

Principles of Vessel Route Planning in Ice on the Northern Sea Route

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ABSTRACT: A complex of ice cover characteristics and the season of the year were considered in relation to vessel route planning in ice-covered areas on the NSR. The criteria for navigation in ice - both year-round and seasonal were analyzed. The analysis of the experts knowledge, dissipated in the literature, allowed to identify some rules of route planning in ice-covered areas. The most important processes from the navigation point of view are the development and disintegration of ice, the formation and disintegration of fast ice and behavior of the ice massifs and polynyas.

The optimal route is selected on basis of available analysis and forecast maps of ice conditions and ice class, draught and seaworthiness of the vessel. The boundary of the ice indicates areas accessible to vessels without ice class. Areas with a concentration of ice from 0 to 6/10 are used for navigation of vessels of different ice classes. Areas of concentration of ice from 7/10 up are eligible for navigation for icebreakers and vessels with a high ice class with the assistance of icebreakers. These rules were collected in the decision tree. Following such developed decision-making model the master of the vessel may take decision independently by accepting grading criteria of priorities resulting from his knowledge, experience and the circumstances of navigation. Formalized form of decision making model reduces risk of the "human factor" in the decision and thereby help improve the safety of maritime transport.

1 INTRODUCTION

The problem of the need to assess the possibility of vessels to pass through the ice-covered areas and, at the same time, the necessity of planning their route resulted from the possibility of use on the Northern Sea Route (NSR) the vessels with relatively low ice class (Pastusiak 2016, 2015/2). Despite favorable conditions for navigation of vessels with low ice classes still have dangerous fast changes of ice conditions, involving periodic blocking of individual sections of the NSR by drifting ice fields. This primarily concerns space constraints in the nodes of vessel's route (narrow passages) and existing there specific behavior of ice cover (processes of

concentration, compression, hummocking, ridging and drift of ice), that reduce the vessel safety in narrow passages more than in the open sea. This particularly applies to vessels with low ice classes. Therefore, hydro-meteorological information, especially information about ice conditions and specific threats appearing at particular sections of the NSR, is very important for maritime transport.

Has been hypothesized that there is a possibility of developing comprehensive method of determining the route of the vessel through the lightest ice conditions. At the same time, this method should take into account the degree of difficulty of overcoming the specific characteristics of ice cover by the vessel

and be universal, that is customized to each season of the year. The aim of the study is to develop a method for routing vessels on the NSR by the lightest ice conditions, taking into account the difficulty of overcoming the ice cover at any season of the year.

Achieving the aim of work will be possible after the dissolution of the partial objectives of the work contained in the questions posed below:

- 1 What are the known ice conditions affecting the ability to overcome the ice cover with specific characteristics by a merchant vessel?
- 2 Is it possible to rank the designated characteristics of ice cover in order, according to the degree of difficulty posed by them to overcome ice by a vessel?
- 3 Are all characteristics of the ice cover equally important at any time of the year, or their importance varies depending on the season?

2 RESEARCH METHOD

A preliminary analysis of the available literature shows that there is no publication which discusses the complex issues of vessel's route planning in ice. This applies to both icebreakers and transport vessels. There are a number of publications relating to ship's voyage planning in areas off the ice-covered regions. Often they involve proceedings of crews at various stages of voyage planning. Much harder to find publications on the routing of a vessel in ice for direct use on board vessels. From the nature of things, the sources of information concerning voyage planning and routing of vessels in ice should be sought in the first place among the coastal states of the Arctic and Antarctic and the States conducting in these regions the economic activity. The Russian Federation has the greatest experience in the field of navigation on the NSR. For this reason, at first analyzed the literature of coastal states of the Arctic Antarctic and the States that conduct in those regions an economic activity with special attention for Russian Federation.

The first step was to determine the optimization criterion for routing of the vessel in ice. As a starting point the author of this paper adopted the statement of Holec and Tzymański (1973), that "the areas of the appearance of any forms of ice should be avoided, if only it is possible and if it does not involve excessive elongation of the voyage time". Same way adopted statement of Jurdziński (2000) that "the basis for planning navigation in ice, or the selection and development of the voyage route, to avoid meeting an ice, that a vessel cannot overcome independently". The publication of Holec and Tzymański (1973) also presented an assessment of the route selection according to the criterion of the shortest voyage time based on H. Seilkopf formula from 1934. The idea of this method seems to reflect in some extent the principle for route selection in ice: "safe and most cost-effective mapping the route of the planned voyage" (Arikaynen and Tsubakov 1987, CCG 2000, Jurdziński 2000, Kjerstad 2011). This idea does not take into account the safety criterion of navigation in ice. The principle of "safe and most cost-effective routing of the planned voyage" takes the safety of navigating in ice among other things, by the selection

of the lightest ice conditions. Therefore, adopted this criterion as the basis for further solving the relative optimization problem for determining safe and cost-effective voyages in ice covered regions.

It was assumed that the work will be a study. During the initial review and sorting of the literature on the subject the publications that meeting needs and research topic were selected. Selected sources of information were analyzed in order to find required partial information. The synthesis of partial information served to develop generalizations with inferences. Assumed, that the final result should be the development of comprehensive procedures for routing of the vessel in ice-covered regions.

3 ANALYSIS OF EXPERTS KNOWLEDGE

When considering a matter of selection of the criteria for appointing voyages in the ice-covered NSR regions noted that Russian sources have in this field continuity in the geographical space over a longer period of time and consistency to solve this problem. Characteristics of ice cover as an environment of navigation same like route selection criteria and priorities of the characteristics of ice in the route planning have been determined in several Russian sources of information (Arikaynen and Tsubakov 1987, Arikaynen 1990, Khvochtchinski and Batskikh 1998, Mironov et al. 2010). These are practically the only sources explaining these issues. Thus it was assumed that they will be the basis to determine the criteria for appointing voyages on the NSR.

In general assumptions assumed that the most important processes from the navigation point of view are the development and disintegration of ice, the formation and disintegration of fast ice and the behavior of ice masses and polynyas. Same time optimal route is selected on the basis of the analysis and forecasts of ice conditions and ice class, draught and seaworthiness of the vessel (Marchenko 2012). The classification rules for different vessels ice classes assumed average quantitative information about the recommended areas of operation and conditions of ice navigation. Is not expected, however, to use this information for the restrictions of permissible conditions for navigating vessels (Marchenko 2012, Pastusiak 2015/2). It was assumed that in the process of use of the vessel, the operator will be guided by the requirements of the Ice Passport or other document setting out the conditions for the safe operation of the vessel in ice, determining the structural limitations of the vessel hull strength and the power of the propulsion system. At the same time it was assumed that the vessel will take into account the ice conditions and safety of navigation in the form of icebreakers assistance (Mironov et al. 2010). This research was conducted in Russia, including determination of the algorithms of navigation recommendations in the planning and implementation of specific marine operations. These studies took into account the impact of the ice cover characteristics on navigation in ice. Statistical and empirical modeling allowed to obtain the vessel's speed in relation to all characteristics of the ice cover, which can be characterized quantitatively on the basis of observations (Mironov

et al. 2010). However, empirical-statistical models did not demonstrate in full characteristics of the ice cover, which formalization proved extremely difficult. In a number of cases, such formalization proved to be almost impossible.

The route planning criteria for the voyages valid throughout the year in order of priority were established by the author based on the analysis of the above-mentioned publications (Arikaynen and Tsubakov 1987, Arikaynen 1990, Khvochtchinski and Batskikh 1998, Mironov et al. 2010). These are:

- Basic characteristics of the ice cover to determine the optimal route of vessel assumed ice concentration and ice age (Arikaynen and Tsubakov 1987, Arikaynen 1990). The speed of vessels while sailing in ice in practice was determined by empirical correlation taking into account the thickness of the ice and concentration. Effect of other ice characteristics taken into account by means of adapted corrections. The Canadian method of administrative regulations for assessment the possibility of the safe navigation of a vessel in ice is also based on the ice concentration and ice ages (Timco et al. 2005).
- Ice floe concentration. At the beginning are determined areas where the concentration of ice is minimal (Arikaynen and Tsubakov 1987, Arikaynen 1990, Mironov et al. 2010). It was found that the speed of powerful icebreaker in the young ice practically does not depend on the concentration of ice floe. With the increasing thickness of the ice, its concentration begins to play a decisive role in determining the icebreaker speed (Arikaynen and Tsubakov 1987, Arikaynen 1990). The optimal route of the vessel is mapped out outside the ice massifs, through areas with low (4-6 / 10), and preferably very low (1-3 / 10) concentration of ice (Khvochtchinsky and Batskikh 1998). Areas of concentration 7-10 / 10 have been by these authors assigned to the difficult navigation conditions that should be avoided.
- Thickness of ice. In the area previously appointed from the distribution of the minimum ice concentration the areas with lowest ice thickness are selected (Arikaynen and Tsubakov 1987, Arikaynen 1990). Is indicated to select the route that passing through areas covered predominantly by young ice (Khvochtchinski and Batskikh 1998). Has been assumed that during the formation of the ice cover on the NSR (November-December) the vessels traffic takes place in young ice on ordinary routes by the shortest way (Mironov et al. 2010).
- Form of ice. When ice concentration and ice age are spatially uniform, the movement of the vessel depends on form of ice (Arikaynen and Tsubakov 1987, Arikaynen 1990). When choosing the optimal path, priority is given to areas of greatest ice comminution, which is the smallest horizontal size of ice (Arikaynen and Tsubakov 1987, Arikaynen 1990, Mironov et al. 2010).
- Ridges and Hummocks. As one of the most important, essential for navigation characteristics of ice at any season of the year adopted its hummocking - degree of ice surface coverage by ridges and hummocks of all types (Arikaynen and Tsubakov 1987, Arikaynen 1990). Adequate impact of ridges and hummocks on the movement of the vessel within purely analytical models

proved impossible to identify and demanded citing of data from modeling and / or tests in natural conditions (Mironov et al. 2010). When selecting the optimal route should be guided by the minimum amount of ridges and / or hummocks (Khvochtchinski and Batskikh 1998, Mironov et al. 2010).

- Compacting of ice. From all these parameters, the most limiting navigation of vessels in ice on the NSR is compacting of ice. Under certain conditions, the most powerful icebreakers could not continue their movement (Arikaynen and Tsubakov 1987, Arikaynen 1990). Compacting of ice is a major cause of forced detention of ships. There have been cases when compacting of ice lasted for 20-30 days and vessels traffic was practically interrupted (Arikaynen and Tsubakov 1987, Arikaynen 1990). Adequate impact of compacting of ice on movement of vessel, within purely analytical models, has proved impossible to identify and demanded citing of data modeling and / or tests in natural conditions (Mironov et al. 2010).
- Uniformity of ice cover. The Arctic and Antarctic Research Institute (AARI) formulated the general principles of optimization. The vessel, after taking into account previously mentioned ice characteristics should move toward areas with lower uniformity of the ice cover (cracks, fractures, channels), if it is in line with the general direction of vessel movement towards destination (Mironov et al. 2010).
- Depths in the basin. In accordance with the principles laid down by AARI the depths along the planned vessel route should meet the safety requirements of navigation (Mironov et al. 2010).

After the criteria governing year-round navigation in ice, based on analysis of research material, the following seasonal criteria were identified:

- in spring and summer period, when there is ice melt, one must choose route so that it passes through regions where there is a maximum disintegration of the ice cover (Arikaynen and Tsubakov 1987, Arikaynen 1990, Mironov et al. 2010) and off ice massifs, in areas of low ice concentration (4-6/10), and if possible - in areas of very low ice concentration (1-3/10);
- in the autumn (November-December), when there is a growth of the ice cover, one should seek routes with minimal compacting of ice and minimal adhesion of ice to vessel hull (Mironov et al. 2010);
- in autumn-winter period, one should look for areas where ice cover shows minimal snow coverage (Arikaynen and Tsubakov 1987, Arikaynen 1990) and areas with a maximum number of young ice forms, polynyas and discontinuity of drifting ice (Khvochtchinski and Batskikh 1998);
- in winter (January-May) one should sought routes in the formation of the polynya areas adjacent to fast ice (Arikaynen and Tsubakov 1987, Mironov et al. 2010). It is then necessary to determine the location of the edge of the drifting ice, the level of development of polynyas adjacent to fast ice, location of dynamically active zones (compacting) and disintegration of the uniformity of ice sheet in ice massifs.

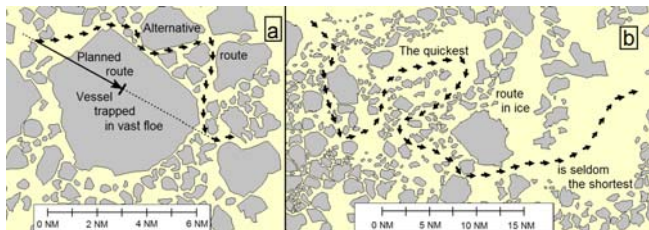


Figure 1. Routing of a vessel through the lightest ice conditions: a – the principle „do not enter ice if an alternative, although longer, open water route is available“; made by the author on the basis of ice map named WSM_SS_20110706_100722_5084_1.dim.tif (<http://www.polarview.aq/arctic>, accessed 08.07.2011), b – „the quickest route in ice is seldom the shortest“; made by the author on the basis of ice map named WSM_SS_20110706_100722_5084_1.dim.tif (<http://www.polarview.aq/arctic>, accessed 08.07.2011)

4 RESULTS

On the basis of information concerning the criteria for routing in ice-covered areas the author has developed procedures for the processing of information for routing passage of vessel on the NSR (Fig. 2, 3, 4). The most important criterion adopted degree of difficulty to continue vessel voyage resulting from the ice conditions. The procedures included timeliness of information available as well as the seasonal nature of the information used. The surprising is the fact that the most frequently described type of information on the ice cover - concentration - is applicable only at the end of this procedure. This information is depicted both in the full-scale of ten discrete or continuous, or in a simplified form as, for example Mariginal Ice Zone (MIZ) or in the form of ice boundary of a certain concentration of ice. It seems that the greatest interest in the value of the concentration of ice resulting from the character of MIZ zone. Boundary of the ice indicates areas accessible to vessels without ice class. Areas with a concentration of ice from 0 to 6/10 are used for navigation by vessels of different ice class. Areas of concentration of ice from 7/10 up are eligible for navigation for icebreakers and vessels with a high ice class with the assistance of icebreakers. In the MIZ zone are sought opportunities to extend the navigation season, so significant due to the transport of goods and the exploitation of natural resources under water and on land. This area is rich especially in the industrial resources of various fish species. At the same time minimizing the resistance of the hull to all ships in the surrounding ice floe plays an important role in the economics of transport and fishing.

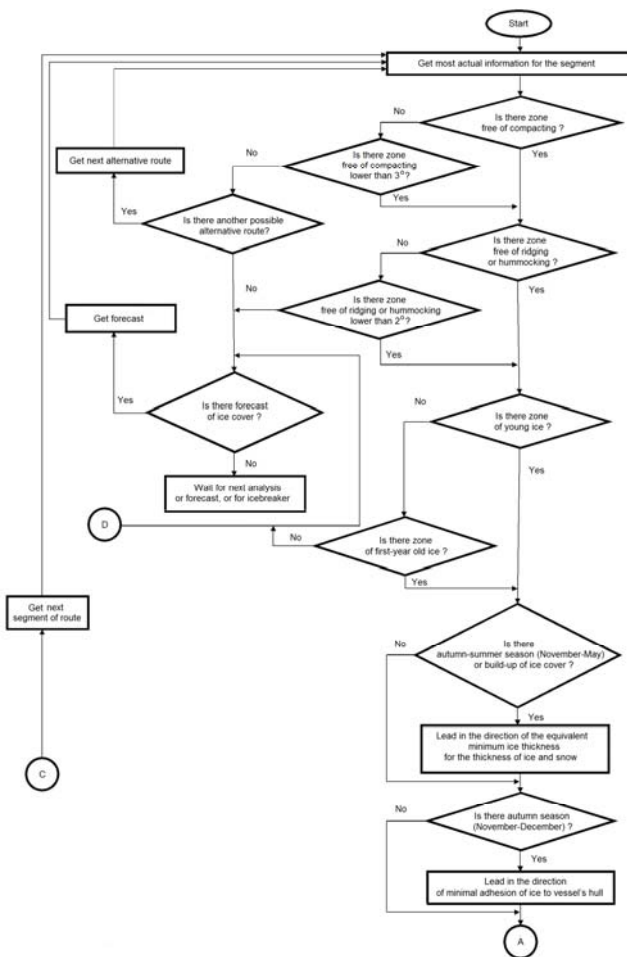


Figure 2. Flowchart of vessel route planning through ice-covered regions on the NSR. Part 1

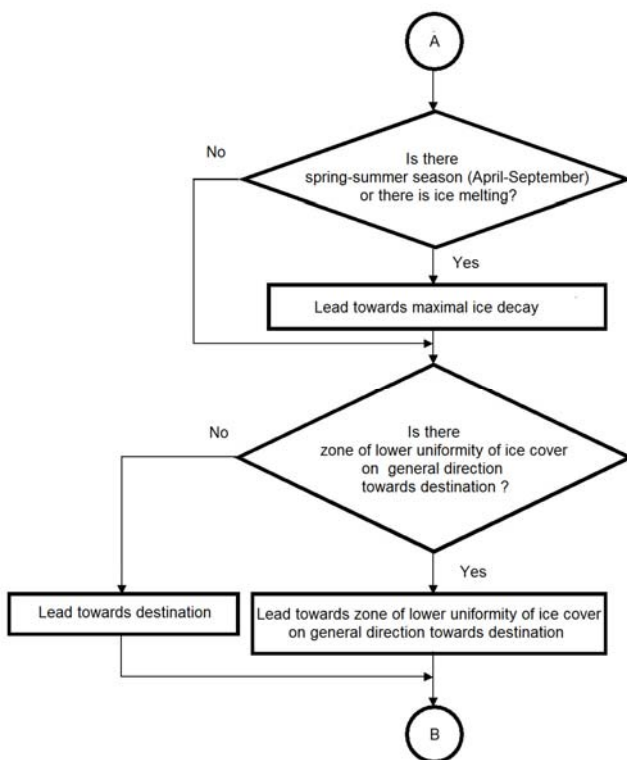


Figure 3. Flowchart of vessel route planning through ice-covered regions on the NSR. Part 2

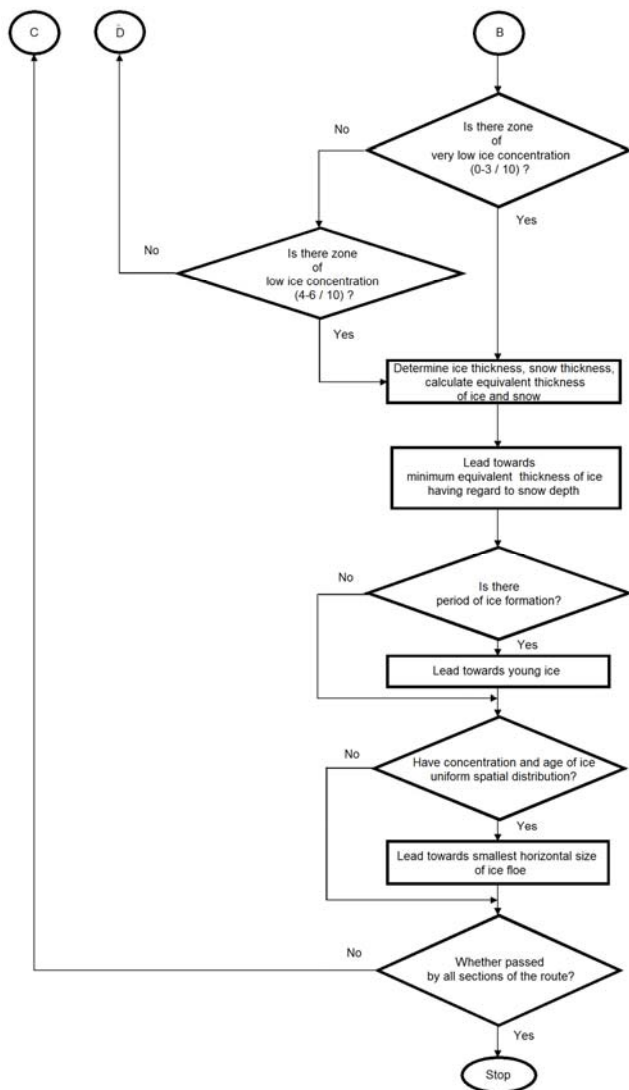


Figure 4. Flowchart of vessel route planning through ice-covered regions on the NSR. Part 3.

5 CONCLUSIONS

The rules for creating voyage plan in ice and limits of navigation devices usefulness have already been described in the literature. Safety of the vessel and travel planning in ice-covered areas were considered in terms of navigation equipment, gathering information about weather conditions and ice, limitations due to cargo and hull strength, the ability to overcome the ice with specific characteristics, the speed of the vessel in the ice, preparing the crew, etc. But not considered a complex of ice cover characteristics and the season of the year to plan a route in ice-covered areas on the NSR. Therefore, just only this additional aspect of the voyage planning has been considered in this work.

The analyzed publications were a compendium of knowledge of experts in the field of vessel route planning in ice. Based on this expert knowledge of determined disordered facts (input) the rules of procedure and finally completed deterministic system in the form of the decision tree (flowchart) were formulated. The presented algorithm is a decision support system. It can be used as the decision-making

patterns (Fig. 2, Fig. 3, Fig. 4), check-lists or computer program. On the basis of such developed decision-making model the master of a vessel may take decision independently by defining grading criteria of priorities resulting from his knowledge, experience and the circumstances of navigation. Formalized form of decision making model reduces risk of the "human factor" in the decision and thereby help improve the safety of maritime transport.

It take into account existing criteria for navigation in ice - both year-round and seasonal. The basic principle of routing in ice-covered areas is to look for the lightest ice conditions on the general direction of the destination of the vessel and thus safe and most economically efficient. It also minimizes the daily fuel consumption. The most important processes from the navigation point of view are the development and disintegration of ice, the formation and disintegration of fast ice and behavior of the ice massifs and polynyas. The optimal route is selected on basis of available analysis and forecast maps of ice conditions, and ice class, draught and seaworthiness of the vessel.

The most important criterion for the designation of the route is level of difficulty to continue vessel's voyage due to the ice conditions. It should be borne in mind that the boundary of the ice indicates areas accessible to vessels without ice class (hull without ice strengthening). Areas with a concentration of ice from 0 to 6/10 are used for navigation of vessels of different ice class. Areas of concentration of ice from 7/10 up are eligible for navigation for icebreakers and vessels with a high ice class with the assistance of icebreakers.

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