Studying the factors affecting the navigation duration along the Northern Sea Route

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Abstract. The problems of year-round navigation in the water area of the Northern Sea Route are considered. The study results are obtained at the Admiral Makarov State University of Maritime and Inland Shipping within the framework of the "Hydrographic support of the Northern Sea Route" scientific school in two main interrelated directions. The first direction is devoted to the study of the main natural - climatic and navigational - hydrographic factors affecting the navigation conditions. The second direction is focused on the collection and analysis of statistical information on the ships movement parameters and on the substantiation of the year-round navigation possibility in all waters of the Arctic Seas and Polar waters. The main trends of changes in the fleet structure, the conditions of ships navigation and the development of the shipping routes network in the Arctic seas over the past ten years are noted. Particular attention is paid to the studies results related to the development of the shipping routes network on the eastern sector of the Northern Sea Route and the prospects for year-round navigation of ships in the Laptev and East Siberian Seas.

1. Introduction
The global task of transforming the Northern Sea Route (NSR) into a permanent year-round transport artery connecting the Atlantic and Pacific Oceans in the shortest way has been considered in the last decade by many authors [1, 2]. In the near future, in the NSR water area, increasing the navigation intensity and extending the navigation periods are expected; to ensure these processes, new generation of icebreakers is planned to build [3]. The implementation of these plans will inevitably require the navigation of vessels in the water area of the NSR not only along the recommended routes, but also with significant deviations from them. This is due to an increase in the draft of vessels up to 12-15 m, for which it is difficult or impossible to use a significant part of the current recommended routes.

Year-round navigation of vessels is currently carried out only in the southwestern part of the Kara Sea, which accounts for the main cargo turnover of the Arctic sea transport. In the near future, after completing the construction and commissioning the powerful nuclear icebreakers capable of breaking four-meter ice, year-round navigation can be carried out along the polar routes that have no restrictions on maximum depths and represent the shortest way from the Barents Sea in the west to the Bering Strait in the east. The problem of the year-round navigation in the seas of the NSR eastern sector is not solved by constructing the powerful nuclear icebreakers, which is associated with the shallow depths and severe ice conditions in most of the waters of the Laptev and East Siberian Seas. The Admiral Makarov State University of Maritime and Inland Shipping, named after renowned scientist and naval commander, who made a significant contribution to the creation of the icebreaker fleet of Russia, the study and development of the Northern Sea Route. By tradition, the Arctic direction plays a significant
role in the scientific activity of the university. In 2016, a scientific school in the direction of "Hydrographic support of the Northern Sea Route", which unites teachers, students, postgraduates and graduates of the Arctic Faculty, who are actively researching a wide range of issues related to the development of shipping in the Arctic waters, was created [4].

The aim of this research is to study the reduction of the winter-spring navigation period on the Northern Sea Route based on the actual data and with an emphasis on shipping in the eastern sector (the Laptev, East-Siberian and Chukchi Seas).

2. Methods and Materials

When performing these scientific studies, all available information which is aimed at ensuring the safety of Arctic shipping and hydrographic and ice support of the NSR, including our own developments based on the use of geoinformation modeling technologies, was taken into account [5].

The sources of the initial data were [5, 6]:
- data from ship's automated identification systems (AIS);
- data from vessel traffic control systems;
- high-resolution satellite images;
- data from the Russian administration of the Northern Sea Route;
- nautical navigation charts;
- ice maps and others.

A comprehensive analysis of the ships movement in the water area of the NSR allows you to obtain the detailed information on the distribution of the number of ships in the Arctic seas, the number of crossings between the sectors, to identify the trajectories of movement, incl. in ice or accompanied by an icebreaker. All of this information is further used for the analysis of ship flows and their detailed classification.

3. Results

Study of depths in the water area of the NSR was carried out using nautical charts. The distribution of depths in the seas is illustrated by the data given in Table 1 on data frame [7].

| Depth of sea, m | Area share, % | Kara sea | Laptev sea | East-Siberian sea | Chukchi Sea |
|----------------|---------------|----------|------------|-------------------|-------------|
| 0-10           |               | 3.5      | 11.1       | 14                | 1           |
| 10-20          |               | 5.3      | 37.4       | 47                | 6           |
| 20-30          |               | 10.1     | 22.7       | 25.5              | 6           |
| >30            |               | 81.1     | 28.8       | 13.5              | 93          |

The obtained quantitative morphometric characteristics show that the area of the Laptev Sea and the East Siberian Sea with depths less than 20 m exceeds 50%, while the area of such areas in the Kara Sea is less than 9%, and in the Chukchi Sea - 1%. Thus, the risk of accidents associated with the ships touching the ground and grounding in the Laptev and East-Siberian seas is objectively higher than in the Kara and Chukchi seas.

Longtime observations of ice conditions [8, 9] show that in the water area of the NSR, ice in the zones of ice massifs shown in Figure 1 can be present throughout the year. At the same time, the most stable massifs are 4, 5, 6, and 7, located in the Laptev and East Siberian Seas.
Figure 1. Scheme of the Arctic ice massifs: 1-Novaya Zemlya; 2-Northern Kara; 3-Severozemelsky; 4-Taimyr; 5-Jansky; 6-Novosibirsk; 7-Aion; 8-Wrangel, and where: - - traditional shipping routes, — — boundaries of ice massifs.

In the Sannikov Strait, bounded by massifs 5 and 6, the average monthly ice thickness over the past twenty years has been changed in accordance with the data given in Table 2 [10]

Table 2. Change in average monthly ice thickness throughout the year.

| Month of year | Average ice thickness, m |
|---------------|-------------------------|
| January       | 1.2                     |
| February      | 1.49                    |
| March         | 1.72                    |
| April         | 1.79                    |
| May           | 1.95                    |
| June          | 1.80                    |
| July          | 0.87                    |
| August        | 0.04                    |
| September     | 0.01                    |
| October       | 0.13                    |
| November      | 0.41                    |
| December      | 0.80                    |

The Sannikov Strait has a limiting depth of 12.8 m and is used for transit navigation of vessels with a draft of less than 12 m. According to the average statistical data, ice has been presented in the strait for 9 months with a thickness of more than 40 cm. Moreover, from February to June, the strait becomes practically impassable.

In the summer-autumn navigation period (mid-July - mid-November), navigation is carried out along the entire water area of the NSR. In winter and spring, navigation in the eastern sector stops. Relatively light ice conditions and relatively large depths in the southwestern part of the Kara Sea allow large-tonnage transport vessels to navigate all year round along the following routes: the ports of the Gulf of Ob - the Barents Sea and the Dudinka port - the Barents Sea. There are about twenty years’ experience of the year-round navigation in the western part of the Kara Sea.
Figure 2. Distribution of the average daily number of vessels by months.

The distribution of transport vessels over the area of the Arctic seas in 2019 is illustrated by a histogram, in Figure 2,3 [11].

During the winter navigation period, from 39 to 52 vessels are operated in the Kara Sea. In the summer - autumn period of 2019, from July to October, more than 100 ships were daily in the Kara Sea. During the winter navigation period in the seas of the eastern sector, navigation was not carried out in 2019. In the summer - autumn period, the maximum number of ships in the eastern sector, equal to 131, was recorded in September. In the eastern sector, river-sea-going vessels constitute the bulk of
the transport vessels. The study of the number of ship calls to the ports of the eastern sector has shown that the intensity of their work has been constantly growing over the past five years. The port of Pevek, located in the East Siberian Sea, handles the largest number of ships. In terms of the total number of ship calls, the Pevek port surpasses the ports of Khatanga and Tiksi located in the Laptev Sea. In 2015, in the eastern sector, there were only 70 ship calls to the ports, and already in 2019 this number was 190, which is almost three times more, however, to the ports of the western sector, the number of ship calls for the same period increased almost five times.

Research carried out with the use of geoinformation technologies made it possible to clarify as much as possible the time spent by the ships in the eastern sector. We will cite only the main results, so in 2018 the first passage from the western part to the eastern part was made through the Vilkitsky Strait by the Arc7 high ice-class YamalMax LNG tanker on June 27 and already on July 5 the ship left the NSR through the Dezhnev Strait, thus the time of crossing from the Ob Bay was 11 days. The last reverse maritime passage from the eastern part of the NSR to the western part was carried out on November 25, so the period of ships operation in the seas of the eastern sector was 5 full months, which corresponds to the normal average annual conditions and the Navigation Rules of the NSR (Russia). At the beginning of 2019, on January 2, an LNG tanker and an Akc7 ice-class gas condensate tanker performed a joint sea passage from the Dezhnev Strait to the Ob Bay; their transition from the eastern part to the western part took place on January 15, which is six days longer than the transition at the beginning of June, and it should be noted that the ice conditions were similar, however, in the first case, they referred to the end of winter navigation, and in the second one - to its beginning. Although these sea crossings were single for the studied periods of navigation, they confirmed the possibility of expanding winter-spring navigation. In the summer of 2019, the first transition to the eastern part was made only on July 1 and ended on July 5; the ship passed the Arctic seas of the eastern sector at high speed in the record 5 days. But the first transition from the east to the western sector of the NSR in 2019 was made only on July 28, which is quite late. During the summer navigation of 2019, the water area north of the Novosibirsk Islands and in the East-Siberian Sea was completely ice-free, which allowed vessels to move at maximum speed, but at the same time, the ice-free period, according to the various estimates, was almost a month shorter than usual. The first passage to the eastern part of the NSR in 2020 was made on May 15, and without an icebreaker escort; the transit lasted almost 15 days. In the first ten days of June, YamalMax-type vessels have already passed from the port of Sabetta to the east, these sea crossings were carried out with full or partial pilotage by an atomic icebreaker in the Laptev Sea and the East Siberian Sea and took from 8 to 10 days, the ice-free period began only at the beginning of July, which corresponds to the normal conditions.

4. Discussion
The performed assessment of the hydrographic knowledge of the NSR water area has shown the presence of several vast areas in the Laptev and East Siberian Seas, the depths of which are absent on the nautical charts. When designing shipping routes, such sections should not be crossed. The lack of hydrographic information in the eastern seas leads to the fact that the large-tonnage vessels with a draft of more than 12 meters are forced to follow the routes passing north of the New Siberian Islands, which shortens the navigation period.
The solution to the problem may be the arrangement of the Sannikov Strait (fig.4) by means of a dense bathymetric survey and the installation of navigation barriers to identify areas (channels) with depths of less than 15 meters, or by conducting sea dredging. In general, we observe an increase in the intensity of shipping along the entire NSR, but if in the western part the number of ship calls increased almost five times, and the turnover of goods - almost six times, then in the eastern sector these rates are lower, although they increase every year.

5. Conclusion
The task of increasing the volume of cargo transportation along the Northern Sea Route will be solved by increasing the intensity of shipping, modernizing existing and building new sea terminals and ports, and taking other measures that are not directly aimed at solving the problem of year-round navigation in the water area of the NSR. The need to solve the problem of year-round navigation will become relevant when the value of the seasonal unevenness of the density of traffic flows in the water area of the NSR will be the main obstacle to the development of the NSR and will directly affect the safety of Arctic shipping.

A prerequisite for year-round navigation in the eastern sector of the NSR water area is the creation of shallow-draft vessels capable to overcome ice fields up to two meters thickness and having sufficient cargo capacity.

Adequate conditions include all types of year-round navigation, including:
- continuous year-round ice forecasts for the entire water area of the NSR;
- modernized maritime rescue service;
- completion of a hydrographic survey of the bottom in all areas of possible movement of vessels;
- Carrying out dredging works in areas with limiting depths.

In addition, the search for innovative solutions to explore and reduce the impact of hazardous ice formations on shipping should be continued.

6. References
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