

# Navigating a Vessel without an Ice Class on the NSR Close to the Front of Ice-free Zone During Ice Melting Period

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**ABSTRACT:** The research work described in this paper extends the author's research results described in the previous monographs. During ice melting period on the NSR ice drifts in different directions under the influence of changing atmospheric pressure systems and thus wind and sea currents. The forehead of transit corridor re-released from ice moves in different directions and even goes hundreds Nautical miles back (in the opposite direction to vessel's planned voyage). A vessel without ice reinforcements, which follows just behind the forehead of ice-free transit corridor, would also have to move in such direction and speed to avoid entering ice and potentially beset or even damage its hull or sink.

This paper presents results of research on impact of number of days of vessel's delay against the forehead of transit ice-free corridor released from ice in ice melting period and by this way possibility of entering vessel into ice-covered zone. Probability of incurring certain additional voyage expenses was determined. described.

## 1 INTRODUCTION

The study considered navigation conditions that occur when passing through the Northern Sea Route (NSR) in two stages. First stage concerns transit passage in one direction to the intermediate port. Second stage concerns passage in same navigation season but back to the first port of departure. In order to plan a transit voyage of a vessel through the NSR, it is necessary to know probable route with the lightest ice conditions. For vessels without ice strengthening, the lightest ice conditions are "ice-free" conditions (Shapaev 1975, Parnell 1986, Arikaynen and Tsubakov 1987, Jurdziński 2000, Buysse 2007, House et al. 2010, Pastusiak 2020, 2018, 2016c). This is particularly important during the period of opening of the NSR seas for ice-free navigation, when ice-free transit corridor begins to appear in ice and connects the Barents Sea with the Bering Sea. Then process of ice decay in individual seas leads to appearance of

ice-free zones (Pastusiak 2020). These zones, forming a transit corridor, allow navigating vessels without ice reinforcements of their hull. In both cases, it is important to set time frame for possible transit navigation on the NSR. This applies to the moment of opening transit corridor and its closing (Pastusiak 2016b). In addition, probability of repetition of transit corridor opening and closing dates in subsequent summer navigation seasons should be considered (Pastusiak 2020, 2018, 2016a,b,c).

The most important questions in economy of vessel voyage planning are moving with normal transit speed, without risk of possible waiting for sea releasing from ice, without risk of necessity of moving back from planned route due to retreat of drifting ice and without risk of being beset in ice. It is assumed that vessel plans to pass the NSR as soon as possible (during period of ice decay and ice disappearance). In this situation, vessel should commence its voyage

immediately and very close to retreating ice, in which there are zones of clean water free of ice. Important are only those clean water zones that open in general direction of connection with the next sea. Only then will they allow to cross one sea to the next. Ultimately, geographical distribution and dates of occurrence of ice-free zones, which form a transit corridor for vessels throughout the entire NSR, should be taken into account. This is especially important for vessels without ice strengthening.

If route of vessel passing through the NSR is calculated as late as possible (during the built-up of ice cover), it should be assumed that vessel will resume voyage back to the first port of departure just before the progressing ice, which occupies areas previously free of ice. In such situation, only those ice-free zones and those accessible to vessels without ice strengthening are important, which close on general direction to the exit from the NSR area. The forehead of melting and disintegrating ice is the most ice-deep part of clean water (ice-free) zone. It is usually deep inside the ice and looks like bight in ice (Fig. 1).

Directions of movement of ice-free corridor and their most likely course, as well as dates of beginning of opening, date of complete opening of transit corridor, date of commencing of closing and date of final closing of transit corridor were described in earlier works by the author (Pastusiak 2018, 2020). The forehead of ice-free transit corridor changes its position under influence of winds and sea currents caused mainly by moving baric systems. For this reason, the forehead of transit corridor and the entire ice-free corridor change their position. It can move in general direction towards destination port (forward) or in general opposite direction (backward) (Fig. 1). Vessel without ice reinforcements that is moving close at the forehead of moving ice-free corridor must move in directions and with speed of that forehead. Sometimes it must go back hundreds of Nautical miles to avoid being surrounded by ice, be potentially beset or even nip, with damage of its hull or even sink. This navigation (close do the forehead of ice-free corridor) on one hand is more risky. But on other hand it increases probability of successful completion of second part of voyage back to the initial port of voyage and, most probably, increases probability of obtaining higher economic benefits of vessel voyage. The problem to be solved is therefore determination of distance and time vessel follows after the forehead of transit corridor released from ice for specific probability of adverse events occurring for vessel (beset, nip, damage to hull or even sink).

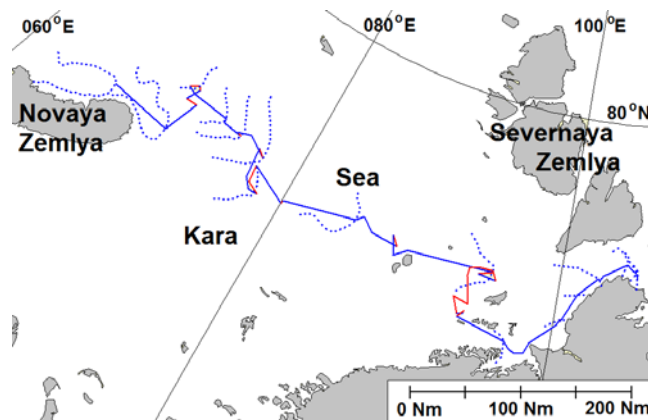


Figure 1. Path of forehead of transit corridor released from ice in the Kara Sea in 2018: — path of forehead of ice-free corridor moving in a general direction towards destination: - - - path of forehead of ice-free corridor moving in general opposite direction to the destination, • • • the forehead of transit corridor that is released from ice. Compiled by the author based on NATICE (2018). Provided courtesy of the U.S. National Ice Center. Made with Natural Earth – Free vector and raster map data @<http://www.naturalearthdata.com>

## 2 PURPOSE AND SCOPE OF THE STUDY

Based on results of the author's previous work (Pastusiak 2016a, b, 2018, 2020) it is possible to specify date of opening of the NSR seas for ice-free navigation towards east and towards west as well as a number of additional factors characterizing the NSR opening time for ice-free navigation. However, these are statistical data that are characterized by means of average value, median, Gaussian curve or cumulative distribution curve. However, these factors do not indicate whether a vessel should move close behind the forehead of ice-free corridor or vessel should proceed with a certain delay. This delay can be expressed in time or distance.

In process of releasing sea from ice, the forehead of corridor released from melting and disintegrating ice changes its position in geographical space and with the passage of time. The forehead moves in general direction of releasing the sea from ice cover, but ice changes its position under influence of wind and currents. Impact of wind direction and speed (resulting from movement of low baric zones and high baric zones) on movement of transit corridor was noticeable in each summer navigation season from 2008 to 2018 (NATICE 2018). Under their influence ice moved both in general direction of releasing sea from ice and in general opposite direction.

It was therefore necessary to determine at what distance or at what time delay a vessel should move behind the forehead of zone released from ice in different directions, so that there was no need to turn back from general direction of sea opening. Such a forced return of vessel from route would cause additional losses of time and losses of fuel consumption. To this end, it was assumed that distances of daily movement of the forehead of zone released from ice should be examined. Movement of the forehead was divided into general direction towards destination (east or west) and opposite

(backward) direction to the destination were taken into account.

Particular attention was paid to both, time (number of days) and route (distance) of a vessel's position delay relative to the forehead of sea release zone from ice. Therefore, a minimum distance and time to move behind the forehead of transit corridor released from ice was sought. Taking them into account when planning a vessel's voyage is to ensure that a vessel will not be surrounded by receding ice. In this way, a vessel would constantly move in general direction towards destination outside zone occupied by ice.

### 3 RESEARCH METHOD

The seas belonging to the NSR and approach seas to the NSR (Barents Sea and Bering Sea), where ports of commencing and completion of voyage are located, were analysed. Beginning of period under analysis took place on date of commencement of systematic formation of ice-free corridor on the first external NSR sea towards the next sea, after which ice-free corridor would not go beyond the border of the first sea on the NSR. This concerned the Kara Sea from the west and the Chukchi Sea from the east of the NSR. The end of period under analysis took place on date of creation of ice-free zone, which connected beginning of first external sea on the NSR with next two seas and formed a transit corridor throughout the entire NSR. Designated route was composed of Rhumb Line sections.

Taking above into consideration, voyages commencing on western side of the NSR (for the Kara and Laptev seas) and voyages commencing on eastern side of the NSR (for the Chukchi and East Siberian seas) were analysed separately. Spatial distribution of ice edges presented on MIZ ice concentration maps issued by the NIC in the United States named `nic_mizYYYYDDDDnc_en_a.zip` in ESRI Shape format available at <http://www.natice.noaa.gov/MainProducts.htm> for the year 2008 to 2016 was analysed (NATICE 2018). Contour maps of the world, in ESRI Shape format in scale 1: 10,000,000, available at <http://www.naturearthdata.com> (Natural Earth 2017) and borders of the oceans and seas specified in IHO documents (1953, 2002) were included.

Based on collected research materials, number of days and path of the vessel moving behind the forehead of transit corridor released from ice was determined, as well as probability of not having to return a vessel from general direction towards destination (in opposite direction to the planned route). Daily average and total distance of path of the forehead of ice-free corridor, number of days of delay and distance of delay of a vessel that assure no need to move back were also calculated. These values made it possible to determine range of distance losses and thus fuel losses, which would be a consequence of navigating too short distance or too short time behind the forehead of the sea being released from ice.

### 4 THE RELEASE OF THE NSR SEAS FROM ICE FROM WEST TO EAST

For release of seas from ice from west to east (Kara Sea and East Siberian Sea), total length of path of released transit corridor from ice was on average 1,445.7 Nm (median 1,410 Nm) with minimal value of 1,106 Nm and maximal of 1,858.0 Nm (Table 1). Meanwhile, path of release from ice of the Kara Sea and the Laptev Sea "straight ahead" was about 500 Nm. Rest of the route towards destination was free of ice. Therefore, values of path of vessel moving directly behind the forehead of released transit corridor would be more than 2 times longer than straight route in ice-free zone. One of main reasons for such high maximum values was, for example, the need to return vessel navigating directly behind the forehead of ice-free corridor to another route variant. For example, Figure 1 shows the need to return from corridor of ice-free zone in the Kara Sea straight ahead to the strait south of the Novaya Zemlya archipelago (but north of the Nordenskiöld Archipelago) and designate new route variant south of the Nordenskiöld Archipelago. Second reason was much longer ice-free transit corridor forehead path along coast instead of straight across the sea to the straits of archipelagos. Therefore, it should be assumed that one of tasks of voyage planning to the east is to determine beginning of voyage with such delay in relation to the forehead of released seas from ice that vessel without ice reinforcements moves at safe speed straight ahead along designated route without having to stop and wait for further releasing the sea from ice, moving in different directions behind the forehead of ice-free corridor and even more so vessel did not have to move back from general direction towards destination.

Number of days vessel's position was delayed in 2008-2016 relative to the forehead of ice-free corridor in western part of the NSR and ensuring that there was no need vessel to move back was on average 32.4 days (median 21 days) with minimal value of 15 days and maximal of 86 days (Figure 2). Path length of maximal movement back of the forehead of transit corridor released from ice (for the Kara Sea and the Laptev Sea opening eastwards) was 77.3 Nm (median 67.0 Nm) with minimal value of 49.0 Nm and maximal of 132.0 Nm. Number of days required for a vessel to be delayed relative to the ice-free corridor forehead for each of above results was approximately half of time of release of these seas towards east.

Average daily distance that the forehead of ice-free transit corridor moved was 21.1 Nm (median 21.0 Nm) with minimal value of 12.7 Nm and maximal of 39.2 Nm. Distance from first quartile to median was approximately half distance from third quartile to median. This indicates asymmetrical distribution of the phenomenon. Average speed of the forehead was therefore 0.9 knots. Vessel navigating at 12 knots would cover this route in 1.75 hours. So it would not be possible to constantly move vessel behind the forehead of corridor released from ice. Waste of time and fuel, even due to waiting in drift for forehead movement would be significant.

Total distance of maximal movement back of the forehead of ice-free corridor was 141.0 Nm (median 95.0 Nm) on average with minimal value of 59.0 Nm

and maximal of 448.0 Nm. One of main reasons for such high maximum values was the need to return vessel navigating directly behind the forehead of ice-free corridor along straight route to the strait south of the Severnaya Zemlya archipelago and to designate new route variant. These delay distances should be taken, in addition to delay time (both named "effective delay"), as additional information characterizing vessel's delay relative to the forehead of ice-free corridor. This information should ensure that vessel do not have to move back from general direction of releasing seas from ice. Average distance of reversal of the forehead of transit corridor corresponds to 11.75 hours of voyage at full maneuvering speed 12 knots in range of possible deviations from 4.9 hours to 37.3 hours.

From all data described above, it was assumed that knowledge of number of days of delay is particularly useful in planning time of vessel departure. Therefore, in addition to discrete results (Table 1), continuous relationship graph was developed for probability of not exceeding number of days of delay ensuring avoidance of the need vessel to move back due to retreat of the forehead of ice-free transit corridor or the need vessel to return from general direction of releasing seas from ice (Figure 3). This delay was named "effective delay". This graph also shows curve of "raw" delay values obtained on basis of ice maps (NATICE 2018) analysis. From raw data chart, it can be seen that most of results are within 15-34 days of delay. For this reason, median number of days of delay ensuring no need to move vessel back was 21 days with average of 32.4 days

(Figure 2). It should be noted that such relationships have shown all studied factors (Table 1). It was assumed that for purposes of vessel voyage planning the function of cumulative distribution of number of days of delay (not exceeding number of days of delay) should be used.

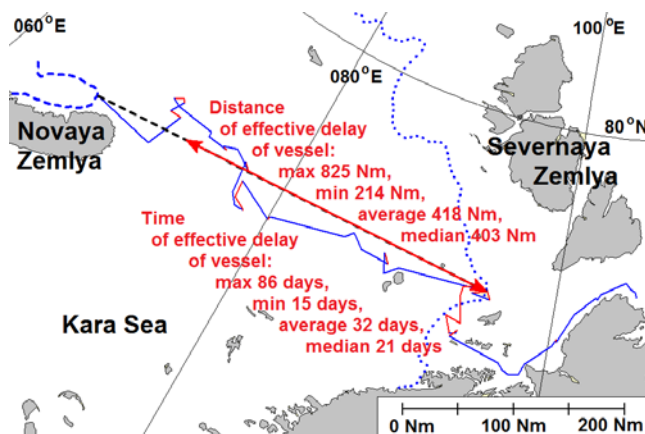


Figure 2. Distance and time of effective delay of vessel in relation to the forehead of transit corridor released from ice: — movement in general direction to the destination, — movement in general opposite direction to the destination, - - - forehead position in the first day of opening, · · · in any day of opening of ice free corridor, - - - the way of vessel "straight ahead" through the sea released from ice, ← → searched delay (distance and time) of vessel movement behind of forehead of ice-free corridor. Compiled by the author based on NATICE (2018). Provided courtesy of the U.S. National Ice Center. Made with Natural Earth – Free vector and raster map data @<http://www.naturalearthdata.com>

Table 1. Statistical results for the forehead of the ice-free corridor on the NSR moving towards east. Compiled by the author based on NATICE (2018)

Factor	Aver. value	St. dev. $\sigma$	Rel. st. dev. RSD [%]	Median	Min.	Max.
Number of days of delay that ensure no need to move vessel back [days]	32.4	24.3	75.0	21.0	15.0	86.0
Total distance of delay that ensure no need to move vessel back [Nm]	417.8	195.7	46.8	403	214	825
Maximal distance of retreat of forehead [Nm]	141.0	126.3	89.6	95.0	59.0	448
Number of days of opening seas towards east [days]	77.3	26.6	34.3	67.0	49.0	132
Total distance made by forehead [Nm]	1446	257.4	17.8	1410	1106	1858
Average daily distance of the forehead [Nm]	21.1	8.1	38.4	21.0	12.7	39.2
Standard deviation of average daily distance [Nm]	30.0	9.9	32.8	30.0	17.8	49.7
Daily distance median [Nm]	8.5	2.8	33.0	8.0	5.0	14.0
Distance of first quartile from median [Nm]	5.9	2.5	42.6	6.0	4.0	12.0
Distance of third quartile from median [Nm]	14.7	7.0	47.5	11.5	8.0	30.0

Table 2. Statistical results for the forehead of ice-free corridor on the NSR moving towards west. Compiled by the author based on NATICE (2018)

Factor	Aver. value	St. dev. $\sigma$	Rel. st. dev. RSD [%]	Median	Min.	Max.
Number of days of delay that ensure no need to move vessel back [days]	44.7	20.4	45.6	48.0	17.0	76.0
Total distance of delay that ensure no need to move vessel back [Nm]	603.4	278	46.1	540	258	1041
Maximal distance of retreat of forehead [Nm]	228.3	231.7	101.5	215	32.0	796
Number of days of opening seas towards east [days]	76.2	22.4	29.4	72.0	59.0	132
Total distance made by forehead [Nm]	1648	498	30.2	1530	927	2486
Average daily distance of the forehead [Nm]	23.2	9.2	39.6	24.5	9.2	38.5
Standard deviation of average daily distance [Nm]	57.7	31.5	54.5	57.7	23.2	105
Daily distance median [Nm]	9.3	5.9	64.1	8.0	2.5	19.0
Distance of first quartile from median [Nm]	6.8	3.9	56.6	5.0	2.5	13.5
Distance of third quartile from median [Nm]	11.8	4.5	37.8	11.0	6.5	20.5



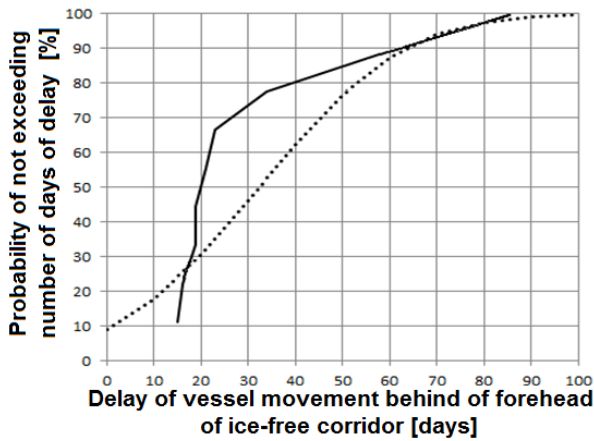


Figure 3. Probability of not exceeding number of days of delay ensuring avoidance of the need vessel to move back due to retreat of the forehead of ice-free transit corridor from general direction of voyage from west to east; — data obtained on the basis of analysis, ••• cumulative distribution graph based on average value and standard deviation. Compiled by the author based on NATICE (2018)

## 5 THE RELEASE OF THE NSR SEAS FROM ICE FROM EAST TO WEST

For release of seas from ice from east to west (the Chukchi Sea and the East Siberian Sea), total length of path of the released transit corridor from ice was on average 1,647.8 Nm (median 1,530 Nm) with minimum value of 927 Nm and maximum value of 2,486 Nm (Table 1). Meanwhile, path of release from ice of the Chukchi Sea and East Siberian Sea "straight ahead" was about 1,037 Nm. Rest of route towards destination was free of ice. Therefore, values of path of vessel moving directly behind the forehead of released transit corridor would be 1.5 times longer than straight route in ice-free zone. One of main reasons for such high values was the need to return vessel navigating directly behind the forehead of ice-free corridor, e.g. route north of Wrangel Island and routing around Wrangel Island and later proceed through the De Long Strait. Therefore, it should be assumed that one of tasks of voyage planning to the east is to determine beginning of voyage with such delay in relation to the forehead of released seas from ice that vessel without ice reinforcements moves at safe speed straight ahead along designated route without having to stop and wait for further releasing the sea from ice, moving in different directions behind the forehead of ice-free corridor and even more so vessel did not have to move back from general direction towards destination. Total lengths of paths along transit corridor of release of sea from ice for both directions (east and west) are comparable. This is despite the fact that path length in western part of the NSR is about twice less than in eastern part of the NSR.

Number of days vessel was delayed relative to the forehead of ice-free corridor at which there would be no need to reverse vessel was on average 44.7 days (median 48 days) with minimal value of 17 days and maximal of 76 days (Table 2). Length of path of maximum regression of the transit ice-free corridor (for the Chukchi Sea and East Siberian Sea opening

westward) was 76.2 days (median 72 days) with minimal value of 59 days and maximal of 132 days. The number of days delayed by vessel relative to the forehead of ice-free corridor westbound for each of above data was less than for eastbound sea releases. This delay was approximately two-thirds of its corresponding eastward time release data.

Average daily forehead movement was 23.2 Nm (median 24.5 Nm) at minimal of 9.2 Nm and maximal of 38.5 Nm. Distance of first quartile of daily forehead distance from median was approximately half distance of third quartile from median. This indicates an asymmetrical distribution of the phenomenon. Average forehead speed was therefore 1.0 knot. A vessel navigating at speed of 12 knots would cover this route in 1 hour and 56 minutes. So it would not be possible to constantly move vessel behind the forehead of corridor released from ice. Waste of time and fuel, even due to waiting in drift for forehead movement would be significant. These results, for westward opening of seas are comparable to those for eastward opening of seas.

Total length of path of maximal recession of ice release corridor was 228 Nm on average (median 215 Nm) with minimal of 32 Nm and maximal of 796 Nm. One of main reasons for such high maximum values was the need to turn back vessel navigating directly behind the forehead of the ice-free corridor route north of Wrangel Island and designate new route through the De Long Strait. These delay distances should be taken, in addition to delay time, as additional information characterizing vessel's delay relative to the forehead of the ice-free corridor. This information should ensure that vessel do not have to move back from general direction of releasing seas from ice. Average distance of reversal of the forehead of transit corridor corresponds to 19 hours of voyage at full maneuvering speed 12 knots in range of possible deviations from 2.7 hours to 66.3 hours. Dispersion of results of total length of path of maximal recession of the forehead of corridor released from ice in general direction from east to west is about 1.5 times greater than in case of general direction from west to east.

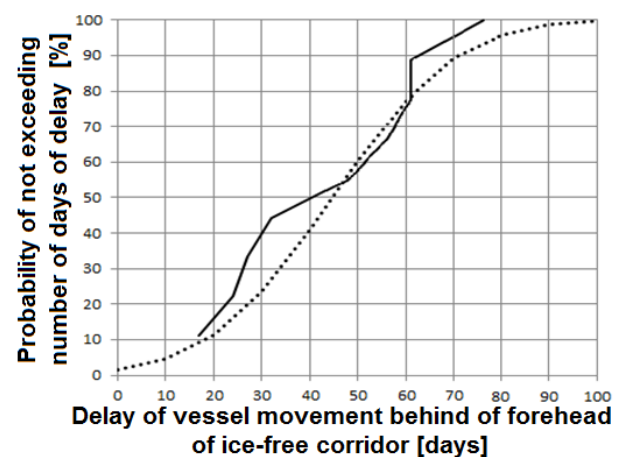


Figure 4. Probability of not exceeding number of days of delay ensuring avoidance of the need vessel to move back due to retreat of the forehead of ice-free transit corridor from general direction of voyage from east to west; — data obtained on the basis of analysis, ••• cumulative distribution graph based on average value and standard deviation. Compiled by the author based on NATICE (2018)

From all data described above, it was assumed that knowledge of number of days of delay is particularly useful in planning time of vessel departure. Therefore, in addition to discrete results (Table 2), continuous relationship graph was developed for probability of not exceeding number of days of delay ensuring avoidance of the need vessel to move back due to retreat of the forehead of ice-free transit corridor or the need vessel to return from general direction of releasing seas from ice (Figure 4). This graph also shows curve of "raw" delay values obtained on basis of ice maps (NATICE 2018) analysis. From "raw" data chart, there is lack of data below 17 days and fairly even increase in delay. For this reason, median number of days of delay ensuring no need to move vessel back was 48 days and was comparable to an average of 44.7 days (Figure 4). It should be noted that such relationships have shown all studied factors (Table 2). It was assumed that for purposes of vessel voyage planning function of cumulative distribution of number of days of delay (not exceeding number of days of delay) should be used.

## 6 SUMMARY AND CONCLUSIONS

Economic efficiency of vessel's planned voyage through the NSR is influenced by correct determination of date of departure. To do this, statistical relationships should be used. One such relationship is probability of an ice-free zone along whole or along western or eastern parts of the Northern Sea Route to designated day of the year in summer navigation season. Second relationship is probability of surrounding vessel by retreating forehead of ice-free transit corridor. In order to avoid vessel beset in ice moving in opposite direction to general direction of opening of the NSR, vessel must move in directions opposite to general direction of expected opening of transit corridor (proceed same direction and speed as forehead). This results in a loss of time, increasing length of voyage, increasing fuel consumption and thus deteriorating economic results of planned voyage.

Diagrams received as a result of the study can be used to support decision making. They are not intended to replace the human factor in making decisions. The decision maker (shipmaster or planner in the office) makes long-term decisions on date of beginning of voyage of vessel based on his own knowledge, experience and ice navigation conditions expected to be in current summer navigation season.

Proposed decision making method is multi-criteria. Decision criteria are date of beginning of voyage (the earlier date, the higher probability of completing voyage before beginning of ice cover growth and closing transit route on the NSR), probability of existence of ice-free transit corridor for the entire NSR (and at the same time the risk of incurring additional costs of icebreaker services, the cost of waiting time for ice conditions improvement, the cost of damage to the hull, propulsion system or steering system), date of opening and date of closing of the transit corridor for ice-free (open water) navigation, delay in distance and time of vessel's

position relative to the forehead of transit corridor through ice at the beginning of summer navigation season.

Tabular results taking into account discrete changes in statistical data, such as average value and standard deviation, do not fully represent changes in occurring phenomena. Median, first and third quartile values are better representing boundaries of data series. Thus, they will be conducive to effective planning of date of beginning of vessel's voyage through the Northern Sea Route. More precise and flexible than discrete relationships will be use of cumulative distribution function or lines approximating "raw" statistical data. With their help, it could be smoothly determined number of days and distance of movement of vessel behind the forehead of ice-free transit corridor released from ice at beginning of summer navigation season, together with probability of having to stop or turn back from the general direction of designated route. Dependencies presented in this way can be used to plan date of commence and completion of vessel voyage, taking into account probability of an ice-free zone leading through the whole NSR or selected part of the NSR with probability of having to stop or turn back from the general direction of designated route. Probabilistic approach to determining time of beginning of vessel's voyage should minimize risk of increasing length of intended route, risk of increasing voyage time and risk of damage to vessel's hull, propeller or steering gear. Therefore, economic efficiency of maritime transport in high latitudes should be increased.

## REFERENCES

- Arikaynen A.I., Tsubakov K.N. 1987. Alphabet of ice navigation. [in Russian] (Азбука ледового плавания). Transport, Moscow: 224
- Buyse J. 2007. Handling ships in ice, A practical guide to handling 1A and 1AS classed ships. The Nautical Institute, London: 166
- House D.J., Lloyd T., Toomey P.R.M., Dickins D. 2010. The ice navigation manual. Witherby Seamanship International Ltd: 409
- International Hydrographic Office, 1953. Limits of oceans and seas. Publication S-23: 40
- International Hydrographic Office, 2002. Limits of oceans and seas. Publication S-23, Draft 4th Edition, 2002: 235
- Jurdziński M. 2000. Planning the navigation in ice [in Polish] (Planowanie nawigacji w lodach). Wyższa Szkoła Morska, Gdynia: 192
- NATICE, 2018. MIZ ice concentration maps in ESRI Shape format. U.S. National Ice Center, [http://www.natice.noaa.gov/Main\\_Products.htm](http://www.natice.noaa.gov/Main_Products.htm). Accessed 19.12.2018
- Natural Earth, 2017. Free vector and raster map data at 1:10 m, 1:50 m, and 1:110 m scales, <http://www.naturalearth-data.com>. Accessed 01.01.2017
- Parnell G.Q. 1986. Ice seamanship, Monograph. The Nautical Institute: 87
- Pastusiak T. 2016a. The time window for vessels without ice strengthening on the Northern Sea Route, Annual of Navigation, No. 23: 103-119
- Pastusiak T. 2016b. The Northern Sea Route as a shipping lane. Expectations and Reality, ISBN 978-3-319-41832-2, ISBN eBook 978-3-319-41834-6, Springer International Publishing AG, Switzerland: 247

- Pastusiak T. 2016c. Principles of Vessel Route Planning in Ice on the Northern Sea Route, *TransNav, the International Journal of Marine Navigation and Safety of Sea Transportation*, Vol. 10 No. 4 - December 2016
- Pastusiak T. 2018. Planning independent transit voyages of vessel without ice strengthening through the Northern Sea Route [in Polish] (Planowanie samodzielnych podróży tranzytowych statku bez wzmocnień lodowych przez Północną Drogę Morską). Akademia Morska w Gdyni, Gdynia, ISBN 978-83-7421-286-1: 278
- Pastusiak T. 2020. *Voyages on the Northern Sea Route*, Springer International Publishing, 1st ed. 2020, XXXVIII, Print ISBN 978-3-030-25489-6: 279
- Shapaev V.M. 1975. Hydrometeorological conditions and navigation [in Russian] (Гидрометеорологические условия и мореплавание). Moscow, Transport: 248