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NAVIGATIONAL INFRASTRUCTURE: ITS STATE, ITS ESTABLISHING AND ITS CHANGES

ABSTRACT In this paper, the navigational infrastructure, i.e. the infrastructure of maritime navigation, has been presented and discussed. There is shown the place of navigational infrastructure in Maritime Safety System and in Maritime Navigation Safety System. There are discussed the parts, kinds and elements of navigational infrastructure as well as the basic requirements towards this infrastructure. There are also presented and discussed the basic features which should be taken into consideration while establishing the new elements of the navigational infrastructure, especially of coastal or local coverage. The basic changes of today's elements of navigational infrastructure have been also presented.

INTRODUCITON

"Infrastructure" means a substructure or underlying foundation, especially of the basic installations, facilitations, etc, being essential to exist and function of the institutions, organizations, companies, industries or societies.

By the term "navigational infrastructure" we mean all, external to the ships, objects, equipment and systems, being necessary to enable of facilitate conducting the ships safely and efficiently at sea especially in confined and restricted areas.

The main characteristic feature of today's navigational infrastructure is permanent increasing its participation and its importance in process of ship's navigation, i.e. in process of safe and efficient conducting the ships at sea not only in the coastal areas but also in open sea.

The second characteristic feature of today's navigational infrastructure is the appearing and growing importance of infrastructure's elements of regional- and global-coverage as well as common using theses elements by all kinds of navigations, i.e. marine, air, land and space navigation.

The following issues are presented below: the place of navigational infrastructure among the components of Maritime Navigation Safety System; the main parts, kinds and elements of navigational infrastructure; requirements towards the navigational infrastructure; general principles regarding the establishing of the objects of the coastal and local navigational infrastructure; and the development tendencies of the navigational infrastructure.

THE NAVIGATIONAL INFRASTRUCTURE AS THE MAIN COMPONENT OF MARITIME NAVIGATION SAFETY SYSTEM

The Maritime Navigation Safety System is the component of the Maritime Safety System. (Fig.1)

The navigational infrastructure is the main component of the Maritime Navigation Safety System. Its place is shown in Fig. 2.

MAIN PARTS, KINDS AND ELEMENTS OF NAVIGATIONAL INFRASTRACTURE

Navigational infrastructure consists of the following parts (Fig. 3):

- spacial elements (objects) of the navigational infrastructure,
- aids to navigation marks and systems,
- traffic management (and navigational assistance) systems.

The elements (objects) of each part of the navigational infrastructure can be divided into the proper kinds and group of elements (cf. Fig. 3).

The main objectives of the navigational infrastructure is to assist the ship and craft in ensuring and maintaining the safety and efficiency of their conducting at sea and preventing the pollution of maritime environment from ships in the following manners:

- by ensuring the sufficient dimension (depths and widths) of the spatial elements of navigational infrastructure,
- by enabling the ships and craft to fix their positions with the sufficient accuracy,
- by signaling and warning the ships and craft about the dangerous depths and underwater obstacles,
- by monitoring, informing, advising and controlling the ships and craft while their passages through the confined and restricted areas.

Spacial Elements of the Navigational Infrastructure

The spacial elements of the navigational, infrastructure constitute mainly the following elements (cf. Fig. 3):

- sea ways, i.e. the different kinds of fairways, canals, recommended routes, traffic separation schemes, and others,
- maneuvering areas, i.e. anchorages, maneuvering and turning basins, terminals, etc.

The spacial elements of navigational infrastructure can be natural, deepened or artificial. However, they are usually mixed.

The main objectives of the spacial elements of the navigational infrastructure is:

- to ensure the safe navigation of ships and craft in confined and restricted areas against the ship-hulls' damages and grounding by ensuring and maintaining the needed parameters (depths and widths) of the sea ways and maneuvering areas in these waters.

The spacial elements of the navigational infrastructure, especially the depths, require to be systematically checked and, when necessary, dredged. These elements are also usually properly marked with buoys and beacons. However, it should be stressed that the main objective of such spacial elements of navigational infrastructure as traffic separation schemes is mainly to regulate the ships' traffic and, therefore, to decrease the ship collision danger.

Aids to Navigational Marks and Systems

The aids to navigational marks and systems constitute the following kinds of objects (cf. Fig. 3):

- coastal and sea-based, natural and artificial position-fixing, signaling and warning marks, such as churches, towers, lighthouses, light-in-lines, buoys (light, sound and radar), beacons, etc.,
- land- and space-based position-fixing systems, such as radiobeacons, Loran C, GPS, GLONASS, DGPS, etc.

The main objective of the aids to navigation marks and systems is maintain the condition of safe and efficient navigation by:

- enabling the ships and craft to fix their positions with required accuracy,
- signaling and warning the ships and craft about the dangerous depths and other underwater obstacles.

It should be remembered that the space-based position-fixing systems provide with the service all kinds of navigation, i.e. space, air, land, and maritime navigation. However, the requirements towards the regional, coastal and local position-fixing systems are higher than towards the space ones. And one more truth. The land-based position-fixing systems are also in higher and higher degree replaced by the regional, coastal and local augmentation systems such as WAASs, DGPSs and others.

Traffic- Management (and Navigation – Assistance) Systems

The traffic management (and navigation assistance) systems constitute mainly the following systems (cf. Fig. 3):

- pilotage services,
- ships reporting systems (SRSs),
- vessel traffic systems (VTSs),
- automatic identification systems (AISs).

The main objective of traffic management (and navigation-assistance) systems is:

- ensuring the safety and efficiency of navigation in confined and restricted areas,
- ensuring the protection of maritime environment from pollution by ships and
- enhancing the economical efficiency of ports and harbors.

The above objectives are achieved mainly by: monitoring, informing advising and controlling the movements of ships and craft while navigating in these areas.

All the elements of navigational infrastructure can be also divided according to the range of their coverage, into the following kinds of elements (Fig. 4):

- global-coverage elements,
- regional-coverage elements,
- coastal-water-coverage elements,
- local-coverage elements.

Space-based global and regional position-fixing systems are joint systems for all kinds of navigation. They also constitute the basis for development of coastal- and local-coverage augmentation systems. The last ones may and are used by all kinds of navigation. (Fig.4.)

The subject of our further considerations (mainly in two next sections) is the elements of navigational infrastructure of coastal and local coverage.

THE REQUIREMENTS TOWARDS THE NAVIGATIONAL INFRASTRUCTURE

The main objective of the navigational infrastructure, as has been mentioned above, is to contribute to the safety and efficiency of maritime navigation, and to prevention of pollution of the maritime environment from ships as well as enhancing the economical efficiency of ports and harbors.

The most general requirements towards the navigational infrastructure are provided by the SOLAS 74 Convention (2002), i.e. by the following regulations of Chapter V Safety of Navigation: Ships routing systems (regulation 10); Ships reporting systems (regulation 11); Vessel Traffic Services (regulation 12); and Establishing and operation of aids to navigation (regulation 13).

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Global Coverage Elements	Regional – Coverage Elements	Coastal – Coverage Elements	Local – Coverage Elements
- Space Based Position – Fixing Systems (GPS, Glonass and GNSS-1 by 2004, GNSS-2, by 2008)	- Wide-Area Augmentation Systems (WAAS, EGNOS, etc.), - Land-Based Position-Fixing Systems, - Recommended Routes, - Traffic-Separation Schemes, and others	- Fairways, - Recommended Routes, - Traffic-Separation Schemes, - Land-Based Position-Fixing, Signaling and Warning Marks, - Sea-Based Signaling, Warning and Position-Fixing Marks, - Radiobecons, - Local Augmentation Systems (DGPS and others), - Traffic-Management (and Navigation Assistance) Systems, and others	- Fairways, - Maneuvering Areas, - Land-Based Position-Fixing and Signaling Marks, - Sea-Based Signaling, Warning and Position-Fixing Marks, - Local Augmentation Systems, - Local Land-Based Position-Fixing Systems, - Traffic-Management (and Navigation-Assistance) Systems, and others

Fig. 4. Division of the elements of the navigational infrastructure according to their coverage-extents

In the particular States, the designing, arranging and maintaining the navigational infrastructure is usually in charge of one or two of the following institutions:

- port harbor authorities,
- proper services (departments) of the Maritime Boards (departments of aids to navigation and/or others).
- hydrographic services,
- coast guards, and others.

The international cooperation as well as establishing the general requirements regarding all the basic characteristics of the navigational-infrastructure elements is provided by the International Maritime Organization (IMO), but especially by her Maritime Safety Committee (MSC).

The international cooperation and establishing the standards regarding the regional, coastal and local Natural and Artificial, Signaling, Warning and Position-Fixing Marks and System (cf. Fig3) is provided by the International Association of Lighthouses Authorities (IALA).

The international cooperation and establishing the standards regarding such special elements of the navigational infrastructure as waterways and maneuvering areas, are provided by three international organizations:

- International Association of Lighthouses Authorities (IALA),
- Permanent International Association of Navigation Congresses (PIANC),
- International Association of Ports and Harbours (IAPH).

The operational rules regarding the Vessel Traffic Services have been worked out and issued (as “World VTS Guide”) by three international organizations:

- International Maritime Pilot Association (IMPA),
- International Association of Lighthouses Authorities (IALA),
- International Association of Ports and Harbours (IAPH).

However, it should be reminded and stressed that the “Guidelines on Vessel Traffic Services” has been adopted by IMO. In this case: Resolution A.857 (20).

It should be stressed that until now there are not worked out, by IMO and IALA, the general requirements and standards regarding the establishing the elements of coastal and local navigational infrastructure.

In Fig. 5, there is shown (as an example) the coastal and local navigational infrastructure in Polish Maritime Areas.

COASTAL AND LOCAL NAVIGATIONAL INFRASTRUCTURE IN POLISH MARITIME AREAS (an example)				
Required Kinds of Navigational Infrastructure	Coastal Navigational Areas	Local Navigational Areas		
		Ports	Harbours	Landing Places
Sufficient Depths and Widths of:				
- offshore fairways	yes	no	no	no
- approaching fairways	no	yes	yes	no
- recommended routes	yes	yes	no	no
- traffic separate schemes	yes	yes	no	no
- anchorages	no	yes	yes	no
- turning basins	no	yes	no	no
Signal. And Pos.-Fixing Marks:				
- lighthouses	yes	yes	yes	no
- landmarks	yes	yes	yes	yes
- lights-in-lines	no	yes	yes	yes (lights)
Buoying of:				
- approaching points	no	yes	yes	yes
- fairways	yes	yes	yes	no
- recommended routes	yes	yes	no	no
- traffic separ. schemes	yes	yes	no	no
- maneuver areas	no	yes	yes	no
Posit-Fixing Systems:				
- radiobeacons	yes	yes	yes	yes
- DGPS	yes	yes	yes	no
- other systems	yes	yes	no	no
Pilot Service	no	yes	no	no
Vess. Traffic Serv. (VTS)	yes	yes	no	no

Fig. 5. The elements of coastal and local navigational infrastructure in Polish Maritime Areas

GENERAL PRINCIPLES REGARDING THE ESTABLISHING THE OBJECTS OF COASTAL AND LOCAL NAVIGATIONAL INFRASTRUCTURE

The process of designing and establishing the new or more perfect objects (elements) of the navigational infrastructure, or even the whole infrastructure of the new port or terminal, demands to solve many navigational, operational, economical and technological issues. The first but very important step in solving these issues is working out the preliminary design of establishing the international infrastructure.
The main objective of the preliminary design is to define:

- the kinds of new or more perfect objects (elements) of the navigational infrastructure and their operational characteristics,
- the places and ways of establishing these objects,
- the provisional cost of project's realization,
- the auxiliary issues that should be solved.

As subjects of the designing and establishing the navigational infrastructure are the elements (objects) of the following kinds of infrastructure (cf. Fig. 3, 4 and 5):

- seaways,
- maneuverings areas,
- land-based position-fixing, signaling and warnings marks,
- sea-based signaling and warning marks,
- land-based and space-based augmentation position-fixing systems,
- pilotage services,
- Vessel Traffic Services,
- Automated Indication Systems, etc.

The whole process of establishing the elements of the navigational infrastructure includes the following subprocesses (steps):

a) definition of the needs,
b) definition of users,
c) specification of most important characteristics of the geographical (hydrographic and hydrometeorologic) environment influencing the operation of the elements of the navigational infrastructure,
d) choosing and selection of the standards (international and national) regarding the realized project,
e) choosing the equipment and systems whose characteristics and prices are suitable for the realized project,
f) evaluation of the amount and scope of the works and their cost,
g) definition of the preliminary project,
h) evaluation of the preliminary project and deciding on the realization project,
i) working out the technological draft of the realized project,
j) carrying out the realization project, including its testing,
k) maintaining and operating the established objects (elements) of the navigational infrastructure.

The first eight steps (a-h) constitute the preliminary designing stage. The next two steps (i-j) constitute the realization stage and last step (k) is the operating and maintaining stage. Below, only the first eight steps, i.e. working out the preliminary design are discussed shortly.

The needs that justify the undertaking the process of establishing the new or more perfect elements of the navigational infrastructure constitutes one or more of the following ends:

a. enabling the access to the new port, terminal, etc.,
b. affording possibility of safe maneuvering the ships in the terminal areas,
c. ensuring or improving the safety of navigation, i.e. decreasing the danger of grounding and collisions,

d. ensuring or improving the protection of the maritime environment by the establishing the new or more perfect port or port-approach vessel traffic services and/or pilotage services, etc.,
e. increasing the navigational efficiency and economic effectiveness of ports by establishing the new or more perfect vessel-traffic- service system, etc.

Definition of the users should take into account:

- kinds of ships and craft: transporting, industrial, special, tourist, recreational, sports and others,
- kinds and amount of the dangerous goods that are, or are to be, transported,
- dimensions of the largest ships that use, or are going to use, ports, terminals, harbors,
- maneuvering characteristics of the ships and craft,
- expected amount of the traffic, its structure, and other important data.

The importance of the particular geographical features for the navigational infrastructure depends upon the kind of the infrastructure's elements (objects) being established or improved. The most important geographical characteristics that should be taken into account, are the following:

- depths and sea-bottom configuration,
- kinds of bottom grounds and bottom structure,
- sea currents,
- tides and tidal currents,
- character and amount of sediments,
- ice conditions,
- distribution of wind directions and forces,
- sea state and flow currents,
- weather, visibility conditions, and others.

As was already mentioned the standards (resolutions, requirements, recommendations, guidelines, etc.) issued and amended by the following international organizations should be taken into consideration while working out the preliminary design:

- IMO (International Maritime Organization),
- IALA (International Association of Lighthouses Authorities),
- PIANC (Permanent International Association of Navigation Congress),
- IAPH (International Ports and Harbors Association),
- IMPA (International Maritime Pilots Associations).

The preliminary design should be based on the carried out evaluations and analyses, but especially on:

- cost-benefits analysis,
- cost-effect analysis.

The expected cost of the project should include:

- investment cost,
- operation and maintenance cost.

The costs should also express:

- non-recovery cost,
- recovery cost.

The following kinds of benefits should be considered and taken into account:

- reduction of risks of grounding and collisions,
- ensuring or increasing the protection of marine environment from pollution by the dangerous goods,
- improving the operational and economical efficiency of ports, terminals or harbors.

For carrying on the cost-effect analysis, the expected benefits must be expressed in the monetary units. The cost- effect analysis should be made for different variants of establishing the new or more perfect objects (elements) of navigational infrastructure.

The cost-benefits analysis should contain:

- assessment of existing situation,
- definition of the proposal based on the cost-effect analysis,
- valuation of the proposals by the practitioners (specialists, pilots, masters, etc.),
- evaluation of the proposals by the means of the mathematical models,
- evaluation of the proposals by the means of the simulation methods.

The evaluation of the preliminary design, carried on by the proper working groups of Maritime Board (and/or) Ports Authority constitutes the foundation for decision on final, i.e. realization design regarding the establishing of the proper objects (elements) of the navigational infrastructure.

The decision on the final, i.e. on the realization (technological) design, is the last step that ends the preliminary designing stage of establishing the new or more perfect objects (elements) of the navigational infrastructure.

THE DEVELOPMENT TENDENCIES OF THE NAVIGATIONAL INFRASTRUCTURE

The beginning of coming-into-existence of navigational infrastructure reaches into distant past. Coming-into-being the lighthouses (then, in form of fires having been burnt on the coasts) is dated on 7th century B.C. These means were developed first in Egypt, Phoenicia, and later in Greece. Also the pilotage services, in their initial stage, must have originated in that period of time. Later, there were developed the other coastal signaling and warnings marks, The floating marks (buoys), first in form of anchored wooden logs, were also the invention of the ancient times (Roman times).

Taking into account the above facts, we can conclude that almost all kinds of signaling and warning marks originated yet in ancient times, i.e. yet in times B.C. They exist until now. However, they were and are a subject of permanent improvement and perfection accordingly to the development of new generations of technologies, i.e. perfecting the sources of light, optical systems, energy sources, means of it supplying, etc.

Artificial spacial elements of navigational infrastructure (dredged fairways and basins) could come into being only in 19th century, i.e. when bucked-equipped, steam-powered dredges have been deployed.

The position-fixing marks and systems began to become independent of the meteorological visibility only in 1920s. The electronic-position-fixing systems came into being during World War II (WW II). These systems, as well as radar, were rendered accessible to civil users only after WW II (in 1946). In 1960s Naval Navigation Satellite System TRANSIT was deployed. However, it could have been used only by seafarers. In 1990s, there were deployed the global positioning systems such as GPS and GLONASS. These systems caused the very important, i.e. revolutionary changes in process of ships positioning. By 2004 will be employed GNSS-1 (WAAS, EGNOS, and other systems). By 2008 will be employed GNSS-2 (European satellite system GALILEO) and will be deeply modernized US's system GPS. There are also rapidly modernized and developed the coastal and local augmentation systems such as DGPS, RTK as well as other carrier-phase-comparison systems.

Today, because of rapid development of the very reliable and effective radiocommunication systems, very precise and reliable position-fixing systems, as well as rapid development of the information technology, there are also rapidly developed and perfected the traffic-management and navigation-assistance systems. The Automatic Identification System (AIS) corroborates the above statement.

The spacial elements of the navigational infrastructure will be further developed and perfected. The following are the reasons for such conclusion:

- There is developed and perfected the dredging technology and its efficiency and, therefore, the cost of dredging works are decreasing.
- There are permanently increased the dimensions of the transporting ships. It must result in increasing the dimensions of spacial elements of navigational infrastructure.
- There are rapidly developed the tourists and sports industries. Therefore the new boat harbors, but especially the new marinas are needed and must be built.

The coastal and sea-based natural and artificial position-fixing, signaling and warning marks will generally preserve their significance. In spite of tremendous increase of the positioning accuracy, being the result from the rapid development of space-based position-fixing system, there is necessary now and will be also necessary in the future to signal and warn the ships, but especially craft (that are becoming more and more numerous) about the surrounding dangers. The last ones (for different reasons) can not be chartered and the seafarers can not be informed about their existence. Of course, these marks will be further modernized accordingly to the development achievements of the proper kinds of technology in order to make these marks more reliable and effective, and their maintenance less expensive. It is worth to mention here that in 1960s and 1970s – thanks to the progress in hydrotechnics – it was possible to replace in Baltic Straits and in similar Northern areas the buoys, which were ice-drifted in winter, by the beacons. It resulted not only in great increase of the reliability of the sea-based signaling and warning marks but also these sea-based marks have become the position-fixing marks.

However, the land-based position-fixing systems will further lose their significance. They are superceded by the more reliable and effective space-based position-fixing systems. The last are much more versatile and comprehensive, and at the same time, they are less expensive. The development of GNSS-1 and GNSS-2 as well as the development of coastal- and local-range augmentation systems do not leave any doubts in this question. The development tendency of these kinds of aids to navigation is clear defined and realized.

Besides the space-based position-fixing systems, also the traffic-management and navigation-assistance systems will be further developed very rapidly. There are many reasons for such conclusions:

- there are permanently developed the radiocommunication, positioning and information technologies what enables further development of the above mentioned systems,

- there exists now and will exists in the foreseeable future the need and demand to keep under control the ships and craft, i.e. to monitor and, when necessary, to control the ships traffic in confined and restricted areas.

The additional reasons for the above conclusions are the following:

- there exists the permanent growth of the amount of ships and craft,
- there exists the permanent growth of dangerous goods transported by sea,
- there are increasing the dimensions of tankers and other transporting ships.

Taking into account the above, it can be concluded that permanently is growing the necessity to ensure and perfect the protection of marine environment of pollution from ships. There will also exists necessity to ensure the smooth ships traffic and smooth and effective economic exploitation of ports.

There is also evident one more tendency in the development of these systems. These systems will be permanently integrated, i.e. it will come into existence more complex but less numerous systems. These, much more integrated systems (e.g. VTS and AIS) will be much more reliable and much more effective for traffic-management and navigation-assistance activities.

Besides the above tendencies, one more should be mentioned because it is very important. The coverage range of the traffic-management (and navigation-assistance) systems is permanently increased. There are coming into existence the traffic management systems for the whole geographical areas such as Baltic Sea, North Sea, and even for the whole European-Union-Coastal-Waters Area.

CONCLUSIONS

In this paper, navigational infrastructure is considered as the main component of the Maritime Navigation Safety System as well as the set of elements belonging to the three main parts of this infrastructure, i.e. the spacial elements; aids to navigation marks and systems; and traffic-management (and navigation-assistance) systems. The content and objectives of the main parts and kinds of navigational infrastructure have been presented and discussed. There is shown the division of the elements of the navigational infrastructure accordingly to their parts and kinds, as well as accordingly to their coverage-ranges.

In paper, have been also given some important principles regarding the preliminary designing of the new objects (elements) of the navigational infrastructure. Besides the above, widely have been also discussed the changes in the navigational infrastructure as well as most probable and most important tendencies of the present and future development.

The authors' belief is that the presented relations, statements and conclusions should be useful both for the educational and research activities. They also create the basic principles of the theory on establishing and operation of the whole navigational infrastructure, i.e. not only on one of its parts, such as aids to navigation or spacial objects of this infrastructure (what was the common practice in the past), but for the whole infrastructure.

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