Maritime Navigation Systems: Role And Place In The Safety Of Navigation

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Summary
The article assesses the level of navigation safety, in theoretical terms, defines the complexity of managing navigational risks in practice. The issues of assessing the navigational safety have been studied due to the importance and relevance of the issue in question, however, due to the great complexity of the problem under consideration, the article considers and indicates the directions for the development of the solution of the given direction, where, first of all, it became necessary to analyze the issue of assessing the levels of navigation risks when navigating vessels of various types in difficult navigation conditions.
Key words:
navigational safety, seafaring safety, navigation, sea.

1. Introduction

History of maritime navigation.
Navigation (Navigation from Latin “Navis” – ship) is the main section of the navigation, in which:
– theoretical foundations and practical methods of driving ships are being developed;
– the issues of choosing the shortest and safest route for a vessel to follow at sea and keeping the vessel on the chosen route are considered.
Maritime navigation originated in ancient times. The simplest methods of driving ships were known not only to the ancient Egyptians and Phoenicians but also to peoples at a lower stage of development.
The foundations of modern navigation were laid by the use of a magnetic needle to determine the course of a ship dating back to the 11th century, the compilation of maps in a straight conformal cylindrical projection (G. Mercator, 1569), and the invention of a mechanical lag in the 19th century.
At the end of the 19th – beginning of the 20th centuries successes in the development of physics served as the basis for the creation of electronic navigation devices and radio-technical navigation aids.

The tasks of modern navigation.
Maritime navigation has its own tasks:
– selection of the safest and most profitable vessel route;
– determination of the direction of movement and the distance traveled by vessel at sea using navigation instruments and devices (including the determination of corrections to the indications of these devices);
– study and selection of the most convenient cartographic projections for navigation and the solution of navigation problems on them by analytical and graphic methods;
– taking into account the influence of external factors causing the vessel to deviate from the chosen path;
– determination of the ship’s position by landmarks and navigation artificial satellites and assessment of the accuracy of these determinations.
A number of navigational problems are solved using the methods of geodesy, cartography, hydrography, oceanology, and meteorology.
Course calculation and seafaring
Sailing a ship between given points requires calculating and plotting its path on nautical navigational charts, as well as determining a course that ensures the ship’s movement along the intended path, taking into account the influence of external disturbing factors – wind and current. The main unit of measure for distance at sea is the nautical mile, and for directions is the degree.
The shortest distance between two given points on the Earth’s surface, taken as a globe, is the smaller of the arcs of the great circle passing through these points (Orthodrome). In addition to the case of a vessel following the meridian or equator, the orthodrome crosses the meridians at different angles. Therefore, a vessel following such a curve must always change its course. In practice, it is more convenient to follow a course that makes a constant angle with the meridians and is depicted on the map in the Mercator projection as a straight line – loxodrome. However, at large distances, the difference in the length of the orthodrome and loxodrome reaches a significant value. Therefore, in such cases, the orthodrome is calculated and intermediate points are marked on it, between which the sail along the loxodrome is made.
Graphical representation of the ship’s path on a nautical chart is called a plot.
During the sailing, the boat-master continuously records

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the position of the vessel in the direction of its movement and the distance traveled based on the ship's compass and log, as well as data on the current and drift of the vessel. The method of taking into account the position of the vessel by the elements of its movement is called a dead reckoning, and the position of the vessel on the map obtained by this method is called the reckoning position of the vessel.
However, no matter how carefully the reckoning is conducted, it always diverges from the actual position of the vessel due to errors in the accepted corrections of the compass and log readings, inaccuracies in accounting for the elements of current, and drift, as well as deviations of the vessel from the course under the influence of other factors. Therefore, during navigation, in order to eliminate errors, the dead reckoning is constantly corrected by periodic determination of the ship's position (observations) by landmarks (that is, by navigation methods) or celestial bodies, using the methods of nautical astronomy.
Navigational methods are based on measuring distances and directions (or their combinations) to objects whose coordinates are known, or the angles between them. Each measurement gives one line of position. The intersection of the 2 lines of position defines the observed position of the vessel. With 3 or more lines, it is possible not only to determine the position of the vessel but also to find the probable values of the observation errors. Landmarks for navigational determinations near the coast are natural perceptible places or artificial structures mapped on the map (mainly aids to navigational equipment – beacons, signs, crossings, etc.), observed visually or with the help of radar, signals of circular or alignment radio beacons, sound signals, as well as distinctive depths. At considerable distances from the coast, pulse, pulse-phase, and phase radio navigational systems or sector radio beacons are used.
An increase in the intensity of traffic on maritime routes, an increase in the size and speed of maritime vessels require the improvement of technical means and methods of navigation.
One of the ways to increase the dead reckoning accuracy is to use the Doppler Effect in hydroacoustic logs, which allows you to measure the speed of the vessel relative to the land.
When approaching ports and navigating in confined fairways, the required accuracy of pilotage is ensured by the usage of precision short-range radio navigation systems or coastal radar stations. For navigation on the high seas, global radio navigation systems are being developed to determine the position of the vessel at any point. The system of navigational artificial earth satellites is very perspective for this purpose.
The development of navigation technology makes it possible to automate the receipt and processing of navigational information and provide data directly to the control system in order to solve the problem of stabilizing the vessel on a given trajectory. A perspective direction is the development and application of autonomous inertial navigational systems on transport ships.

2. Theoretical Consideration

Radio navigation is a section of navigation and air navigation that studies and develops theoretical issues and practical techniques for navigating ships and aircraft using radio equipment and devices.
The main tasks of radio navigation are to determine:
– coordinates of the vessel or aircraft, as well as their relative position; and
– directions of exit to specified areas (points), etc.
To solve radio navigational problems, radio compasses are used, radio range finders, radio beacons, and radio navigation systems.

VORTAC radio beacon of the air navigation system, Germany.
A radio beacon is a transmitting radio station that emits radio signals used to determine the coordinates and direction of movement of various objects, mainly aircraft, and ships. The parameters of the radio beacon signal depend on the direction of radiation: for example, its intensity or the moment of direction-finding.
Radio beacons are classified as goniometric (azimuth) radio navigation devices, since they are intended only for determining the direction, and finding coordinates becomes possible after special calculations based on direction information for at least two radio beacons.
Objects that are not specifically designed for radio navigational purposes but have distinctive radio signal parameters (for example, frequency) and, possibly, known constant coordinates – broadcast radio stations, radio acoustic beacons, radiobuoys, radar beacons, emergency radio beacons, are also used as radio beacons.

Beacon classes by measurement method
Radio beacons are divided into classes, in accordance with the parameter of the radio signal, changing in direction, and the corresponding method of radio engineering measurements:
Amplitude beacons, the direction to which is determined by measuring the intensity of the received signal;
Phase beacons – the phase of the signal is measured to determine the direction;
Frequency beacons – the signal frequency is measured to determine the direction;
Temporal beacons – the moment of signal reception is detected to determine the direction;
the most common are amplitude beacons.
Types of radio beacons by purpose

– Course beacons, alignment beacons – designed to set courses in the horizontal or vertical plane, used in course glide systems;
– Bearing radio beacons. Designed to determine the bearing by comparing the time of receiving the signal of the rotating directional pattern of the beacon with the time when the position of the directional pattern (DP) is known. For such a measurement, the rotation of the radiation pattern must be strictly synchronized, or the beacon must emit a short omnidirectional signal when the DP passes through the zero marks;
– Marker beacons. They have a narrow constant DP, oriented vertically upward, and are used to mark points that are important in navigational terms (for example, checkpoints when aircraft are approaching and when ships are approaching a port, breakpoints in routes, or fairways, etc.).
– Drive radio stations are radio stations with non-directional radiation and with signals (call signs) that are distinctive for each of the stations. Determination of the direction is possible only with the help of a special radio direction-finder.

Range and accuracy

Radio beacons operating in the long-wavelength ranges (kilometers and more) have a range of up to 500 km. They ensure the accuracy of direction-finding from the object of ~1-3 ° (in azimuth). Omnidirectional radio beacons operating in the decimeter and centimeter wave ranges have a limited line-of-sight range and provide azimuth accuracy up to 0.1-0.25°.

The satellite navigation system is an integrated electronic technical system, consisting of a combination of land and space equipment, designed to determine the location (geographical coordinates and altitude), as well as movement parameters (speed and direction of movement, etc.) for land, water, and air objects.

Main elements

The main elements of a satellite navigation system are as follows:

- An orbital constellation consisting of several (from 2 to 30) satellites emitting special radio signals;
- Land control and monitoring system, which includes units for measuring the current position of satellites and transmitting the received information to them to correct information about the orbits;
- Receiving client equipment ("satellite navigators") used to determine coordinates;
- Optional: information radio system for transmitting corrections to users, which can significantly improve the accuracy of position determination.

Principle of operation

The principle of operation of satellite navigational systems is based on measuring the distance from the antenna on the object (the coordinates of which must be obtained) to the satellites, the position of which is known with great accuracy. The table of the positions of all satellites is called an almanac, which must be available to any satellite receiver before starting measurements. Typically, the receiver stores the almanac in memory since the last shutdown, and if it is not out of date, it instantly uses it. Each satellite transmits the entire almanac in its signal. Thus, knowing the distance to several satellites of the system, using conventional geometric constructions, based on the almanac, it is possible to calculate the position of an object in space.

The method of measuring the distance from the satellite to the receiver antenna is based on the certainty of the propagation speed of radio waves. To make it possible to measure the propagation time of a radio signal, each satellite of the navigational system emits precise time signals as part of its signal using atomic clocks precisely synchronized with the system time. When a satellite receiver is operating, its clock is synchronized with the system time, and upon further reception of signals, the delay between the emission time contained in the signal itself and the time of signal reception is calculated. With this information, the navigation receiver calculates the coordinates of the antenna. Most navigation receivers use the Doppler Effect to obtain speed information. Additionally, by accumulating and processing this data for a certain period of time, it becomes possible to calculate such parameters of movement as speed (current, maximum, average), distance traveled, etc. [7].

In reality, the operation of the system is much more complicated. Some of the problems that require special techniques to solve are listed below:

- Lack of atomic clocks in most navigation receivers. This disadvantage is usually eliminated by the requirement to obtain information from at least three (2-dimensional navigation at a known altitude) or four (3-dimensional navigation) satellites; (If there is a signal from at least one satellite, you can determine the current time with good accuracy).
- Inhomogeneity of the Earth's gravitational field, affecting the orbits of satellites;
- Inhomogeneity of the atmosphere, due to which the speed and direction of propagation of radio waves can vary within certain limits;
- Reflections of signals from ground objects, which is especially noticeable in the city;
- The impossibility of placing high-power transmitters on satellites, which is why the reception of their signals is possible only in a direct line of sight in the open air.

Current state

The following satellite navigation systems are currently in operation or are being prepared for deployment:

NAVSTAR (GPS)

It belongs to the US Department of Defense, which is considered by other states to be its main drawback. It is better known as GPS. The only fully operational satellite navigation system.

GLONASS

It is at the stage of deploying a satellite constellation. Belongs to the Ministry of Defense of Russia. It has, according to the developers, some technical advantages over NAVSTAR, but at present, these statements cannot be verified due to the lack of satellite constellation and the lack of available client equipment.

Běidǒu

A GNSS subsystem that is currently being deployed by China for usage in that country only. Its feature is a small number of satellites in geostationary orbit.

Galileo

A European system at the stage of creating a satellite constellation.

GPS – navigation

Modern satellite communication technologies have found their application in almost all spheres of human life and activities. Today it is impossible to imagine a modern office or home without the Internet, satellite TV, or other equally significant achievements of the "satellite age". Satellite navigational systems and GPS navigators have firmly taken their place among the necessary electronic devices in our life. GPS navigator and echo sounder are successfully used in shipping and fishing, GPS navigators are no less popular among amateur fishermen. Today, many car manufacturers offer a large selection of GPS navigators of various classes as options for car equipment. Some cars are equipped with a GPS navigator in the "base". GPS receivers have found their application in the tourism sector, today on the shelves of electronics stores you can often see PDAs with GPS and mobile phones equipped with navigational systems. Over the past few years, a GPS navigator has turned from professional expensive equipment into an affordable household device, and GPS maps can be bought even on the Internet [6].

Contrary to popular belief that a GPS receiver serves only to determine the location of an object on the ground and correlates its coordinates with an electronic map, GPS navigators perform a number of other useful functions. They include the choice of the optimal direction, determination of the speed and distance to the object, and much more. Modern GSM maps allow you to locate an object with an accuracy of up to meters, find the desired city, house, or street. It is worth noting that a modern GPS navigator can be mastered by anyone who has at least once encountered a computer or other electronics. There is nothing complicated in its settings and use, and even a beginner can master a convenient logical interface.

Navigational safety is the most important quality property of the navigation process. The navigation process is the implementation of purposeful behavior of a qualitatively complex organizational and technical system of navigation. This system operates under the influence of stochastic factors, which are formed by changing navigational and hydrographic conditions, hydrometeorological conditions, and also depends on the state and controllability of the vessel itself, the ability of navigators to assess the situation, and other features. That is why it is difficult to assess the level of navigation safety even in theoretical terms, all the more difficult it is to manage navigational risks in practice. Quite a lot of works [1,2,3] have been devoted to the study of the assessment of the navigation safety of navigation, due to the importance and relevance of the issue in question, however, due to the great complexity of the problem under consideration, not all the issues were resolved, and first of all, the issues of assessing the levels of navigation risks when navigating vessels of various types in difficult navigation conditions. Obviously, the probability of a hazardous navigational situation should be considered as the main characteristic of the assessment of navigational safety. This is explained by the stochasticity of the manifestation of various properties of the organizational and technical system of navigation on the one hand and the multitude of states that characterize the behavior of this system on the other hand. For example, many random factors generated by the variability of navigation and hydrographic conditions and hydrometeorological conditions give rise to a change and, in some cases, a deterioration in the navigation situation. The control of the ship itself, as follows from the practice of navigation, is reduced to assessing the situation, making a decision on the maneuver, and actually performing the maneuver, and all these actions can be accompanied by errors that make an additional contribution to the emergence and development of a hazardous navigational situation [4].

It is clear that the navigational safety of navigation will be determined by the peculiarities of the navigation and hydrographic conditions of the navigation area and the ability of people to assess the navigational situation, make a decision, perform a maneuver, and control these actions. It is known that navigation areas can be simple and complex in terms of navigation, and the complexity of the navigation area may be associated with the variability of the characteristics of the fairways, significant variability of the recommended courses, the presence of narrowness, the remoteness of the fairway axes from hazardous isobaths, etc. [1-3, 5].

In any case, difficult navigation areas are characterized by the natural location of recommended routes near navigational hazards. Difficult sailing conditions can themselves affect the navigational safety of navigation and create hazardous navigational situations. A hazardous navigational situation should be understood as the approach of a vessel with a static (usually a navigational hazard understood in navigation) or dynamic hazard (an oncoming vessel or a floating object) at a distance less than a predetermined one. In the general case, the navigation area can be characterized by a combination of navigational hazards and a certain area of accessible positions. In addition, the navigation area is characterized by the recommended routes along which a number of vessels move for a sufficiently long time. All this provides grounds to characterize navigational safety by the probability of an event that the vessel does not approach the navigational hazard when navigating in a certain area at a distance less than the specified one. At the same time, the risks of hazardous navigational situations should be understood as the mathematical expectation of hazardous navigational situations. This, with knowledge of the dynamics of the development of hazardous navigational situations into navigational incidents, accidents, and disasters, makes it possible to estimate the expected losses of personnel, environmental and economic losses during navigational accidents and disasters, i.e. assess the consequences of the manifestation of hazardous navigational situations. Consequently, when assessing navigational safety, it is necessary to determine the probability of a complex event, reflecting the behavior of a qualitatively complex organizational and technical navigational system, in which the distance to the aforementioned hazards will be less than specified. It is clear that this is a fairly general formulation of the problem, which can be clarified in relation to a specific ship project, a specific navigation area, and its features, etc.

Thus, the formalization of the behavior of qualitatively complex systems using the assessment of hazardous navigational situations allows a new assessment of the navigational safety of navigation of ships in difficult conditions, linking the objective navigational situation with the degree of ability of the persons operating the ship to assess the navigational situation, make decisions on maneuvers, and perform maneuvers. In addition to hazardous navigation situations associated with approaching navigational hazards, when a vessel navigates, as a rule, there is a danger of collision of ships when diverging in difficult conditions, as well as the risk of grounding when diverging in difficult conditions. Using situational analysis techniques, it is possible to assess the risk of collision hazards when diverging in difficult conditions.

Conclusions

Thus, it is necessary to develop new approaches to assessing the navigational safety of ships' navigation in difficult navigational conditions, allowing us to take into account the variety of navigational situations generated by the difficult navigational conditions of navigation and the ability of command personnel to assess the situation and make the right decisions for maneuver. Such methods for studying the navigational safety of navigation of ships in difficult navigational conditions allow solving a number of applied problems, for example, assessing the level of training of specialists in navigation in modern integrated simulators, conducting an examination of design solutions for navigation, hydrographic and hydrometeorological support of navigation of ships in difficult conditions, assessing the impact of systems vessel traffic control for the navigational safety of navigation, assess the potential navigational accidents in the areas of construction of new ports, etc.

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