.

Developments in docking systems, in turn, will tend towards integration with shipboard navigational systems, including pilot and dynamic positioning systems.

The growing importance of land-based centres in vessel traffic control processes, with remote pilotage performed by some centres, necessitates an extension of the range of functions to include those used by ships. It also seems necessary to widen the range of automatic information exchange with co-operation and negotiation mechanisms operating between a land-based centre and a ship, executed by program modules aboard and on land.

One can expect that navigational decision support systems will be broadening their range of acquiring, processing and using knowledge (knowledge bases). The development of these systems presently observed tends to proceed towards intelligent decision support systems. These systems are based on models of operational activities (optimization) and artificial intelligence (discovering knowledge from data), applied within new computing units using the psychological and cognitive knowledge of processes taking place in the human mind. This will enable creation of active IT systems characteristic of learning and adaptation. It is expected that the construction of intelligent decision support systems will open way to more effective support of actual decision processes by up-to-date navigational and IT methods. Such advancements translate into enhanced safety of navigation – the safety of people, ships, cargo and the environment.

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NAWIGACYJNE SYSTEMY WSPOMAGANIA DECYZJI W TRANSPORCIE MORSKIM

Streszczenie: Instalowane na statkach oraz w ośrodkach lądowych urządzenia i systemy nawigacyjne usprawniają i automatyzują procesy pozyskiwania, przetwarzania oraz udostępniania informacji nawigacyjnych. Realizują głównie funkcje informacyjne, wspomagające procesy podejmowania decyzji. Rosnący zakres i liczba dostępnych informacji oraz wynikające stąd trudności z ich przetworzeniem i wykorzystaniem stanowią potencjalne źródło błędów ludzkich, będących jedną z głównych przyczyn wypadków morskich. Podejmowane są działania dotyczące rozbudowy istniejących oraz budowy nowych systemów nawigacyjnych, realizujących w szerszym zakresie funkcje wspomagania decyzji. W artykule przedstawiono stan obecny oraz kierunki rozwoju systemów nawigacyjnych w transporcie morskim ze szczególnym uwzględnieniem systemów przeznaczonych do stosowania na statkach morskich.

Słowa kluczowe: bezpieczeństwo żeglugi, transport morski, system wspomagania decyzji