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Changing the Model of Maritime Navigation

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ABSTRACT: The paper describes a short history related to the development of maritime transport at the turn of the 20th century. A classic navigation model used since the mid-twentieth century as well as the development directions of current integrated navigation model have been described here.

1 DEVELOPMENT OF MARITIME TRANSPORT TECHNOLOGY

More than 90 percent of the world trade is transported by sea. In maritime shipping of the last decades of the twentieth century there were changes and technological innovations. In maritime transport, automation and optimization have been introduced in the transhipment process. Technological progress took place also in the construction of marine vessels. As the world tonnage went up, the parameters of vessels used for the transport of general cargo and bulk cargo also increased.

In 1971 the first ship with the cargo carrying capacity of 372 400 tonnes was built. Specialized vessels were built. Changes in transport technology resulted in the modifications of the model of maritime navigation.

All changes were initiated by the International Maritime Organization (IMO) on the basis of legal instruments such as conventions, resolutions, handbooks and programs for the development of technical systems in maritime shipping.

Ruthless economic calculation caused competition in maritime transport among the ship-owners. Economic battle on the freight markets brought about transport development, namely the development in cargo handling and transhipment technologies.

The reduction of the cost of cargo shipping by sea depended on the operating costs of the ship. Fixed and variable costs play a major role in achieving efficiency in vessel operation. It is about fitting vessels to a given shipping line, fuel costs and conditions for choosing marine environment including navigation optimization. There was development of reliable models of weather forecasts. An important element in the sea transport process is the technology of cargo loading, discharging and its carriage. Ship parameters such as loading capacity and draft play a major role in assessing the efficiency of cargo transport. Introduction of cargo containerization was a revolutionary solution to lowering the costs of general cargo transport by sea.

As far as bulk cargo is concerned, the size of the cargo carrying capacity of a ship was determined by the type of cargo and conditions on the shipping route.

In 1947 ISO started work on the principles of standardization of containers used in shipping [2]. The first container was patented in 1956 by an inventor M. McLean. In 1966 the first ship with 236 containers on board sailed [3] and in 1968 a 1000 TU container ship was built. Between 1970 and 1980 there was rapid development of container transport technology; in 1983 around 12 million containers were employed around the world.

Application and development of containerization all over the world strengthened globalization in maritime trade [4, 5]. Container ships sailed at high speed of over 20 knots which required accuracy in navigation. Time tables and rotation to the ports required timely arrival at ports. A new model of navigation process was created. After 2000 large container ships were built, i.e. over 3000 TU. Container vessels were employed on Asian and American lines.

After 2000 the turnover of 300 million of 20-foot containers was reported worldwide. A new commercial process was developed in the form door-to-door chain. This was a revolutionary change in the operation of commercial vessels in the shipping industry. The main advantage of containerization was the efficiency of cargo transport; an example is the comparison of the cost of cargo handling. In 1956 the cost of transhipment of one tonne of bulk cargo was 5.86 US$ and after the introduction of the containerized shipment the cost decreased to 0.16 US$ [6].

There was tonnage specialization. Large vessels with drafts above 15-20 meters were built. Large vessels had problems navigating in shallow areas (ports, roadsteads, fairways). There was a need for shore based assistance to control the movement of vessels. The development of computerization opened up new possibilities for the development of navigation technology. Navigators on bridges of high-speed ships received more and more information so they needed help from shore to cope with them quickly and correctly. Competition forced the use of scientific and technological advances to be employed in sailing. Kalman filter [7] was used for information processing and navigation integration.

The development of shore systems began supporting the captain's decisions in navigating the vessel in areas covered by Vessel Traffic Management (VTS). Advice was rendered from specialized centres to optimize the ship's passage in ocean shipping. Traffic Separation Systems were introduced in congested areas and in difficult navigable areas. Radar anti-collision algorithms were applied and computer systems were developed to support radar observation of vessel motion (ARPA). Global positioning systems (GPS) were established. Earth's artificial satellites were used for maritime communication. Distress alerting system was established (GMDSS). New models of electronic charts were created. It is mandatory to plan a ship's passage from berth in port A to a berth in port B.

In the late 90-ties electronic charts and ECDIS system began to be widely used in shipping and in the future, after a certain period they must replace paper charts on board the ships. A dynamic model for determining under keel clearance was created. Full maritime integrated navigation is used on standardized navigational bridges. A new e-navigation model is being created. For years the new model was discussed and improved on the IMO forum. Automatic identification of vessels (AIS) on bridges is mandatory and it is a starting point of the process of creating a new navigational model in marine navigation.

2 CHARACTERISTICS OF THE CLASSICAL MODEL OF THE MID-20TH CENTURY NAVIGATION

Phases of navigation were divided into four separate navigation areas:

1 Restricted waters;
2 Coastal navigation;
3 Land approach from the ocean or the open sea (landfall);
4 Ocean navigation (Figure 1).

Voyage planning process consisted of operational preparation of the vessel regarding water supply, bunkers, spare parts and ship maintenance materials. Preparing for navigation concerned the selection of charts and aid to navigation such as: Pilots, Sailing Directions, List of Lights, charts, etc.

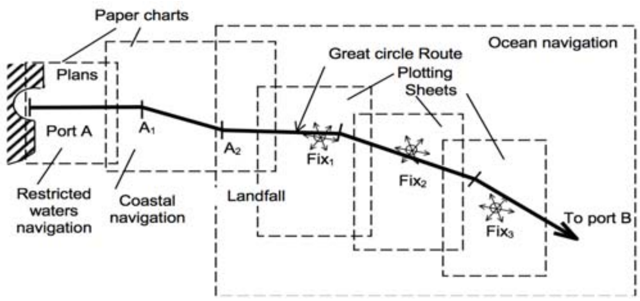

Figure 1. The phases of navigation and method for determining the position in the classical model of navigation [author's own work]

The process of planning included plotting the courses from Port A to Port B on charts appropriately segregated. The courses were plotted from buoys when leaving the port to buoys marking the entrance to port (pilots). Shipping routes were developed on the basis of *Ocean Passages for the World* as climatic routes, in consultation with the Pilot books covering given area. The routes varied according to region and time of sailing.

The position on the ocean was determined as dead reckoning, corrected by astronomical observations. During the day the position was determined from the sun (planets or moon) whereas in the morning and evening (twilight, dusk) the position was fixed from stars and planets. On approaching the land radio navigation systems were used (on some ships that had such systems installed). In restricted areas and coastal navigation, compass bearings and radar or seamarks and systems such as buoys, lightships and leading lines were used.

The working conditions of navigators were complex; they had to prepare a comprehensive process for fixing ship's position which was made up of planning, measurements and their correction, calculating and plotting the results on a paper chart. The duration of the process varied and was time-consuming depending on the method, external conditions, the abilities and skills of the navigator. The whole process was both labour consuming and erroneous.

A simplified diagram of classical navigation model is shown in Figure 2.

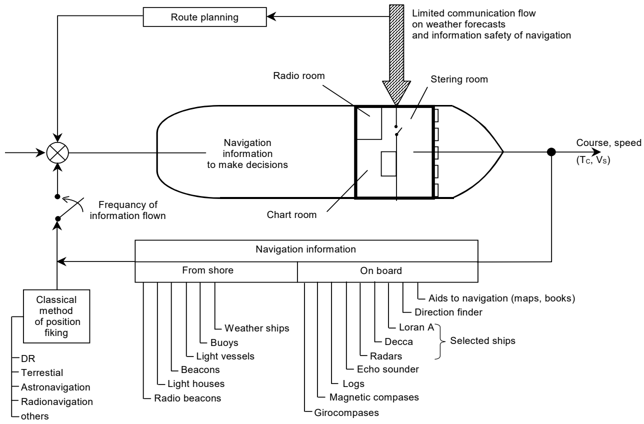

Figure 2. Simplified diagram of navigation model from the second half of the 20th century
[author's own work]

Because weather forecasts were limited, it was difficult to make navigation decisions connected with the choice of the navigation route. Similarly, archival information in navigational aids was limited as a result of the lack of updated corrections of aids to navigation. The working conditions of the navigator were deteriorated by poorly arranged bridges. The bridge consisted of two separate rooms, i.e. a wheelhouse and a chart-room. In navigation model the navigating bridge plays a special role in a decision-making process. Remarks on the role of the navigation bridge in decision-making are presented below.

3 NAVIGATION PROCESSES IN CLASSICAL MODEL OF NAVIGATION

1 Decisions regarding navigation were based on incomplete and uncertain information, in particular, concerning external forecasts on traffic disturbances.
2 There were limitations in obtaining accurate continuous positions in real time. They were dependent on the time of day of the sailing area and hydro meteorological conditions.
3 Information regarding vessel position was related to measurements, analytical processing and graphical representation on a paper chart and this process was labour-consuming and erroneous.
4 The sources of information on the bridge were chaotic, i.e. accessible in the wheelhouse and in the chartroom so navigator lost valuable time in order to get them.
5 External communication with the land was impaired as a result of transmitters and receivers working at low-frequency influenced by propagation changes during the day.
6 The credibility of hydro meteorological forecasts received by Morse key - was limited. The restrictions were on both quality and frequency.
7 No support in navigational processes from shore-based systems.
8 Only paper charts and other old fashioned aids to navigation, such as Pilots, List of Lights, Paper Charts, etc., were used for navigation, quite often with delayed access to corrections.
9 Navigation planning was limited to plotting the courses – true courses for some sailing areas depending on the captain's needs.
10 Radar was used for anti-collision, usually without plotting, which was time consuming and generated errors.

4 DISADVANTAGES AND LIMITATIONS OF THE CLASSICAL MODEL OF NAVIGATION

– There were limitations on the continuity of determining the vessel position at various phases of navigation.
– No global, reliable high reliability system to determine the position.
– Lack of continuous communication with other ships and with land stations.
– Limitations of radar function on identification of other ships traffic.
– There are no uniform seamarks and landmarks in ports all over the world.
– Lack of a unified map projection for charts.
– Lack of traffic separation zones in restricted areas.
– No vessel traffic control system in port approach areas.
– No shore-based systems rendering advice to masters in voyage planning.
– No unification in constructing ergonomic navigating bridges.
– Lack of legal instruments on maritime safety and the protection of the marine environment.
– Onset of the activities of International Maritime Organization in the field of maritime globalization.

5 CREATING AN INTEGRATED NAVIGATION MODEL

The new integrated navigation model was forced by the development of transport technology as a result of the merciless competition of ship owners on the freight markets. Maritime transport could not develop without the introduction of new technologies in the field of computer science and engineering. The intense development of globalization in maritime shipping picked up the pace of this process.

The development of shipping has been under the technical and legal supervision of the International Maritime Organization (IMO) since its founding. In this way IMO has become the most important organ of technological and legislative progress in world maritime shipping.

Remarkable changes in navigation model started after the introduction and use of artificial satellites of the Earth. The satellites were used in several major directions in the development of navigation model, such as:

1 Reliable, unlimited, continuous communication at sea.
2 In the construction of global satellite navigation systems.
3 In hydrometeorology; observation of the surface of the seas and oceans.
4 In rescue at sea.
5 In managing the ships operation.
6 In the safety of ships and human life at sea.

The use and application of the Kalman filter theory [8] brought about further advances in the development of theoretical basics and the creation of a new model of integrated navigation.

Kalman filter has been applied in navigation in the following areas:
1 Integration of navigation processes.
2 Optimization of shipping routes.
3 Global positioning systems using signals from satellites.
4 In automation of ship navigation.
5 Voyage Data Recording (VDR) [9].

Thanks to the development of theoretical foundations in computer science, there were prospects for process changes and navigation development in such directions as:
1 Ways of getting information on the navigating bridge.
2 Change in the design of navigating bridge with reference to ergonomics.
3 Type and methods of visualization of elements regarding navigational information.
4 The time needed to make navigation decisions on the basis of the information received.
5 The volume (amount) and type of information entering the navigating bridge needed to make the decisions regarding the choice a safe motion vector (course and speed).

It is clear from the aforementioned considerations that the processing of navigational information on the navigating bridge must be solved to present the information to the navigator in a simplified form. In this way, the idea of collecting and working out the information in an integrated form appeared.

5.1 *Definition of 'integration'*

The Integrated Navigation System is a navigational control system that allows the navigator to navigate the ship as well as the whole ship's propulsion system. The heart of this system is a processor that integrates a lot of information from various sources.

An integrated navigation system is used as one of the elements used in modern navigation model. In a broader sense, the modern integrated navigation model must take into account components such as:
1 The system for acquiring and processing information on the bridge.
2 Methods of determining the position of own ship and the position of other ships in vicinity (mutual identification).
3 A system for acquiring information on the state of the marine environment in the real time and prognostic/ in the future.
4 External and internal communication systems.
5 System of safety of life and property at sea.
6 Help and cooperation of ship's crews with institutions on land.
7 Legal system governing shipping regulations.
8 Training system and qualifications of ship's crews.

5.2 *Goals and tasks of the new integrated navigation model*

Such model on a ship must meet specific objectives, such as:
- reduction of bridge crew;
- reducing bridge crew fatigue;
- improving the navigator's job performance and work efficiency;
- increasing the volume of information flow and the frequency of information exchange about the external environment;
- facilitating operation of the bridge equipment;
- increasing the utilization of bridge space efficiency;
- quick collecting and processing of navigation data;
- overall increase in the safety of operation of sea-going vessels.

6 CONTEMPORARY MODEL OF NAVIGATION

The simplified integrated navigation model employed on modern ships in international shipping consists of six main elements. This model is shown in Figure 3.

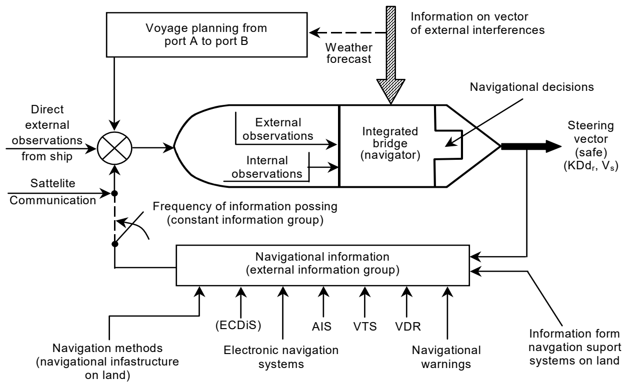

Figure 3. Simplified model of integrated navigation [20]

6.1 *Integrated Bridge Systems*

The goal of navigation integration on the navigating bridge is to reduce the risk of accidents: collisions, grounding and storm damage by increasing system reliability as well as increasing safety of navigation.

The integrated navigation bridge consists of the following subsystems:
- technical system;
- the human system;
- man-machine interface;
- procedures.

Figure 4 shows information unit processed in an integrated bridge system.

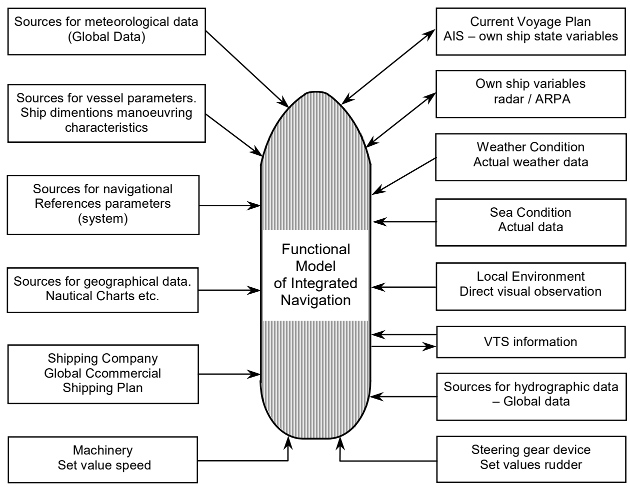

Figure 4. Context diagram of process task "integrated navigation" author's own study based on [19]

Input data on the bridge include information from sources such as:

- direction-determining devices (compasses);
- speedometer (log) over ground and the water;
- water temperatures and salinity;
- ship motion control system (x, y, z);
- echo sounder/water depth meter;
- navigational aids for defining ship's position(φ, λ) true position and dead reckoning;
- radar (S and X bands);
- ARPA;
- a satellite receiver (SATCOM), AIS ... VTS, etc.;
- the autopilot;
- memory range that maintains data from sensors such as main engine, fuel, cargo and various alarms and warnings;
- indicators showing navigation warnings;
- weather forecasting receiving system;
- information on the port of call.

Output data: course made good, speed over ground and information on deviations from the planned route on electronic charts in visual form.

6.2 *Navigational use of the system on the bridge*

The modern navigational model is based on an integrated navigation bridge. The simplified model of the integrated bridge can be divided into four functional groups as [10]:

- technical system;
- operator system;
- man-machine interface;
- operational procedures.

The main components of the integrated bridge system are:

1. Dual ECDIS installations (captain and officer).
2. Dual Radar ARPA (double installation).
3. Conning display for the presentation of navigational information.
4. GPS / DGPS positioning system.
5. Ship's speed measuring system – log (Doppler).
6. Autopilot with gyrocompass.
7. Communication system Full GMDSS (operational).
8. Black box/VDR.

Systems include full internal ship communications and means for monitoring fire control, alarm status and propulsion control; in addition, the function of loading/discharging cargo and stability control.

The integrated bridge is centralized for anti-collision monitoring, risk assessment for grounding and automatic navigation control. At the command post, the navigator monitors the equipment's indicators, such as course, rudder angle, depth, propeller revolutions, speed, yawing, and distance covered measured with log as well as power of the main engine.

As a result of navigational integration, changes have been made to the navigational model, from the perspective of users working on the navigating bridge. These improvements are as follows:

- All navigation functions have been successfully integrated.
- The standardized presentation has simplified the operation of the equipment.
- The standardized process of operating the systems simplified the familiarization with the operation;
- Ease of operation has reduced operator's errors.
- Multifunction workstations.
- Bridge crew have been reduced to a large extent.
- Low equipment costs and easy maintenance of system components.
- Easy training for efficient, trouble-free operation.

7 SCOPE OF CHANGES IN THE MODEL OF NAVIGATION AT THE TURN OF 20^{TH} AND 21^{ST} CENTURY

Changes in navigation model were based on economic, technological and legislative progress in the global economy. Special changes have taken place in the field of maritime transport, such as:

- IMO legislation on shipping safety;
- improvement of navigation equipment and systems;
- creation of new navigational infrastructure;
- improvement of communication forms (satellite);
- new ergonomics of navigating bridge construction;
- establishing separation zones and optimizing the selection of navigable routes;
- development of shore-based navigation systems such as VTS and captain advice on optimal route selection;
- unifying the training of marine staff in accordance with the International Conventions;
- issuing handbooks, conducting training courses to improve professional knowledge of seafarers;
- establishment of global maritime rescue systems;
- introduction of black boxes/VDR for sea-going ships;
- globalization of legislation regarding the application of life safety and property at sea and refinement of other maritime shipping processes.

The process of changes in model comprised reduction in workload of navigators on the navigating bridge. At the same time fewer mistakes were made during the decision-making process. There have been changes in statistics of vessel casualty frequency. It facilitated human contact with the machine, which as a result, affected the safety of shipping. Below is a definition of modern marine navigation.

Marine navigation is the process of acquiring and processing navigational information, taking into account the set of binding requirements and restrictions in relation to the planned route and control of vessel movement, which results in the following functions:
- ship route planning;
- ship traffic control;
- determining the position of the ship and its actual motion vector (CMG, SOG);
- avoiding collision hazards with moving and fixed objects;
- minimizing the adverse effects of the environment on the movement of the ship and its construction components as well as on technical subsystems and cargo [13].

Figure 5 shows a contemporary bridge model in the integrated navigation system.

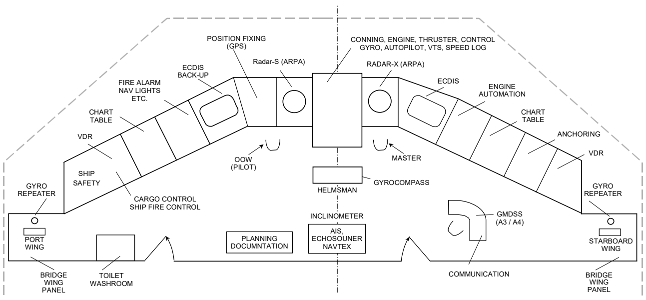

Figure 5. Selected model of integrated navigation Bridge (Composition Based on [14–18]

The wheelhouse equipment of a ship consists of bridge consoles as follows:
1 Autopilot,
2 Bow Thrusters,
3 Chart table,
4 Doppler log (speed),
5 Desk,
6 Magnetic Compass,
7 Gyrocompass,
8 Engine desk,
9 Control Centre, Alarm monitor,
10 Group Alarm Display (cargo, cabin etc.),
11 Group Alarm Display (cargo, cabin etc.),
12 Deadman Alarm Panel,
13 Emergency Telegraph,
14 Signal Lights, navigation lights etc.,
15 Search Light,
16 Radar S, Radar X, ARPA,
17 Lighting Switchboard,
18 Nav. Workstation,
19 Radiostation (VHF, Inmarsat, GMDSS),
20 Position finding panel,
21 Talk back system,
22 Watch receiver,
23 Toilet, Washroom,
24 Planning and documentation,
25 ECDIS and ECDIS back-up,
26 Bridge Wing Panel,
27 VDR,
28 Emergency Exit Window.

8 SUMMARY

1 The main factors that change the model of navigation in time include three groups:
   - technological progress of ship systems;
   - development and implementation of legal elements such as conventions and regulations;
   - level of training and qualifications of ship crews and onshore personnel.
2 Dynamic changes in the development of marine navigation model have resulted from the development and implementation of a number of technical systems such as:
   - Automatic anti-collision radar (ARPA);
   - satellite communications systems (GMDSS);
   - Global positioning system (GPS) satellite;
   - automatic identification systems (AIS);
   - vessel traffic control services (VTS);
   - integrated navigation bridges (IBS).
3 The implementation of legal systems was often delayed in relation to the development of technologies applied in marine shipping which also delayed the development of the model. Likewise, programs for training seafarers were implemented with delay.
4 Technological advances in marine transport will force users to develop and implement a new e-navigation model [1].
5 International Maritime Organization is the main coordinator of creation and implementation of a new navigation model – e-navigation [11, 12]. The definition of e-navigation implies that it is a process aimed at "harmonized collection, integration, exchange, presentation and analysis of marine information on board ships and ashore by electronic means to enhance navigation from berth A to berth B and other services for safety at sea as well as protection of marine environment". To complete the above definition program, seven major programs have to be activated [11]:
   - electronic charts and weather information;
   - electronic positioning systems;
   - electronic information on the ship's routes, such as courses, manoeuvring elements, etc.;
   - transmission of information on ship's position and navigation information for ships;
   - presentation of information;
   - information reporting, priority information system and distress alert;
   - transmission of distress warnings and safety information.
6 Similarly, a model for managing ships without crew from shore stations is expected to be created.

ATTACHMENT 1

Contemporary technical measures used in maritime navigation are shown below

Raytheon Anschütz now delivers (https://www.janztec.com/en/references/detail-seite/raytheon-anschuetz-gmbh-iec60945-certified-pcs-for-ship-bridge-systems/):

- Complete "Bridge Control" Integrated Bridge Systems,
- Turn indication equipment,

– analog and digital navigation data distribution,
– gyro compasses for all ship types and sizes,
– analog and digital display slave devices,
– maritime autopilot and track control systems with digital and adaptive controllers,
– ATA/ARPA radar systems,
– electronic chart display and information systems (ECDIS),
– nautical information displays (NautoConning),
– multifunction workstations for radar/ECDIS and Conning,
– electric rudder control systems and combined helms (NautoSteer),
– "Marine-Inertial-Navigation-System", MINS, a high-precision Ringlaser-platform system for surface and underwater ships,
– battery control systems and helms for submarines
– sonar systems for maritime traffic and measurement,
– GPS/DGPS systems,
– GMDSS communication systems for A1 to A4,
– Automatic Identification Systems (AIS),
– Voyage Data Recorder (VDR),
– user-specific Software,
– crew information and training programs,
– equipment for depot and service stations.

The product range is built with a modular structure, which allows individual modification for all application areas, such as maritime shipping, inland water navigation, coastal shipping, and the challenging yacht market.

The integrated Synapsis bridge systems represent a new generation of intelligent multifunctional workstations which allow not only nautical functions such as Radar, Chart Radar, ECDIS and Conning systems, but also the integration of additional applications and data presentation. The scalability makes it a perfect platform for most ship types – from basic systems with simple functions up to complex systems with all available features.

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