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DO VESSELS REMAIN WITHIN THEIR OPERATIONAL LIMITATIONS IN ICE? ANALYZING THE RISKS OF VESSELS OPERATING IN THE KARA SEA REGION USING POLARIS

Nabil Panchi[1]
Department of Ocean Engineering and Naval Architecture,
Indian Institute of Technology Kharagpur,
Kharagpur, India

Ekaterina Kim, Sheng Xu
Department of Marine Technology,
Norwegian University of Science and Technology,
Trondheim, Norway

ABSTRACT

This study investigates whether the vessels remain within their operational limitations in ice using the risk index calculated based on the Polar Operational Limitations Assessment Risk Indexing System (POLARIS) - an acceptable methodology for the assessment of operational limitations in ice infested waters, referenced in the Polar Code of the International Maritime Organization (IMO). The speeds and positions of the vessels in the Kara Sea region were analyzed from January through April for 2017–2019 using the navigational data provided by the Northern Sea Route Administration. For each vessel, except for the icebreakers, the risk index based on POLARIS was calculated using the open-access ice information that was provided by the Arctic and Antarctic Research Institute in Russia. The variation of risk index was analyzed with respect to various parameters such as the ice-class of the vessel, the reported operating speed of the vessel, and the built year of the vessel. Furthermore, we explored the limitations of the risk assessment system as well as the limitations of the available ice information and its implications on the risk assessment system. This paper reports preliminary results from the analysis.

Keywords: Arctic, POLARIS, Kara Sea, risk

INTRODUCTION

Melting of ice encourages greater maritime activities in the Arctic waters, where the operating conditions are dynamic, and the weather is harsh. Keeping all vessels within their operational limitations in ice is of great importance when the safety is considered. This is specifically important in the regions where national regulations have been imposed in addition to those of the IMO's Polar Code.

To guide maritime stakeholders on how to tailor their operations to the ice conditions, the IMO developed the Polar Operational Limitations Assessment Risk Indexing System (POLARIS) [1]. The basis of POLARIS is an assessment of the risks posed by the surrounding ice conditions to the ship in relation to the ice-class assigned to the ship. Even though POLARIS is not a mandatory requirement, it is being used by classification societies, shipowners, and their crew. Examples of applications of POLARIS in research work include voyage planning and evaluations of the ice navigability of a vessel in the Canadian Arctic, the Kara Sea, and the Antarctic [2-6]. The use of open-access historical ice charts for route evaluation and planning has been discussed in [2], where the authors have used weekly ice charts from the National Snow and Ice Data Centre (NSDIC). Another example of the use of digital ice charts from the Canadian Ice Service (CIS) for risk calculation has been presented in [3]. Detailed analysis of the practical use of POLARIS as a voyage planning tool using ice charts has been discussed in [4]. Risk analysis has also been applied to the ice transit simulations [5]. Apart from this, the application of POLARIS for evaluation of the suitable ice-class for operations in Antarctica and the Kara Sea was studied in [6].

Available applications of POLARIS to the conditions in the Russian Arctic are limited to the analysis of a couple of vessel voyages in the Kara Sea region. This study aims at addressing these shortcomings by investigating whether the new vessels in the Kara Sea region remain within their operational limitations in ice. In addition, we have investigated if other ship parameters such as the type of the ship and the deadweights are implicitly connected to the risk index values calculated using POLARIS.

METHODS

The speeds and positions of the vessels in the Kara Sea region were analyzed for the period starting from January through April for 2017-2019 using the navigational data

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[1] Contact Author: panchinabil@gmail.com

provided by the Northern Sea Route Administration (NSRA). For each vessel, except for the icebreakers, the risk index based on POLARIS was calculated using the open-access ice information. The variation of risk index was analyzed with respect to various parameters such as the ice-class of the vessel, the reported operating speed of the vessel, the built year of the vessel, and the type of the vessel. By doing so, we could explore the limitations of the risk assessment system as well as the limitations of the available ice/vessel information and its implications on the risk assessment system. The following subsections describe the data, data processing techniques, and applied analysis method.

Ice Data

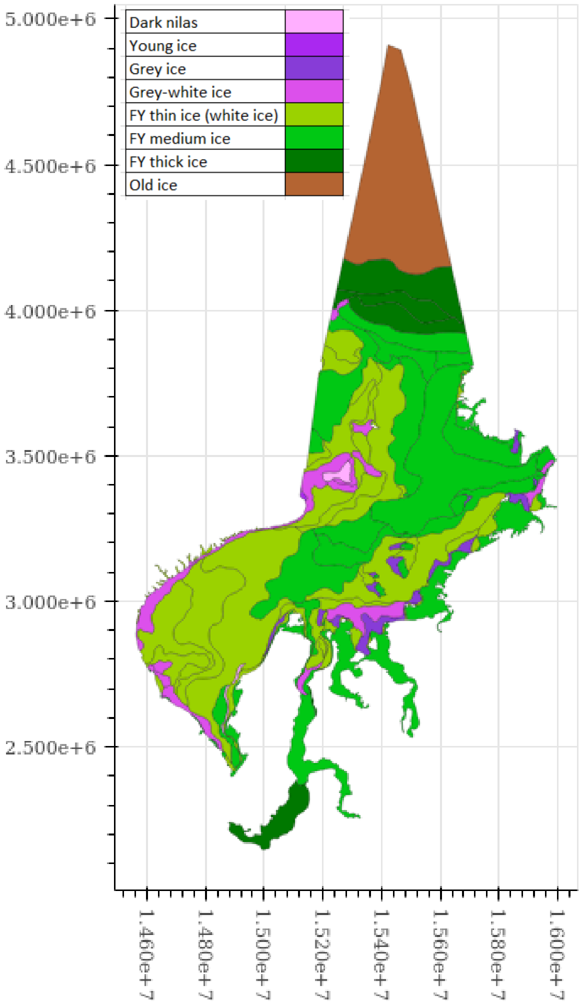

FIGURE 1: SAMPLE OF ICE DATA (FOR 21-02-2017); COLOR-CODED BASED ON THE VALUE OF STAGE OF DEVELOPMENT OF THE THICKEST ICE (FY – FIRST YEAR)

The calculation of risk values based on POLARIS requires the data on ice conditions. In our case, we used the open-access ice conditions provided by the Arctic and Antarctic Research Institute (AARI) in Russia. The weekly ice data were downloaded from the website of AARI [7] for the three years – 2017, 2018, and 2019 (January – April). For the duration considered, the ice data were available for 42 days in SIGRID-3 [8] format. A typical example of ice conditions for the Kara sea region is shown in Fig. 1. The ice maps provided by AARI are divided into polygons, and for each polygon, a set of attributes is provided. These attributes are provided based on the Egg code notation from the WMO Ice nomenclature [9]. The essential attributes that were used in this study are described in Table 1.

TABLE 1: ATTRIBUTES OF THE ICE DATA CONSIDERED (ADOPTED FROM [8] WITH SMALL MODIFICATIONS)

Attribute	Representation
CT	The total concentration of the ice
CA	The partial concentration of thickest ice
CB	The partial concentration of second thickest ice
CC	The partial concentration of third thickest ice
SA	Stage of development of thickest ice
SB	Stage of development of second thickest ice
SC	Stage of development of third thickest ice

CT, CA, CB, and CC columns contain the code for the concentration; the actual value of the concentrations is obtained by looking up the code from Table 1 in [8]. Similarly, the SA, SB, and SC columns contain the code for the stage of development of the ice, and the actual value is obtained by looking up the code in Table 2 in [8].

Navigational Data and Vessel Characteristics

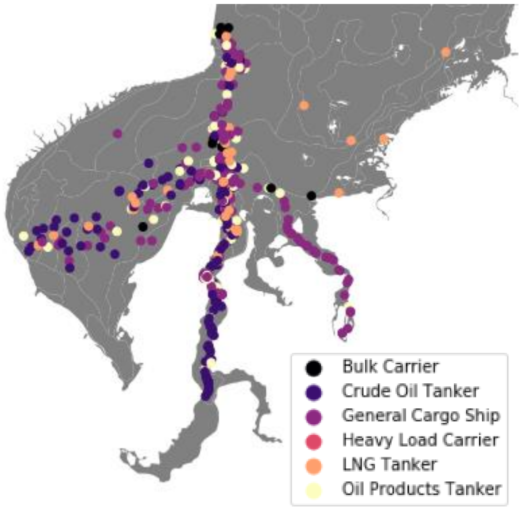

FIGURE 2: NAVIGATIONAL POSITIONS DOWNLOADED FROM [10] PLOTTED ON A SAMPLE MAP OF THE NSR PART OF THE KARA SEA REGION. THE POINTS (POSITIONS) ARE COLOR CODED BASED ON THE TYPE OF THE VESSEL

The navigational records (consisting of Vessel's name, IMO number, position, heading, and speed) for the Northern Sea Route (NSR) were downloaded from the website of the NSRA [10]. It was ensured that the navigational records are from the same date as the ice conditions. The collected data (latitude and longitude information, the speed, and the headings) was pre-processed and cleaned to remove missing or erroneous entries. Also, ice-classes for the IMO numbers were collected from the NSRA website [11] and added to our dataset. In addition to that, the type of vessel, the year built, deadweight, and the gross tonnage of the vessel was also collected from various open-source websites [12, 13] using the IMO numbers and vessel names. A total of 388 navigational records were collected. All the analysis in this study was done based on this navigational information, vessel characteristics, and the corresponding ice conditions.

Procedure for Risk Index Outcome (RIO) Calculation

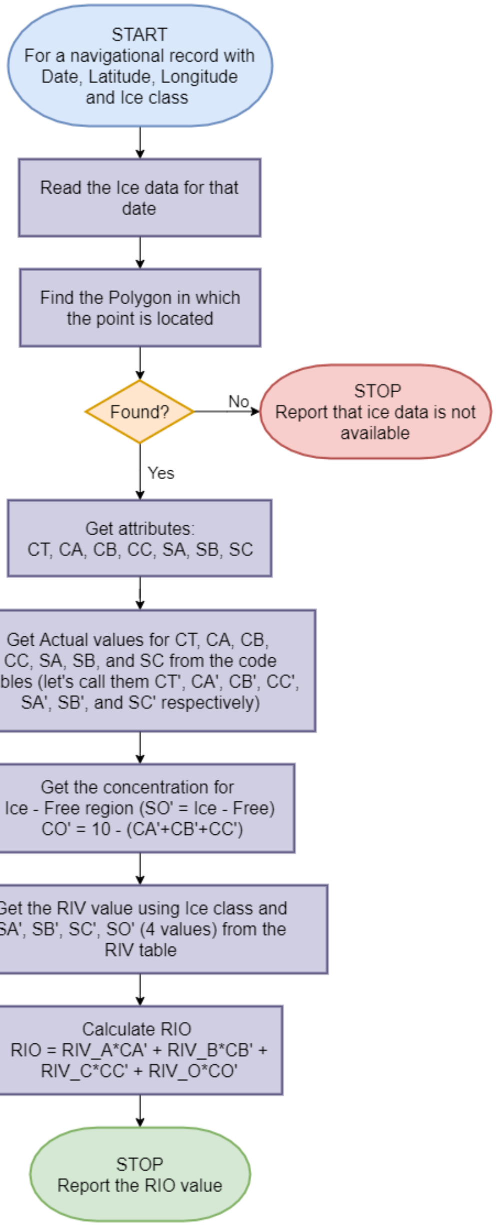

FIGURE 3: ALGORITHM FOR CALCULATION OF RIO VALUE

The formula for the calculation of RIO from POLARIS is given as:

$$RIO = (C1 \times RIV1) + (C2 \times RIV2) + (C3 \times RIV3) + \ldots + (Cn \times RIVn) \quad (1)$$

C1, C2, ..., Cn are the concentrations (in tenths) of ice types within the ice regime and *RIV1, RIV2, ..., RIVn* are the corresponding Risk Index Values for each ice type. Figure 3 provides a summary of the steps for calculation of the RIO for a set of position, ice-class, and date. The same process was repeated for all the navigational records.

The concentration for a date and position was obtained by locating the position on the map and obtaining the corresponding attributes (CT, CA, CB, CC, SA, SB, SC). For the RIV value, the ice-class and stage of development of ice must be known. The ice-class for the vessel was collected along with its navigational data. In the Kara Sea region considered in this study, the ice-classing system is applied based on the regulations of the Russian Maritime Register of Shipping (RMRS) [14]. The ice-classes under these rules are different from the Polar class rules by the International Association of Classification Societies (IACS) [15]. Therefore, the PC ice-class equivalent to the Arc ice-class was used based on Table 18 from [16]. The ice-class equivalence is provided in Table 4 in the appendix. The RIV values were obtained by looking up the Stage of developments and the ice-class in the RIV Table (Table 1.3 in [1]).

RESULTS AND DISCUSSION

There are three possible operational levels as described in POLARIS, normal operation ($RIO \geq 0$), elevated operational risk ($-10 \leq RIO < 0$) and operation subject to special consideration ($RIO < -10$). There were 16 instances of vessels in 'elevated operational risk' zone and two instances of vessels in 'operation subject to special consideration' zone, i.e., a total of 18 instances with $RIO < 0$. In all these instances, the vessels belonged to either 'Arc 4' or 'Arc 5' ice-class. There were four vessels that had multiple ice-class values (i.e., 'Arc 4/Arc 5') based on their operating drafts. For such cases, the calculations were done while considering the lower ice-class to be on the safer side. Such cases are marked separately on the plots wherever necessary. In most of the instances (14 out of 18) of a negative RIO value, the vessels were operating in the Gulf of Ob.

The calculated risk values (RIO) were analyzed with respect to the vessel speed, the built year, the ice-class, and the type of the vessel. The following sections explain the effect of the aforementioned parameters on the RIO value.

Speed

Collected navigational data (including vessel characteristics) were compared to the data reported in a previous study of ship speed regimes in the Kara sea [17]. For the purpose of comparison, navigational data (2017-2019) for Yamal Max vessels was used (for classification details refer to Table 1 of [17]). The aggregated speed (per day) for November to May is plotted in Fig. 4. The trend (grey line in Fig. 4) was calculated using simple curve fitting methods from NumPy [18]. The month on month decrease in the speed was found to be ~ 6%. This decreasing trend is in coherence with Fig. 1 of [17], where the authors reported a decrease in the speed of 7.2 %.

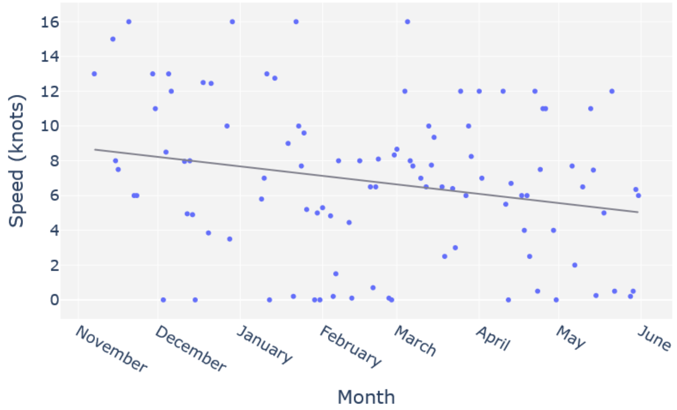

FIGURE 4: SPEEDS AND A TREND FOR YAMALMAX LNG TANKERS

There is no direct formula relating the RIO values with the vessel's speed, but it is understood that the ice conditions play a significant role in dictating the speed of the vessel. It is also described in POLARIS, and recommendations for speed limits for operations in the 'elevated operational risk' zone are given. The following Table 2 is from [1], modified to include the ice-classes in the RMRS system.

In Fig. 5, the RIO values are plotted against the speed. We found that out of the 18 instances with RIO < 0, 9 instances have a speed of zero, and the maximum speed of vessels with a negative RIO value is 10.5 knots.

TABLE 2: RECOMMENDED SPEED LIMIT FOR VESSELS WHILE OPERATING THE REGION OF ELEVATED RISK (ADOPTED FROM [1] WITH SMALL MODIFICATIONS)

Ice-class	Recommended Speed Limit
PC1 (Arc 9)	11 knots
PC2 (Arc 8)	8 knots
PC3 - PC5 (Arc 6, Arc 7)	5 knots
Below PC5 (Arc 1 – Arc 5)	3 knots

Out of the 16 instances in the 'elevated operational risk' zone, the recommended speed limit (the dashed red line for 'Arc 4' and 'Arc 5' vessels in Fig. 5) was crossed on seven occasions. We checked if these vessels were following an icebreaker (within a reasonable distance, we checked with various values for this distance from 1 - 5 miles). A detailed procedure of this check is outlined in the Appendix.

On four out of the seven occasions, the vessels are following an icebreaker. The details of these are given in Table 3.

Out of the two instances of 'operation subject to special consideration' zone, one vessel is following an icebreaker. The details of this instance are also present in Table 3.

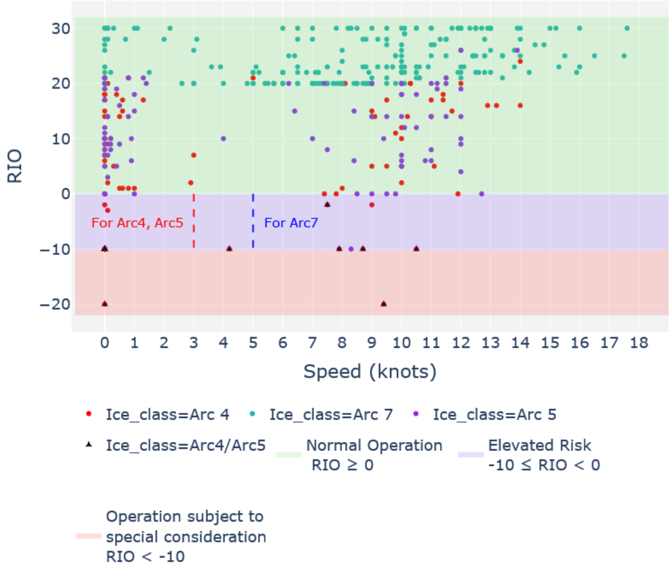

FIGURE 5: RIO VALUES PLOTTED AGAINST THE SPEED OF THE VESSEL

TABLE 3: VESSELS FOLLOWING ICEBREAKERS

Speed (knots)	RIO*	Distance from the nearest icebreaker (miles)	|Heading of the vessel – Heading of the nearest icebreaker| (degrees)
8.7	-10.0	0.57	0.0
7.5	-2.0	1.59	5.0
9.0	-2.0	1.87	13.0
8.3	-10.0	3.96	6.0
9.4	-20.0	0.63	2.0

*It is advised in POLARIS to add 10 to the RIO value if the vessel is following an icebreaker.

In Fig. 6, the speed was plotted against the RIO value with speed being the dependent variable to find out if there was any change in speed as the risk index (RIO) increases. For all possible values of RIO in the range -20 to 30, a box plot was drawn based on the corresponding speed values. The box plot was generated using Plotly [19] with the standard settings. The trend line was drawn by fitting a curve through the mean values of speeds for the RIO range. As evident from Fig. 6, there is a general increase in the mean speed of the vessels with the increase in the RIO.

To summarize, although the speed is not directly related to RIO in the POLARIS, speed values increase with the increase in RIO. The POLARIS only suggests operational speed limits in the region with elevated risk, but the RIO values contain information about the ice conditions around a vessel, which dictate the speed.

This is very well reflected in the trend of speeds with respect to change in RIO values.

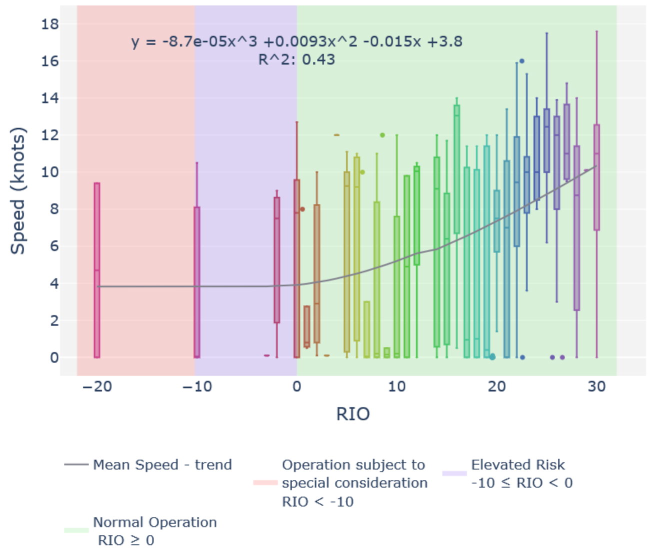

FIGURE 6: SPEED OF THE VESSEL PLOTTED AGAINST THE RIO ALONG WITH A BEST FIT CURVE FOR THE MEAN SPEEDS FOR CORRESPONDING RIO VALUES

Year built

FIGURE 7: RIO VALUES PLOTTED AGAINST THE BUILT YEAR OF THE CORRESPONDING VESSEL

Figure 7 contains the variation of RIO values with respect to the built year of the vessel. It can be seen from Fig. 7 that there is a general increase in the RIO values as the built year increases. Ice-class has a direct impact on the values of RIO (explored in-depth in the next section), and therefore it is noteworthy that towards the end (2010-2019), most of the vessels are of 'Arc 7' ice-class and have a very high RIO values. We can also see that in the earlier years (before 1990), the ice-class of most of the vessels is 'Arc 4' while from 1990-2005, the ice-class of most of the vessels is 'Arc 5'. The vessels with negative values of RIO were built in 1976, 1995, 1999, 2000, and 2002.

As can be seen from Fig. 8, the deadweight of the vessel has increased drastically in the post-2005 period, and the ice-class in the region of the vessels with high deadweight is 'Arc 7'. So, if Fig. 7 and Fig. 8 are analyzed together, it can be seen that all the vessels in this high deadweight category also have a high RIO and none with RIO < 0.

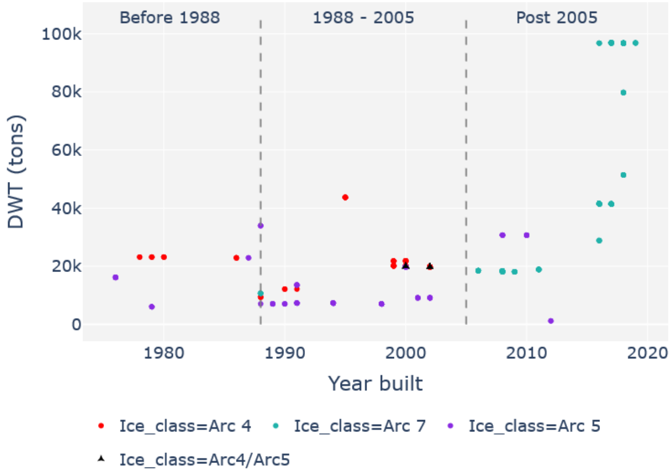

FIGURE 8: DEAD WEIGHT (DWT) PLOTTED AGAINST BUILT YEAR OF THE VESSEL

In summary, newer vessels have higher ice-classes and thus significantly higher RIO values. These same vessels have the highest deadweights as well.

Ice-class

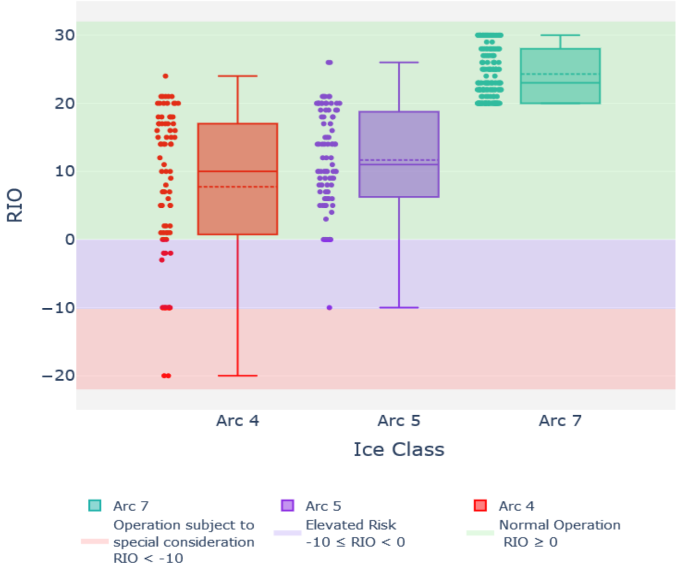

FIGURE 9: RIO VALUES PLOTTED AGAINST THE ICE-CLASS OF THE VESSEL

Figure 9 presents the boxplot of the RIO values versus the ice-class of the vessels. The median RIO values are 10, 11, and 23, and the mean values (the dashed lines in the boxes in Fig. 9) are 8, 12, and 24 for ‘Arc 4’, ‘Arc5’, and ‘Arc 7’ respectively. It can be seen from Fig. 9 that the RIO values are spread somewhat evenly over the RIO range in case of vessels with ice-class of either ‘Arc 4’ or ‘Arc 5’, But in case of ice-class ‘Arc 7’, the minimum value of RIO is 20. It is understood that these RIO values are calculated for different ice conditions, and hence it cannot be directly concluded that Ice-class ‘Arc 7’ always has a minimum RIO value of 20 for all the ice conditions that are present in our analysis. It may happen that the vessels in ‘Arc 7’ never faced ice conditions as severe as faced by the other ice classes. Therefore, we recalculated the RIO values for the vessels with negative RIO (All vessels with RIO < 0 have an ice-class of either ‘Arc 4’ or ‘Arc 5’), for an Ice-class of ‘Arc 7’.

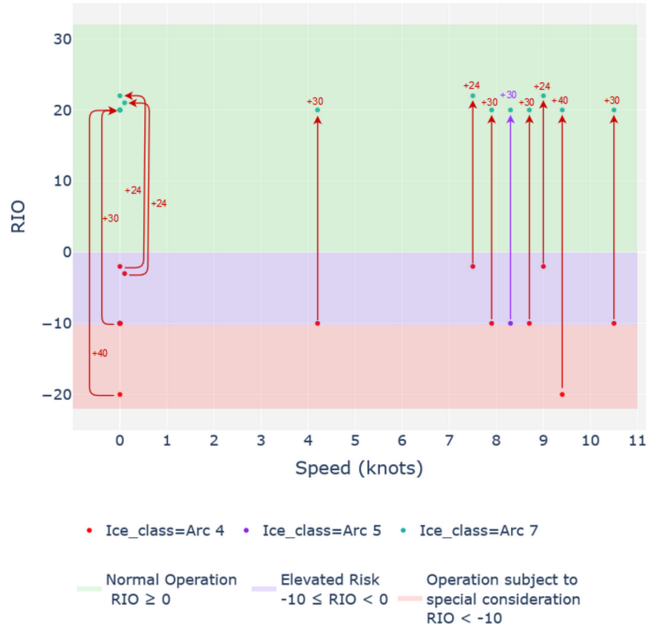

FIGURE 10: RECALCULATED RIO VALUES CONSIDERING ICE-CLASS TO BE ‘ARC 7’ (ARROWS INDICATE THE CHANGE IN RIO VALUES)

Figure 10 contains the updated RIO values as well (in green, as the ice-class has been changed to ‘Arc 7’, plotted against the speed). Even now, all the RIO values calculated with ice-class of ‘Arc 7’ have a minimum of 20. So, according to POLARIS, all vessels with ice-class equal to ‘Arc 7’ in the navigational records collected by us, always lie in the zone of ‘normal operation’. No matter the ice conditions.

Theoretically, it is possible to get a negative RIO value for ice-class of ‘Arc 7’ since there is a negative value for RIV in Table 1.3 of [1]. To find out if it ever happens in practice, we collected all available ice data for the last five years (2015-2019) from AARI and calculated the RIO values for all recorded ice conditions, for the ice-class of ‘Arc 7’. Figure 11 contains a map of the Kara sea region. The red region indicates an RIO value below zero, and the green region indicates an RIO value of zero and above. Similar plots have earlier been analyzed for the whole Arctic region by the Korea Research Institute of Ships and Ocean Engineering (KRISO) [20].

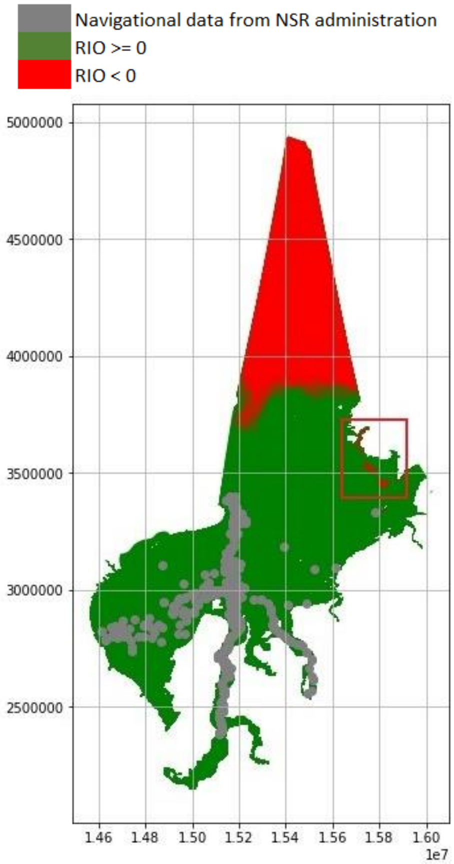

FIGURE 11: A MAP OF KARA SEA REGION COLOR SHADED BASED ON RIO VALUE

As can be seen from the map in Fig. 11, the RIO value for the ‘Arc 7’ vessels does go below zero in practice as well, but we did not find any record of the vessel in the red region nearing the Northern Sea Route (small red region contained in the rectangle in Fig. 11). There were some cases where the stage of development of ice was reported as “unknown”. To deal with this, two possible options were considered: a) Skip the calculation for these polygons and b) Assume the ice condition to be the worst possible it could be. A similar assumption was considered in [4]. The results from these two were compared. For Fig.11, the calculation was skipped for the ice conditions with unknown stage of development. If we consider the unknown stage of development to be the worst-case scenario, the entire map turns red.

To summarize, ‘Arc 7’ vessels analyzed in this study have no speed restrictions from the risk assessment (apart from the speed limits in Ice Certificate), even though, in theory, it is possible for ‘Arc 7’ vessels to have a negative RIO and be subject to these speed restrictions. While the mean value of RIO for ice-classes ‘Arc 4’, ‘Arc 5’ are close to each other, the mean of RIO value for ‘Arc 7’ vessels is much higher, and the minimum value is also much higher for all the navigational records analyzed. This suggests that ‘Arc 7’ vessels are almost practically never operating in a region of elevated risk, provided the underlying ice data.

Type of the Vessel

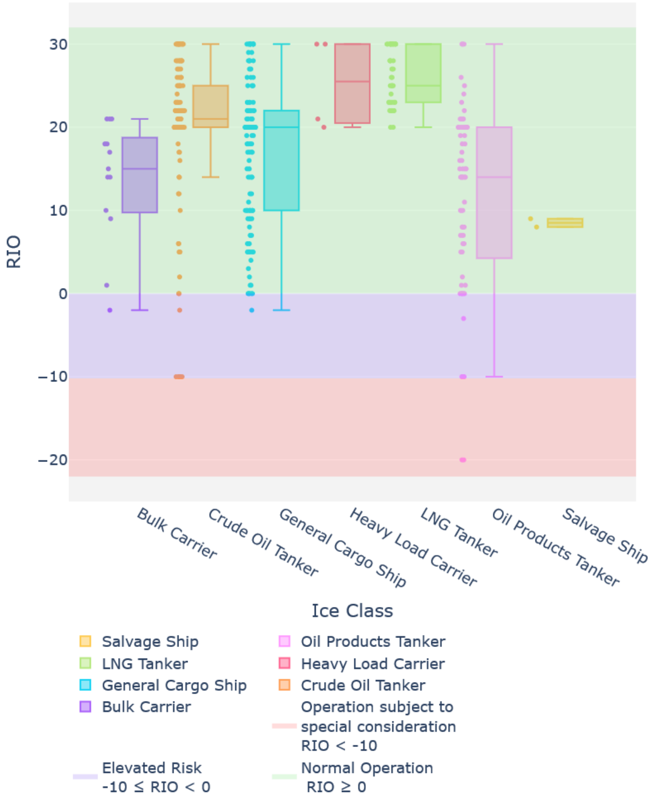

FIGURE 12: RIO VALUES PLOTTED AGAINST THE TYPE OF THE VESSEL

It was found that all the vessels were one of the following types: General Cargo Ship, Oil Products Tanker, Crude Oil Tanker, Bulk Carrier, Salvage Ship, LNG Tanker, and Heavy Load Carrier. Figure 12 contains the boxplot of RIO values against the Ship Type. Crude Oil Carrier and Oil Products tanker were found to be operating in the ‘Elevated operational risk’ zone on eight instances each while General Cargo Ship and Bulk Carrier were found to be operating in the ‘Elevated operational risk’ zone on one instance each. LNG tankers, Heavy Load carriers, and Salvage Ships were always found to be operating in the ‘normal operation’ zone. Only the Oil Products Tankers were found to be operating in the ‘operation subject to special consideration’ zone on two instances.

The POLARIS by nature does not account for vessel type, and it is only the ice-class that is considered. Therefore, it seems that the risk index does not reflect the risk picture with respect to the consequences of an accident. If the risk indices of a general cargo vessel and an oil tanker (both having the same ice-class) are calculated in the same ice conditions, the risk indices would be equal. However, in case of an accident, the consequences will be much worse for an oil tanker, and thus risk (probability times the consequences) could be greater for an oil tanker than for a cargo vessel. This is not reflected directly in risk index calculations.

CONCLUSIVE REMARKS

In this study, we have used publicly available data on ice and vessel traffic to investigate whether the vessels in the Kara Sea region remain within their operational limitations in ice. The speeds and positions of the vessels in the Kara Sea region were recorded from January–April from 2017 to 2019 from the Northern Sea Route administration website. For each vessel, except for the icebreakers, the risk index based on POLARIS was calculated using the open-access ice information that was provided by the Arctic and Antarctic Research Institute in Russia. The variation of risk index was analyzed with respect to various parameters such as the ice-class of the vessel, the reported operating speed of the vessel, and the built year of the vessel. Based on the presented results, the following conclusions can be made:

- In the southwestern part of the Kara Sea, where vessel traffic is the highest, the risk index values never go below zero for ‘Arc 7’ and for the publicly reported ice conditions.
- There is an increase in the vessel speeds with increasing risk index.
- The operational speed limits suggested by IMO for ‘Elevated operational risk’ zone, seems to be only useful for lower ice-classes as the vessels with higher ice-class (‘Arc 7’) never operate in the considered region with elevated risk for all the collected navigational records and ice conditions.

POLARIS takes into account the complex interaction of ice concentration, ice type, and ice-class of the vessel to come up with a comprehensive measure of the operational limit while being simple enough to be calculated by anyone with a reasonable knowledge of ice charts. It provides enough flexibility to ensure that it can be used by all ship types in most operational scenarios. However, it does not explicitly consider any ship specific factors apart from the ice-class. The results of this study suggest a connection between the risk index value and the ship type as well as its dead weight, and further development of POLARIS could focus on refining the RIVs for ship-specific characteristics.

The results of this study are limited by the fidelity and frequency of the publicly available navigational information and ice data. In the future, similar analyses will be conducted using Automatic Information Systems (AIS) data and reports of the local ice conditions from vessels. Furthermore, the analysis methods presented in this study can be extended to other Arctic regions.

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APPENDIX

TABLE 4: ICE-CLASS EQUIVALENCE BASED ON TABLE 18 FROM [16]

Ice-class - RMRS	Ice-class - IACS
Arc 9	PC1
Arc 8	PC2
Arc 7	PC3
Arc 6	PC4
Arc 5	PC6
Arc 4	PC7

*The ice classes PC5 and PC6 both correspond to ‘Arc 5’, now, that we have to transition from RMRS classes to IACS classes, i.e., Arc – PC, ‘Arc 5’ could be either ‘PC 5’ or ‘PC 6’, but we chose to keep ‘Arc 5’ = ‘PC6’ to be on the conservative side.

Determination of Escorted operations

To find out which vessels are escorted by an icebreaker, the icebreakers in the vicinity of the vessel were analyzed. Let us say for a vessel X; if there is an icebreaker within a fixed distance (equal to d) of the vessel X and has a direction which is close to the direction of the vessel, then it was assumed that the vessel X was being assisted by that icebreaker. For e.g., in Fig. 13, case - 1, the (icebreaker) IB 1 has $\alpha 1 < 100$ degrees and is within a radius d of the vessel as hence the vessel is following IB1, whereas IB 2 has $\alpha 2 > 100$ degrees (Assuming that we have a difference threshold for $\alpha = 100$ deg), and hence vessel is not following IB 2. For case 2, since there is no IB in the vicinity of the vessel (within a distance d), the vessel is assumed to be in a non-escorted operation. Various values of d and α were tried out. This way of analyzing the assistance of the icebreaker was based on the fact that the reported values for the position were at a fixed time for all the vessels.

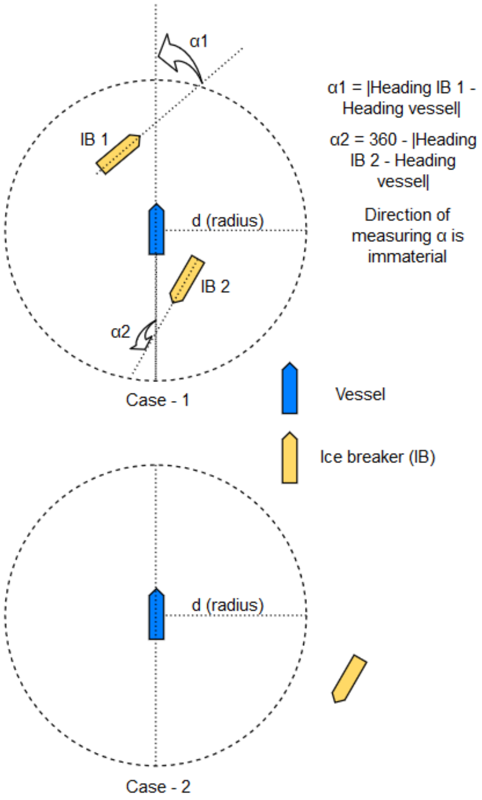

FIGURE 13: SCHEMATIC DIAGRAM - DETERMINATION OF ESCORTED OPERATIONS (IB – Icebreaker)