Shipping Safety in the Arctic

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Abstract. Ensuring the safety of shipping in the Arctic and along the Northern Sea Route has some specifics associated with adverse climatic conditions. The presence of ice makes navigation difficult, and the interannual and interseasonal variability of its condition makes the timing of the start and duration of navigation in clear water uncertain. Collisions of ships and other accidents in northern waters can lead to more negative environmental consequences than in the southern seas, since there is a particularly vulnerable ecosystem, the restoration of which is very slow. The fishing fleet has traditionally posed security concerns for major shipping in the Arctic. In recent years, an increase in the intensity of shipping has been associated with exploration and production of hydrocarbon raw materials on the sea shelf. To support the technological processes of drilling platforms, a specialized supply fleet is used here, which creates additional risks of a technical, technological and technogenic nature, and also increases the risks of emergency situations associated with the human factor. This work is devoted to the development of measures to improve the information and telecommunications support of navigation safety systems in the Arctic. The issues of improving the electromagnetic accessibility of ship communication systems during navigation in the waters of the Northern Sea Route, the reliability of the GMDSS system, the information and technological support for navigation safety have been considered. To solve these problems, it has been proposed to accompany the construction of marine rescue coordination centers and sub-centers with the deployment of NAVTEX automated systems and equipping the RF radio frequency range with coastal radio communication equipment. To eliminate the predicted areas with reduced electromagnetic accessibility, it is recommended to replenish ship's antenna systems with anti-aircraft antennas. The issues of incorporating the IRIDIUM satellite system into the GMDSS radio equipment to expand the coverage area of global satellite communications in the navigation safety system have been studied. It has been proposed to supplement the existing vessel traffic services (VTS) systems with an intellectual component – a mobile VTS, which will expand the functional and technological capabilities of traditional VTSs and remove territorial restrictions on use.

1. Materials and methods
The development of the Arctic transport system, focused on the year-round functioning of the Northern Sea Route (NSR), is closely related to the socio-economic and technical development of the Arctic zone. Further improvement of the transport infrastructure includes the following: expansion of the icebreaker fleet, reconstruction and construction of port facilities, creation of coastal complexes adapted to the Arctic conditions, improvement and construction of modern information and telecommunication infrastructure that meets the specific requirements for ship radio communications, introduction of in-
novative means and methods of information and technological support for security navigation, including navigation and hydrometeorological information.

In order to concentrate the management of the development of the NSR, the State Atomic Energy Corporation Rosatom has received the authority of the infrastructure operator of the Northern Sea Route. Rosatom Corporation is responsible for turning this transport artery into a real alternative to the southern sea route from Europe to Asia [1].

Ensuring the safety of shipping in the Arctic zone has its own specifics. The main factor that distinguishes the Arctic zone from traditional highways is the adverse climatic conditions. The presence of ice complicates navigation, and the interannual and interseasonal variability of its condition makes the timing of the start and duration of navigation in clear water uncertain.

Collisions of ships and other accidents in northern waters can lead to more negative environmental consequences than in the southern seas, as there is a particularly vulnerable ecosystem, the restoration of which is very slow.

The lack of natural light and limited visibility, low temperatures, the presence of ice and strong winds in the Arctic make oil spills more likely, and the elimination of its consequences is associated with greater costs than in other regions. The situation is complicated by the fact that on the NSR route there are protected areas and biosphere ranges with corresponding restrictions when sailing, such as Gydansky, the Big Arctic, Ust-Lensky, Wrangel Island.

Another factor which influence on the safety of navigation has been growing in recent years is the increase in shipping in the offshore areas. Intensive hydrocarbon production in the continental zone has led to the depletion of many highly efficient fields. For this reason, maritime states associate further prospects for obtaining natural energy resources with the extraction of hydrocarbon-containing raw materials in the areas of the coastal shelf. In Russia, the Arctic shelf has the richest hydrocarbon reserves. Exploration work to identify reserves and oil and gas production on the shelf requires the deployment of high-tech drilling platforms and installations. To maintain the technological processes of the drilling platforms, a specialized supply fleet is used, which additionally increases the intensity of shipping on the main logistics highways and creates additional risks of a technical, technological and technogenic nature, as well as increases the risks of emergency situations associated with the human factor.

These factors require special attention to the problem of ensuring the safety of shipping in the Arctic zone along the NSR routes. Currently, 1,043 coastal navigation facilities, as well as 195 floating warning signs with a maritime safety information center in St. Petersburg and the NAVTEX coast station in Tiksi are operated for this purpose. Information on the actual ice situation and forecasts of changes determines the start and end dates of navigation and the most optimal paths for vessels in ice, recommendations for providing icebreaking support and accurate operational ice reconnaissance, both aviation and using unmanned aerial vehicles. In turn, the range of the radar horizon from ships and coastal radar stations can vary depending on hydrometeorological conditions.

The importance of radio communications during navigation can hardly be overestimated, since its use increases the efficiency of solving basic production problems and ensures the safety of navigation:

– the remote control of the operating parameters of engines and mechanisms allows to reduce wear and maintenance costs;
– receiving real-time information on the characteristics of navigation can reduce fuel consumption and emissions into the environment;
– ensuring the arrival at the mooring and unloading place on time optimizes technological processes and minimizes port costs;
– the remote support of a number of services, such as an Internet cafe, inexpensive publicly available radiotelephone communications, e-mail, access to social networks, helps maintain the morale of the crew and helps reduce the negative impact of the human factor on the safety of navigation.

Effective retention in predetermined coordinates with the help of thrusters of technological platforms during work on the sea shelf requires positioning systems with precision accuracy. This level of orientation accuracy is realized by differential positioning systems by updating the results according to
the data obtained via radio channels from another receiver installed at the coast station with known coordinates [2].

This work is devoted to the development of measures to improve the information and telecommunication support of navigation in the Arctic zone in order to increase its safety.

2 Research methods and objects

The development of the NSR routes and the expected growth in freight traffic poses a number of tasks, their solution, on the one hand, requires taking into account the peculiarities of navigation in the Arctic zone, and on the other hand, should be focused on innovative approaches using advanced technologies.

Among the most significant tasks aimed at improving the safety of navigation in the Arctic, the following can be noted:

– improving the electromagnetic accessibility of shipboard communication systems during navigation in the waters of the Northern Sea Route;

– improving the reliability of the GMDSS system;

– improving the information and technological support for navigation safety.

It is known that an increase in the intensity of maritime navigation is accompanied by an increase in the number of accidents at sea. One of the most dangerous types of accidents is collisions of ships that occur for various reasons, including due to crew errors.

Increasing clashes indicate problems in the organization of ship traffic. Areas of increased danger of collisions are areas of heavy shipping. Such zones include areas of offshore mining and biore-sources, as well as fishing regions, areas of movement of ships on the main and near sea routes, port access areas and some others.

Collisions with tankers are of particular danger, as there are no special sea corridors provided for them in the territorial waters of Russia.

The receipt of all types of necessary information for safe navigation in the Arctic zone is defined in the "Rules for Navigation in the Northern Sea Route" [3]. It states that radio communication of ships and icebreakers, as well as monitoring, operational reporting and management of the NSR Administration should be carried out in accordance with the Radio Regulations of the maritime mobile service and the maritime mobile-satellite service of the Russian Federation [4]. The rules pay special attention to guaranteeing the reliability of telecommunications by radio communications when navigating in an ice caravan and when the vessel moves independently in the A4 Marine Area of the Global Maritime Distress Communication System (GMDSS), which is outside the satellite coverage of the INMARSAT system (north of the parallel of 75 degrees north latitude). In polar latitudes, only HF radio communications can provide electromagnetic accessibility to shipboard communication systems. For operational radio communications with coastal centers, digital selective calling (DSC) and single-band radiotelephony and narrow-band direct printing (UBHR) systems are used. Moreover, the radio equipment of marine radio communications using shipborne RF transceivers has a number of disadvantages, including low reliability and instability of communication, exposure to atmospheric interference and processes in the ionosphere at polar latitudes, and low telegraph signal transmission speed. In order to provide ships with information on maintaining the proper safety and efficiency of navigation, the network of coastal and base transceiver stations along the NSR must be equipped with RF communications equipment and NAVTEX transmission points. As a result, the reliability of communication between ships and marine rescue coordination centers (MSCs) and sub-centers (MSCCs) will improve, and monitoring will be ensured. The components of the NAVTEX shipboard automated systems responsible for receiving weather forecasts and navigation warnings, with switching to the onboard GNSS receiver or GPS antenna, equipped with small-sized active antenna devices, fully meet modern requirements. It should be noted that the Ministry of Transport of the Russian Federation along the Northern Sea Route has already created MSCCs in Dikson and MSCC in Tiksi and Pevek, however they are not provided with radio communications for the VHF, MF and HF wave ranges. There are no necessary coastal radio stations along the coast of the NSR.
The recent optimization of antenna equipment used for radio communications with ships has led to a number of problems. Thus, the trend of almost total rejection of using traditional horizontal polarization dipole antennas in ship's antenna equipment and the transition to whip antennas as part of antenna-feeder devices have reduced the reliability and efficiency of the use of the high-frequency range. Vertical vibrators press the maximum radiation pattern to the horizon, and at improperly selected frequencies of the high frequency range, electromagnetic accessibility on radio lines may generally be absent due to the dead zone characteristic of the propagation of these radio waves. In addition, unintentional interference, which also has mainly vertical polarization, also reduces the reliability of radio communications.

The refusal on ships of dipole antennas of horizontal polarization providing in addition to slightly directional an anti-aircraft radiation, made the NVIS RF method of communication – Near Vertical Incidence Skywave propagation – insolvent. NVIS practice is based on the effect of an almost vertical effect on the ionospheric layer of a radio wave with its subsequent reflection also almost vertically downward. As a result, sufficient field strength is provided from transmitters located at distances of tens and hundreds of kilometers, which practically covers the dead zone [5]. The retrofitting of vessels for Arctic navigation with anti-aircraft radiation antennas could increase the reliability of telecommunications on the NSR routes by increasing the electromagnetic accessibility and expanding the areas of reliable reception of high-frequency radio waves at controlled distances from MSCCs, ISMCs and port infrastructures rarely located along the coast.

In addition, during optimization in coastal radio centers, they began to resort to simplified versions of deploying RF antenna fields, installing fleet of antennas near technical buildings and leaving previously widely used antennas such as a horizontal band vibrator and horizontal band shunt vibrator unclaimed. It is possible to increase the efficiency of the horizontal band vibrator antennas without drastic intervention by performing a minor refinement of the antenna mast system design by incorporating an additional passive triangle-loop element [6].

The greater effect can be achieved if coastal radio centers are retrofitted to communicate with remote vessels in-phase horizontal band antenna systems [7], more adapted to coastal conditions of use, without the need to increase the size of the occupied area, compared with the areas occupied by antennas such as a horizontal band vibrator and horizontal band shunt vibrator.

Thus, the construction of a unified navigation safety system in the Arctic zone should include equipping the coast with a more extensive NAVTEX system and HF communications stations. Currently, for this purpose, in addition to the VTS, in the seaports of Murmansk, Kandalaksha, Arkhangelsk and Sabetta on the banks of the Gulf of Ob, as well as the existing station in Tiksi of the Republic of Sakha (Yakutia), coastal stations of the NAVTEX service are already being deployed in the port of Dikson in Taimyr and in the seaport of Pevek in Chukotka. However, NAVTEX stations, being a mandatory component of the GMDSS, due to the physical characteristics of the used range of electromagnetic waves, have limitations on the transmission range of information up to 200–400 kilometers and therefore cannot guarantee a continuous electromagnetic field along the entire Northern Sea Route.

Only satellite communication systems, including GMDSS systems based on INMARSAT geostationary satellites, can provide full coverage of the NSR route and provide a full range of broadband services. Some shipping companies in the NSR use the VSAT geostationary satellites and low-orbit IRIDIUM with full coverage of the Earth's surface and with a range of services provided by Federal State Unitary Enterprise MORSVYAZSPUTNIK. There are prerequisites that soon the IRIDIUM system will be included in the list of radio equipment that meets the requirements of the GMDSS, which will expand the capabilities of radio communication systems and their reliability in providing freight transportation in the Arctic zone.

Along with monitoring, transport processes in the Arctic should receive positional data from GLONAS satellites. The GLONASS system covers the entire Arctic zone, and it works in conjunction with GPS. Thus, the problem of navigation support in the Arctic is practically solved.
When sailing in the Arctic waters, it is necessary more thoroughly to assess the risks of the potential consequences of accidents, especially when transporting dangerous goods, and make fuller use of modern achievements in the field of information and technological support. Further development of maritime safety systems is associated with the development and implementation of new digital technologies, such as e-Navigation, the modernized Global Maritime Distress and Safety Communication System, and intelligent management technologies. It is possible to reduce the costs of placement and maintenance of navigation signs in hard-to-reach places of the NSR by supplementing the automated identification (information) system with virtual navigation equipment. A promising area is the intellectualization of transport processes, aimed at reducing the share of human participation in decision-making procedures, including for ensuring safety.

The state system for ensuring the safety of navigation in Russia provides for the use of vessel traffic control systems (Vessel Traffic Services – VTS). VTS systems are currently the most effective means of ensuring safety of navigation near the coast, but at the same time they have a number of disadvantages, which include:

- the localization of use near coastal facilities, territorial stationarity, which makes it difficult or impossible to use them in the offshore hydrocarbon production zone or in the fishing area;
- the complexity of the organization and the high cost of deployment on the ground;
- the bulkiness and complexity of management procedures focused on the use of expensive specialized equipment and requiring developed energy supply;
- the strong dependence on the influence of the human factor on the decision-making procedure due to the key role of the operator of the Center for MAC.

It is possible to improve the efficiency of the navigation safety management system, reduce the human participation in deciding on safe movement and give additional dynamics to maritime transport processes by improving ship traffic management procedures based on using artificial intelligence technologies.

Intelligent management when using knowledge-based systems is already starting to compete with the human operator. Unlike expert methods used in VTS systems, knowledge-based systems are not intended for consulting support of vessels such as radar wiring from the shore, but for direct monitoring of traffic objects and their management. Such a system operates in a continuous, non-interactive dynamic mode in real time. It interacts not with the human operator, but with the dynamic object (vessel), for which it develops control. Special territorially localized ship traffic control systems called mobile (МСУДС / MVTS – Mobile Vessel Traffic Services, similar to СУДС / VTS) can expand the functionality and remove a number of limitations of modern VTSs [8]. In the proposed solution, the intellectualization of procedures for determining the optimal safe paths is based on the use of code methods for presenting travel information and special procedures for calculating coded routes that meet security requirements that are performed at the MVTS Center. The central concept is a virtual network of ship traffic priorities, which is an informational and graphic image of the space of real traffic [9]. This network is used to determine the trajectories, time parameters and estimated functions of ship traffic safety [10]. The generated formalized messages via radio channels are transmitted to ship client stations for direct execution of commands. Information and technological support of all vessels accepted for servicing by the MVTS system in the controlled waters allows us to exclude the human operator from the control loop and practically remove the problems of the human factor, as well as make fuller use of modern information technologies and computing, navigation and telecommunication equipment.

The MVTS systems do not have territorial restrictions on use, are not critical to location, and can be deployed in any water area, sea, lake or river, with a center located on the shore or on a flagship.

Mobility, efficiency, speed of deployment and termination, simplicity and cost-effectiveness with respect to computing resources when implementing management procedures, the ability to use familiar software environments make the MVTS systems attractive for practical use, both as an independent means of ensuring navigation safety in places where there are no VTS, and as an additional tool that extends the functionality of traditional stationary VTS.
The methods and algorithms used in the MVTS can easily find an application in multimodal transport systems for the implementation of transport processes and logistics functions, as well as in the management of unmanned moving objects.

3. Conclusion
The fulfilled studies allow us to state that in Russia conditions have been created to ensure transport processes in the Arctic zone and safe shipping by the Northern Sea Route.

In order to increase the reliability of the high-frequency communications, to eliminate the predicted "dead zones", it is recommended to replenish ship's antenna systems with anti-aircraft radiation antennas. The construction of marine rescue coordination centers and sub-centers should be accompanied by the deployment of not only NAVTEX automated systems, but also the equipping of high-frequency coastal equipment. With the inevitable deployment of coastal radio centers, there is a need to introduce antenna devices more adapted to coastal conditions with increased electrical efficiency and mechanical reliability for communication with remote vessels, without increasing the area occupied by typical coastal antennas. The inclusion of the IRIDIUM satellite system in the GMDSS radio equipment will expand maritime global satellite communications in the system of ensuring the safety of maritime transport in the Arctic zone, increase the accuracy of identification of search objects and reduce the time of delivery of disaster messages.

The development and implementation of new digital technologies and the intellectualization of transport processes will improve the safety of navigation. The addition of the existing VTS systems with the intellectual component of the MVTS will allow expanding their functional and technological capabilities and removing territorial restrictions on use.

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