China-Russia collaboration in shipping and marine engineering as one of the key factors of secure navigation along the NSR

Gao Tianming & Vasilii Erokhin

Currently, about 80% of globally traded cargo is carried by maritime transport, including increasingly along the routes in the North, which have not been secured previously due to heavy ice conditions and extreme temperatures. In recent decades, however, climate change has been affecting the reduction of ice coverage in the Arctic Ocean and thus providing opportunities for the development of commercial navigation. Many countries are becoming increasingly interested in the exploration of opening maritime routes. With the incorporation of the Polar Silk Road into the Belt and Road Initiative (BRI) network, China has rapidly emerged as the major non-Arctic actor in the region. Contributing to the development of commercial shipping in the North, China aims at the diversification of its trade routes and linking itself with Arctic countries by a network of maritime corridors. Implementation of the Polar Silk Road initiative requires first and foremost improvement of navigation safety and passability of northern routes, primarily through the Northern Sea Route (NSR). The existing network of operable routes along the Russian coastline of the Arctic Ocean allows commercial shipping during summer and autumn only. Due to the prevailing shallow depths, the operation of icebreakers is limited. Extension of the secured navigation window is hindered by the lack of icebreaking and supporting fleet and underdeveloped navigational infrastructure in Russia. In this paper, the authors discuss how China may collaborate with Russia to ensure the development of secure navigable routes by determining the areas suitable for the development of deep-water shipping and allowing the operation of large-tonnage tankers and icebreakers. The paper presents an analysis of water areas in the NSR suitable for the development of deep-water routes and operation of large-tonnage vessels with high categories of ice reinforcements. The authors provide an overview of the current condition of the shipbuilding industry in Russia in relation to the construction of vessels and marine equipment for the Arctic in such segments as icebreaking, transport, port, and dredging fleet. In the conclusion, the existing obstacles and opportunities for China and Russia are summarized in light of the establishment of more secure and stable navigation along the NSR.

Introduction

During the past fifteen years, there has been a substantial decrease in ice coverage in the Arctic Ocean during the summer-autumn navigation window (by 14-20% of total ice cover, on average). In winter, the ice situation has become lighter (Dumanskaya, 2016). Due to warming, the ice-free water area in the summer has increased. It allows for extending the navigation window and expanding the zones of potential transport routes which have been previously covered by ice.

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By 2050, owing to climate change, the character of navigation in the Arctic Ocean will undergo a fundamental change. The temperature increase affects the processes of formation, growth, and movement of ice. Associated processes have been emerging and influencing the conditions of ice cover in a non-linear manner. Ice melting increases the area of open water which has a lower solar reflectance coefficient compared to ice. As a consequence, absorption of the sun's warmth in the zones of open water increases and the temperature of surface water rises which results in the cyclical process of ice melting (Parkinson, 2014). Such an effect is observed in both seasonal and long-term perspectives: warming up of surface layers of seawater causes a delay of ice freezing in autumn and thus shortens the period of ice growth. As a result, next year, sea ice is thinner, spongy, and more exposed to earlier fracture. According to Mokhov and Khon (2015), by 2025, with less than 15% of water area covered by ice during summer, the average duration of the navigation period may increase up to 3-4 months; by 2050 up to 4-5 months; and by 2100 to 5.5 months.

The melting of ice in the Arctic has opened up opportunities for transporting through the northern passages. Among non-Arctic countries, the one which is concerned the most about the effects of climate change and ice melting on navigation is China. China has formalized its involvement in the development and exploration of the Arctic by its inclusion of northern maritime routes into a network of blue maritime passages of the Belt and Road Initiative (BRI) (Zhang, 2018). A fundamental part of the future Polar Silk Road is the Northern Sea Route (NSR) which runs along Russia's Arctic coast and provides easier access for cross-continental shipping in polar waters. By potential integration of the NSR into the BRI economic and transport corridors, China is attempting to take an active role in the development of the northern transport routes and is becoming more comfortable with being forthcoming about its interests in Arctic shipping and engineering rather than solely emphasizing science and climate change (Bennett, 2017; Erokhin & Gao, 2018).

The development of stable and secure navigation along the NSR is also one of Russia's core interests in the Arctic (Zysk, 2010). The persistence of risk and uncertainty during sailing along the NSR includes the scarcity of port facilities and navigation aids, the inaccuracy of nautical charts, and isolation (Lasserre, 2018). Among the priorities in the sphere of transportation along the NSR are the construction of new icebreakers and support vessels, development of coastal infrastructure for sustainable all-year-round cargo shipping, and the establishment of a system for monitoring the safety of navigation and transport flow management in the areas of intense traffic (Østreng, 2010). To ensure secure navigation and meet the requirements of increased economic activity along the NSR, Russia recognizes the need to modernize its Arctic fleet and therefore supports China's growing involvement in shipping along the NSR. In its turn, China is willing to assist Russia in the development of the NSR by the modernization of the fleet and provision of advanced marine engineering technologies.

From the Chinese side, there have been many studies related to China's emerging activities in the Arctic. Most of them have addressed the growing interests of China in the Arctic in various bilateral and multilateral formats and thus examined the nature of China's interests and motivations in wanting to maintain its involvement and presence in the region (Li, 2009; Hong, 2018; Zhang, 2018; Gao, 2018). Many scholars like, for example, Sun (2014), Liu (2017), Hong (2018), Xiao (2012), Guo and Guan (2009), Li and Tian (2009), and Wang and Shou (2013) advocated the idea that maritime routes in the Arctic had a strategic importance for China and would generate strong traffic due to a shorter distance and lower transportation costs. However, while discussing China's interests in potential Arctic routes, no critical analysis of the feasibility or security of navigation along such routes has been considered (Huang et al, 2015), except by Shyu and Ding (2016) and Li et al (2018), who demonstrated that navigation safety and navigation information were the most important aspects affecting the building of Arctic shipping routes for China.

There is a branch of studies which underline the need to assess the navigability and feasibility of Arctic shipping and therefore focus on navigation conditions and commercial features, as well as examine the necessary conditions and requirements for trans-Arctic shipping routes to be viable (Xu, 2013; Huang et al, 2015; Meng et al, 2017; Zhang et al, 2013, Tillman et al, 2018). Mao et al (2011), Zhang et al (2006), Liu et al (2016), Kelmelis (2011), and Hong (2012) studied the effects of climate change on the security of navigation in polar waters and China's maritime transport. Chinese publications, however, barely tackle the issue with an assessment of difficulties linked with Arctic shipping, infrastructure development, and engineering, leaving all those technical issues at the mercy of collaboration with Arctic countries. Specifically, since the early 2010s, China has been reportedly interested in collaboration with Russia on all those "technical" issues, but few studies have investigated the possible convergence of Chinese initiatives with Russia's current needs in the NSR, specifically those related to practical issues of infrastructure development, shipping, navigation, and marine technologies.

This study attempts to add to the discussion of the prospective directions of China-Russia collaboration in the spheres of shipbuilding and marine engineering to ensure the development of secure navigable routes in polar waters. In section 1, the authors present the major navigable paths in the Russian sector of the Arctic which may be used for transit shipping and discusses the major threats and risks to secure navigation along the high latitude and littoral routes in the NSR. The authors summarize safety requirements to navigation on the following parameters: (1) type of a vessel; (2) ice navigation mode; (3) parts of the NSR; (4) navigation window. In Section 2, the authors discuss how China's vision of bilateral and multilateral cooperation in the Arctic matches Russia's current interests and needs in shipping and engineering. Section 3 includes an overview of the current conditions of Russia's shipbuilding industry in relation to the construction of vessels and marine equipment for the Arctic in such segments as icebreaking, transport, port, and dredging fleet. The authors determine the areas suitable for the development of deep-water shipping and the operation of large-tonnage tankers and icebreakers. In the conclusion, the existing technological, engineering, and economic obstacles and opportunities for the two countries are summarized in light of the establishment of more secure and stable navigation along the NSR.

Safety of navigation along the NSR

The NSR passes along the northern coast of Russia in the Arctic Ocean (Barents Sea, Kara Sea, East Siberian Sea, Chukchi Sea, and Bering Sea). It connects seaports in the European and far eastern parts of Russia and navigable rivers of Siberia into an integrated transport network. The length of the route varies from 2,700 nautical miles (high latitude paths) to 3,500 nautical miles (littoral paths) depending on the particular route, ice situation, weather conditions, and other factors. In the west, the NSR starts in the Kara Gate, in the north – in Zhelaniya Cape in the Kara Sea. The distance between Murmansk and the Kara Gate is 528 nautical miles and between Murmansk and Zhelaniya Cape it is 758 nautical miles. In the east, the NSR is accessed through Dezhnev Strait. The distance between Murmansk and Petropavlovsk-Kamchatsky is 1,037 nautical miles. The lengths of the littoral paths are 4,640km (Kara Sea), 5,590km (Laptev Sea), 1,745km (East Siberian Sea), 1,890 km (Chukchi Sea), and 1,450km (straits along the NSR).

In the context of navigation, the NSR may be divided into three climatic zones: Atlantic, Siberian, and Pacific. The Atlantic zone includes the Barents Sea, western part of the Kara Sea, and a part of the water area of the Arctic Ocean northward of those seas. There are frequent storms in winter and fog and rainfall in summer. In the Barents Sea, the mean temperature in summer does not exceed 7°C, while in winter falls down to -20°C. Wave height is 7m. At the coast of the Kara Sea, mean temperature in summer does not exceed 6°C, and in winter it falls down to -28°C.

The Siberian zone includes the eastern part of the Kara Sea, the Laptev Sea, and the western part of the East-Siberian Sea. In winter, the temperature is lower compared to that in other zones, while in summer, it is higher along the coast. In the northern parts of the zone, it is cold even in summer. In the northern part of the Laptev Sea, the mean temperature in July is 1°C, while in winter, it reaches -34°C.

Pacific zone includes the eastern part of the East-Siberian Sea and the Chukchi Sea. In winter, the climate of the zone is affected by the Pacific Ocean, which results in a higher mean temperature, stronger winds, and more precipitation compared to other zones. The average monthly temperature in the East Siberian Sea is +7°C in summer and -33°C in winter. In summer, there are frequent storms and heavy fogs because of the substantial oscillation of air temperature (Erokhin et al, 2018).

The depths vary substantially. Littoral routes pass through the shallow water areas of the Arctic seas. In terms of the water depth, the most insecure areas are Severnaya Zemlya Archipelago, Novosibirsk Islands, Dmitry Laptev Strait, Vilkitski Strait, and Skokalsky Strait.

Figure 1. Straits in high latitude and littoral paths of the NSR
Source: ABS (2016)

Depending on the particular path, the route passes through one or more straits with the lowest depths in Dmitry Laptev Strait (8-9m), Yugorsky Shar Strait (13m), and Sannikov Strait (13-15m)

(Figure 1). Seaports along the NSR are predominantly shallow-water with the limiting depths of 1.6m in Amderma, 12.0 m in the seaports in the Gulf of Ob, 8.0m in Dikson, 11.8m in Dudinka, 4.2m in Khatanga, 3.9m in Tiksi, and 9.0m in Pevek.

There is no universal optimal way to pass the NSR but rather a scheme of indicative optimal shipping routes (Figure 2).

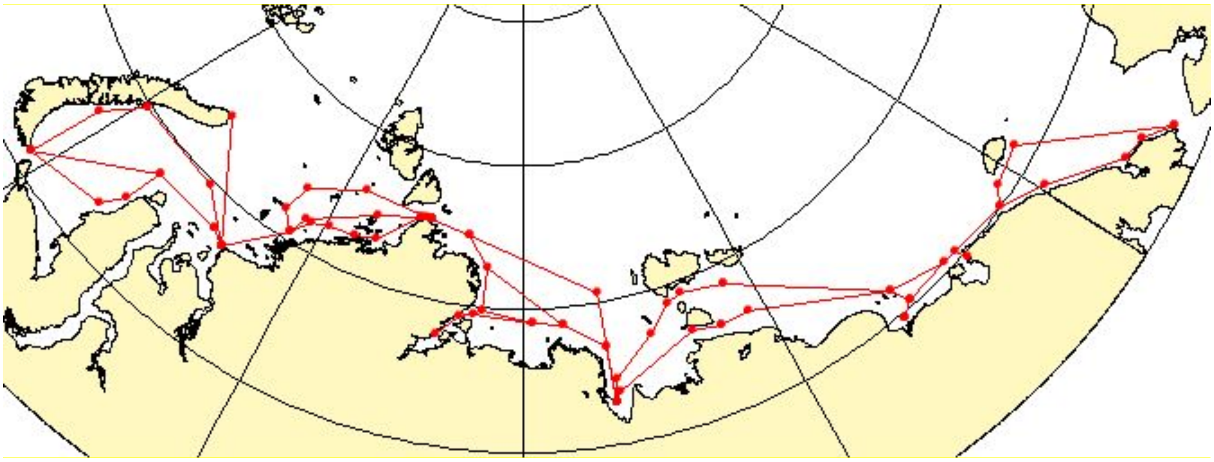

Figure 2. The scheme of indicative optimal shipping routes in the NSR
Source: Arctic and Antarctic Research Institute (n.d.)

For transit vessels, the optimal path usually varies depending on the season (Figure 3). In October-May, shore ice spreads along the coastline of the Arctic Ocean and accumulates in the main navigation straits (except the Kara Gate, Long Strait, and Bering Strait). Most commonly, an optimal path passes through coastal flow leads which are formed alongside shore ice under the influence of atmospheric circulation and under-ice currents.

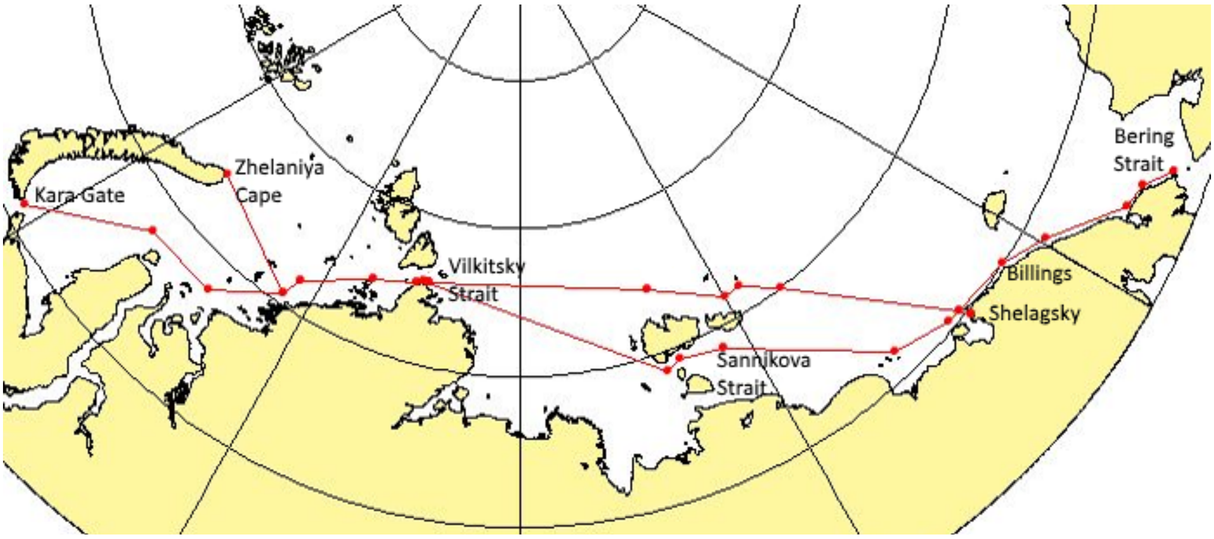

Figure 3. The scheme of transit paths in the NSR
Source: Arctic and Antarctic Research Institute (n.d.)

According to the Arctic and Antarctic Research Institute (n.d.), during the entire period of regular ice monitoring, there have been registered singular events (5-10% frequency) when the optimal path passed from Zhelaniya Cape directly to West Coastal Flow in Severnaya Zemlya Archipelago, then through Vilkitsky Strait to West Novosibirsk Coastal Flow, and then to the north of Wrangel Island. In June-September, during summer navigation, the location of the most optimal path for the entire NSR route is determined by the condition of shore ice (before its fracturing) and the position of ice massifs.

In the most western part of the NSR, in June and July, the optimal transit route usually passes through the Kara Gate and Yugorsky Shar straits, while in September and October it passes around Zhelaniya Cape (55-80% frequency). In August, the usage of the two routes is equally probable. Further to the east, the most optimal route passes through Vilkitsky Strait (95-100% frequency). In the Laptev Sea and in the realm of Novosibirsk Islands, the location of the optimal route varies seasonally. Prior to the period of intensive ice erosion in Taimyr ice massif, the route passes alongside the southern border of the massif (55-90% frequency), while in August-October it passes through the massif (65-90% frequency). In July, the usage of the two routes is equally probable. In the water area around Novosibirsk Islands, prior the fracture of shore ice (June and July), the optimal route passes northward of the islands, while in August-October it passes through Sannikov Strait (50-85% frequency). In the eastern part of the NSR, transit passage of the East-Siberian Sea and the Chukchi Sea most commonly passes along the border of shore ice, while after the shore ice fracture it passes along the coast of the Chukchi Peninsula (65-90% frequency).

Due to the low sea depth in the straits, littoral paths are only accessible for low-tonnage vessels. Large-capacity vessels (up to 15m draw) have to use high latitude routes. The variants of high latitude routes for transit navigation were approved in 2009-2010 with due account of the length of the route segments, limiting depths, passability for the large-capacity vessels, and ice conditions (Figure 4).

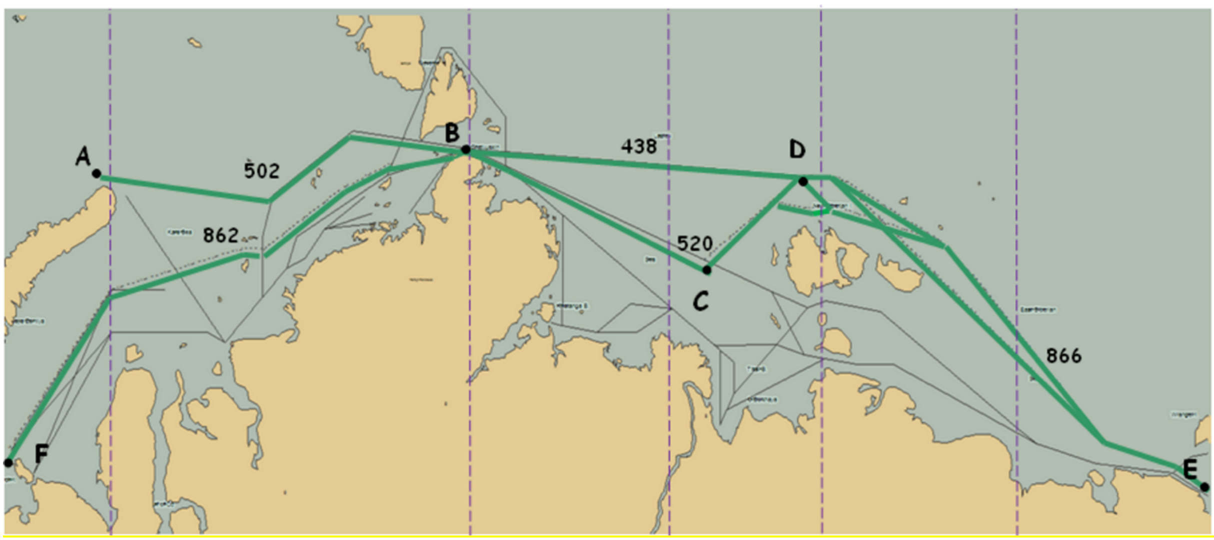

Figure 4. High latitude paths in the NSR
Source: Afonin et al (2019)

The A-B-C-D-E route passes from Zhelaniya Cape to Dezhnev Cape. The A-B section limits the part of the route in the Kara Sea, sections B-C and B-D in the Laptev Sea, and D-E section in the East Siberian Sea. In the Chukchi Sea, the route continues from E point to Dezhnev Strait. The total length of the A-B-C-D-E route is 2,200 nautical miles. The A-B-D-E route is shorter by 100 nautical miles. The B-D section is used in case of the deviation of ice cover front to the north. When the ice situation is easier, navigation is carried out along the conventional route through C point. The F-B-C-D-E route passes from the Kara Gate to Dezhnev Cape. The F-B section limits the part of the route in the Kara Sea, sections B-C and B-D in the Laptev Sea, and the D-E section in the East Siberian Sea. The total length of the route from the Kara Gate to Dezhnev Cape is 2,500 nautical miles.

The NSR is used seasonally during the summer navigation window (typically, July-November) and winter navigation window (the remaining part of the year). During the summer navigation window, the positioning of particular paths is determined by the location of ice massifs, distribution and characteristics of floating ice, and ice-free water areas. In winter and spring, when the coast and the islands are blocked by ice, the positioning of the paths depends on the ice situation and the capacities of icebreaker assistance.

After November, all the seas along the NSR (except the southern part of the Chukchi Sea) are covered by ice. When the ice situation is heavy, the seas are covered by pack ice even in summer. Commonly, ice melting begins in mid-June and ice freezing begins in mid-September (northern parts of the Kara Sea, the Chukchi Sea, and the Laptev Sea). By the end of October, ice sheet thickness typically reaches 25-30cm and by December it reaches 70-90cm. Ice sheet thickness reaches its maximum (140-210cm) by May prior to the opening of the navigation window. In the northern parts of the transit zone, multi-year ice may exceed 3m.

In winter, the water areas along the NSR are affected by anticyclonic circulation of air masses. In summer, atmosphere circulation is opposite to that in winter, but its influence on climate is not that big. Navigation directly depends on the direction, speed, and continuity of winds and currents. Along the entire NSR, the currents are predominantly cold. There are relatively warm currents in the western parts of the NSR (Barents Sea) and in the far east at the exit from the Chukchi Sea to the Pacific Ocean.

Due to the unstable ice situation and rapid transfer of ice by the currents and winds, navigation along the NSR requires the usage of not only icebreaker assistance but also transport and cargo vessels of Arctic class. Under icebreaker assistance, the average speed of a vessel is 13-14 knots. A nuclear icebreaker forms a channel in the ice appropriate for a passage of a cargo vessel of 75,000 tons deadweight. Two icebreakers are able to lead large-capacity vessels of up to 150,000 tons deadweight (similar to the tankers which are projected to be employed for the transportation of liquefied natural gas from the Yamal LNG site). Water depths along the NSR allow routing the vessels of 12.7m draw through Sannikov Strait and the routing of vessels of over 18.0m draw northward of Novosibirsk Islands. The Kara Gate located between Vaigach Island and Novaya Zemlya Island is the hardest for navigation because of the ice exchange with the Kara Sea. There is predominantly first-year pack ice with thickness that reaches 0.12-0.14m by end of the winter. Ice fields in the Kara Gate are frequently compressed and hummocking which tremendously aggravates icebreaking. In that region, ice flows periodically drift with high speed which may disable even nuclear icebreakers (Mayorova et al, 2013).

The most serious obstacles to secure navigation are (1) Novozemelsky, (2) North Kara, (3) Severozemelsky, (4) Taimyr, (5) Yansky, (6) Novosibirsk, and (7) Ayonsky ice massifs (see Figure 5).

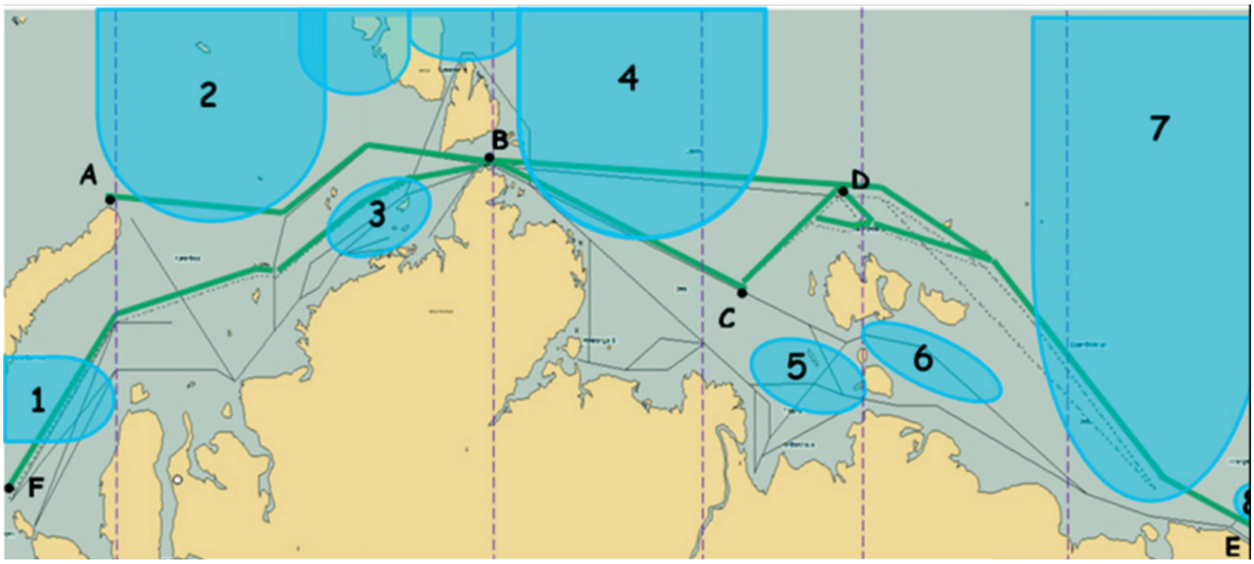

Figure 5. Littoral and high latitude paths in the NSR and the location of major ice massifs
Source: Afonin and Tezikov (2017)

The apparent alleviation of the ice situation in the Arctic should not be categorically associated with the improvement of navigation conditions. Dynamic forces which affect the ice, as well as icebergs detached from an ice shelf, pose severe risks for navigation. Thus, in some of the parts of the Arctic Ocean, deformed first-year ice may reach 5-7m in thickness (Landy et al, 2016), which aggravates or almost blocks the passage of sea vessels, specifically in narrow straits where the currents press the ice and in such a way increase its thickness. Drifting ice is another danger to navigation. Because of the decreasing thickness of ice cover and the area of the ice shelf, ice becomes more mobile, drift velocity increases, and the behavior of ice becomes more dynamic and less predictable. Owing to the changes in climate and sea ice regime in the Arctic, wind and cyclonic regimes in the atmosphere, as well as sea disturbance and icebergs' activity in the water area of the Arctic Ocean will also change. Specifically, wavelength will grow and surface winds will become stronger. The increase in sea disturbance will cause the emergence of coastal erosion.

From the beginning of monitoring in the 1980s by the end of 1997, annual average reduction of ice cover was 26,000±3,600 km^2, or 2.1% per decade (compared to the period average). From 1998 to 2006, the tendency changed and the annual average reduction reached 114,800±8,800 km^2, or increased up to 10% per decade. During 2007-2017, a variability of sea ice in the Arctic was observed while the annual average reduction of ice cover peaked up to 40,200 km^2 (Shalina & Bobylev, 2017). From 1979-2016, September minimums of ice extent decreased by 87.2 km^2, or 13.3%, per decade (National Snow and Ice Data Center, 2016). The record minimum in September 2012 was 3.41 million km^2, or only 54% of the average minimum from 1981-2010 (Liu, Q. et al., 2016). Apart from the reduction of ice cover, there has been registered growth of the share of thin and young ice in the overall structure of the ice cover.

Microwave satellite monitoring allows for the assessment of change in the duration of the ice season. This parameter has been changing in various degrees in different parts of the Arctic, but in general, it has decreased in most of the Arctic Ocean. The area where the duration of ice season decreased at the rate of minimum five days per decade was 12.4 million km^2. The area where the duration of ice season increased at a similar rate was 1.1 million km^2. On the one hand, the basic parameters of ice cover (coverage of the central part of the Arctic Ocean by ice during the entire year and ice-free water area to the north-east of Scandinavia) persist. On the other hand, substantial transformations have been observed. Specifically, the area of year-round distribution of ice has decreased, the part of the Barents Sea and the Sea of Okhotsk has become free of ice during the entire year, while the ice season in the Russian Arctic has extended. In most of the Arctic seas, the duration of the ice season has been decreasing at a rate above five days per decade. In the north-east part of the Barents Sea, the rate of decrease was over 60 days per decade (Parkinson, 2014).

The gradual decrease of ice which undergoes summer melting has determined the change in the percentage ratio of first-year and multiyear ice. Currently, first-year ice dominates in the Arctic with up to 78% of the ice cover. The area of ice older than five years decreased from 16% in the mid-1980s down to 1.2% in 2016-2017. First-year ice is thinner than multi-year ice, which is why it melts faster. In spring, ice melting starts earlier and in autumn, ice freezing starts later than several decades ago. The change in ice dynamics in the Arctic Ocean is also associated with the thinning of ice. Thinner ice is more mobile and more vulnerable due to destruction under the influence of winds and waves. The speed of ice drift in the Arctic has grown substantially after the 2000s.

According to Friedlander (2018), during the past decade, the rate of loss of ice in the Arctic has doubled in comparison with the previous 60 years. Ice massifs have been decreasing in both area and height. From 1953 until 2020, the average annual rate of melting of ice massifs was 18 cm. From 2011 until 2015, the rate increased up to 32 per year. The ice melts irregularly – in northern Canada, the massifs are decreasing faster than in the Russian Arctic. Because of warming, a displacement of ice fields by open water may happen (Lind et al, 2018). In the eastern sector of the Russian Arctic, meteorological and ice conditions have deteriorated compared to those in 2013-2017.

In hard ice conditions in littoral areas, the vessels are forced to deviate from the recommended paths in both non-escorted voyages and under icebreaker assistance shipping. During winter navigation, vessel speed is limited by a speed of the escorting icebreaker. In summer, a vessel is able to sail independently in ice-free water areas with required speed, but it has to have certain ice class to pass particular paths (Table 1).

To operate in the Kara Sea during summer and autumn, a vessel must be at least of Arc5 class. Arc4 class vessels are allowed independent navigation under easy and moderate ice conditions. During winter and spring – Arc8. Independent operation of Arc5 and Arc6 class vessels are permitted under easy ice conditions only and Arc7 is permitted under easy and moderate ice conditions.

In the Laptev Sea during summer and autumn – at least Arc6. Arc5 class vessels are allowed independent navigation under moderate ice conditions. During winter and spring – Arc9. Independent operation of Arc6 and Arc7 class vessels are permitted under easy ice conditions only and Arc8 is permitted under easy and moderate ice conditions.

In the East-Siberian Sea during summer and autumn you need at least Arc6. Arc4 class vessels are allowed independent navigation under easy ice conditions and Arc 5 class vessels are permitted under moderate ice conditions. During winter and spring you need Arc8. Independent operation of Arc6 and Arc7 class vessels is permitted under easy ice conditions only.

Table 1. Safety requirements to the vessels in the NSR

<table>
<tr><th rowspan="3">Ice class</th><th rowspan="3">Operation mode</th><th colspan="4">Kara Sea</th><th colspan="4">Laptev Sea</th><th colspan="4">East Siberian Sea</th><th colspan="2" rowspan="2">Chukchi Sea</th></tr>
<tr><th colspan="2">Summer</th><th colspan="2">Winter</th><th colspan="2">Summer</th><th colspan="2">Winter</th><th colspan="2">Summer</th><th colspan="2">Winter</th></tr>
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<tr><td rowspan="2">N/S</td><td>No assistance</td><td colspan="14">-</td></tr>
<tr><td>Icebreaker assistance</td><td colspan="2" rowspan="4">L</td><td colspan="2" rowspan="7">-</td><td colspan="2" rowspan="8">L</td><td colspan="2" rowspan="7">-</td><td colspan="2" rowspan="8">L</td><td colspan="2" rowspan="7">-</td><td rowspan="6">L</td><td rowspan="7">-</td></tr>
<tr><td rowspan="2">Ice1</td><td>No assistance</td></tr>
<tr><td>Icebreaker assistance</td></tr>
<tr><td rowspan="2">Ice2</td><td>No assistance</td></tr>
<tr><td>Icebreaker assistance</td><td colspan="2">M/L</td></tr>
<tr><td rowspan="2">Ice3</td><td>No assistance</td><td colspan="2">L</td></tr>
<tr><td>Icebreaker assistance</td><td colspan="2">H/M/L</td><td rowspan="4">M/L</td></tr>
<tr><td rowspan="2">Arc4</td><td>No assistance</td><td colspan="2">M/L</td><td colspan="2" rowspan="5">L</td><td colspan="2" rowspan="7">L</td><td colspan="2" rowspan="7">L</td><td rowspan="6">L</td></tr>
<tr><td>Icebreaker assistance</td><td colspan="2" rowspan="5">H/M/L</td><td colspan="2" rowspan="2">M/L</td><td colspan="2" rowspan="2">M/L</td></tr>
<tr><td rowspan="2">Arc5</td><td>No assistance</td></tr>
<tr><td>Icebreaker assistance</td><td colspan="2" rowspan="5">H/M/L</td><td colspan="2" rowspan="7">H/M/L</td><td rowspan="5">H/M/L</td></tr>
<tr><td rowspan="2">Arc6</td><td>No assistance</td></tr>
<tr><td>Icebreaker assistance</td><td colspan="2">M/L</td></tr>
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<tr><td>Icebreaker assistance</td><td colspan="2">H/M/L</td><td colspan="2">H/M/L</td></tr>
<tr><td rowspan="2">Arc9</td><td>No assistance</td><td colspan="14" rowspan="2">H/M/L</td></tr>
<tr><td>Icebreaker assistance</td></tr>
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Note: N/S – non-strengthened vessel; SW – south-west; NE – north-east; H – hard ice conditions; M – moderate ice conditions; L – light ice conditions
Source: Authors' development based on ABS (2016)

In the Chukchi Sea during summer and autumn you need at least Arc6. Arc4 class vessels are allowed independent navigation under easy or moderate ice conditions. During winter and spring you need Arc8. Independent operation of Arc6 class vessels is permitted under easy ice condition only and Arc7 class vessels are permitted under easy or moderate ice conditions.

During winter navigation (January-June) and in the period from November 16 until December 31, operation of conventional non-strengthened vessels along the NSR is not allowed. Non-strengthened oil and gas tankers of over 10,000 tons displacement are permitted to sail in ice-free water areas under icebreaker assistance in the period from July to November 15.

The NSR and Polar Silk Road: China's vision of bilateral and multilateral cooperation in Arctic shipping and engineering

So far, the NSR has been first and foremost a transportation route for Russia's domestic shipments. The passage has been used by major Russian companies, namely, Gazprom, Lukoil, and Rosneft, among others, for the transportation of extracted oil and gas, as well as machinery and people between their production sites in the Russian Arctic (Erokhin & Gao, 2018).

By the Federal Law of the Russian Federation "About Internal Sea Waters, Territorial Sea, and Contiguous Zone of the Russian Federation" (Government of the Russian Federation, 1998), the NSR is recognized as a historical national transport route of Russia in the Arctic. Russia's recent ambitious plan declared by President Putin is to increase the volume of cargo transported via the NSR up to 80 million tons by 2024. However, due to technological, economic, and political reasons, Russia is not able to increase the constriction of ships and marine equipment to such an extent as to support the growing volume of cargo transportation in the Arctic. Here is an opportunity for China to contribute its technologies and investment and to benefit from collaboration with Russia in this sphere.

In January 2018, China issued its Arctic policy and in such a way articulated the perception of its role in the region. According to Liu (2016), China wants to contribute to shaping Arctic governance and believes that the changing environment and resources of the Arctic have a direct impact on China's climate, environment, agriculture, shipping, and trade as well as its social and economic development. China's position is that the management of Arctic shipping routes should be conducted in accordance with international law and that the freedom of navigation enjoyed by all countries in accordance with the law and their rights to use the Arctic shipping routes should be ensured. China also wants to coordinate development strategies with Nordic countries and encourage joint efforts to build secure navigable routes in the Arctic (Gao, 2019).

China's perspective vision of its role in the Arctic is not only about opening and securing new trade routes. The overarching goal is to facilitate Asia-Europe connectivity and to bridge the gap between traditional industries in the Arctic and China's market. Within such a vision, China's BRI network was supplemented by its Polar Silk Road branch in an attempt to expand the existing bilateral formats to a multilateral cooperation with all stakeholders concerned. The extension of the BRI to the Arctic means that China wants to work with Arctic and non-Arctic countries to establish the Polar Silk Road through the development of shipping routes. In the format of the Polar Silk Road, China expects its involvement in the navigation of cargo vessels in polar waters, as well as in marine and ice engineering to pave the way for Chinese commercial, exploration, transport, and logistics operations in the Arctic. China also attaches great importance to navigation security in the prospect maritime routes of the Polar Silk Road, particularly along the NSR in the seas of the Arctic Ocean controlled by Russia.

Despite the fact that shipping was mentioned first among the economic sectors of interest in China's Arctic policy, collaboration with Russia in shipping and engineering in the NSR was not specifically outlined. From the Chinese perspective, it may be seen as a reluctance to view the Polar Silk Road as an appendix to Russia's plans in the Arctic (Moe & Stokke, 2019). There is, though, a Russian perspective as well since Russia seems rather reluctant to support a possible emergence of China's role in the Arctic (Ananyeva, 2019). In 2015, on the wave of Russia's "turn to the East" after the imposition of Western sanctions against Russia, the Russian officials explicitly linked the NSR to the BRI and proposed the creation of a "Cold Silk Road" or "Ice Silk Road" (Lenta.ru, 2015; RIA News, 2015; Xinhua, 2017). Since 2016-2017, however, Russian rhetoric has been toned down and the terms "Cold Silk Road" and "Ice Silk Road" have been dropped out of speeches while the use of "Polar Silk Road", the term officially recognized by China, has been avoided by Russia in official documents, even those concluded bilaterally with China. During the Belt and Road Summit in April 2019, President Putin announced the plan to connect Arctic shipping through the NSR to the BRI but still did not use the "Polar Silk Road" term (Ehret, 2019). He emphasized that Russia gave major attention to the development of the NSR and connection between the NSR and the BRI, not substitution.

Russia claims to control the navigation and resources along the NSR and China's Arctic policy actually supports persevering with the existing rules of the Law of the Sea (Górski, 2019). Specifically, China stipulates that (1) the management of the Arctic shipping routes should be conducted in accordance with treaties including the UNCLOS and general international law and that the freedom of navigation enjoyed by all countries in accordance with the law and their rights to use the Arctic shipping routes should be ensured; (2) China hopes to work with all parties to build the Polar Silk Road through developing the Arctic shipping routes; (3) China respects the sovereign rights of Arctic States over oil, gas and mineral resources in the areas subject to their jurisdiction in accordance with international law, and respects the interests and concerns of residents in the region (State Council of the People's Republic of China, 2018).

Nevertheless, in defiance of the formal compliance of China's approach with Russia's stance on the status of the NSR, continuing expressions of interest in Arctic shipping from Chinese government and major actors, as well as declarations of and statements on various formats of collaboration announced during big forums (the most recent ones made by Russian and Chinese authorities at the International Arctic Forum in Moscow on April 2019 and the Eastern Economic Forum in Vladivostok on September 2019), China's activities in the NSR have remained modest. Since the early 2010s, when the NSR was actually opened and promoted by Russian authorities for international transit sailings, China has increasingly encouraged its enterprises to participate in the infrastructure construction in the Arctic and declared its interest in commercial trial voyages along the NSR in accordance with the law to pave the way for regular commercial operations (Hong, 2018). In 2015, three years before the articulation of China's Arctic policy, COSCO announced that "the group was actively studying the feasibility of operating regular services on the northern route" (Paris & Chiu, 2015). But since that time, few vessels under Chinese flag have transited the whole NSR (one in 2015, two in 2016, five in 2017), while the annual number of full NSR transits never exceeded fifteen.

As noted by Moe and Stokke (2019), one of the reasons for China's very modest use of the NSR for transit is weak development of international transit infrastructure. Aside from state-backed COSCO, most Chinese shipping companies balk at the risks of navigation in polar waters and the high investment costs required for the construction or purchase of ice-strengthened ships (Huang et al, 2015). Cost-sharing mechanisms of collaboration with Russia, the sole operator of the NSR, in shipbuilding, marine engineering, and navigation safety would appear commercially advantageous for Chinese companies to be increasingly involved in more intense shipping in the North. One of the mechanisms was actually established in 2018 with a $9.5 billion credit line from China, aimed at joint integration processes on the area of the Eurasian Economic Union and the BRI, with the NSR mentioned as a priority (Moe & Stokke, 2019). Currently, China-Russia collaboration in polar shipping and engineering is still in its embryonic stage, but Russia remains the main area of interest for China's Arctic joint investment (Blaxekjaer et al, 2018).

Towards secure shipping and navigation: Prospective areas for China and Russia to collaborate in the NSR

Russia operates a certain number of vessels that are capable of handling current traffic demands (Drewniak et al., 2018), but not the expected future increase. Most of the vessels, including icebreakers, were built in Soviet times almost three decades ago. The useful life of the four lead icebreakers expires in 2024 which, first, jeopardizes China's ambitious plans to explore trading routes in the North, and second, poses a threat to secure navigation in the NSR. For China, the lack of icebreaking and shipping capabilities is somewhat disconcerting given the attention the country pays to the promotion of the Polar Silk Road. Major cargo shipped along the NSR are liquefied natural gas, oil, petroleum products, coal, mineral fertilizers, construction materials, and industrial equipment. Types of cargo vary which requires the development of a multi-purpose fleet including icebreakers, tankers, and support vessels.

Russia's icebreaking fleet consists of 38 vessels, including nuclear-powered, diesel-electric, and diesel icebreakers. Among the nuclear-powered icebreakers, there are two icebreakers with double-reactor nuclear power facility (power capacity – 75,000 horsepower, or 55 MWT), two icebreakers with one-reactor power facility (power capacity – 50,000 horsepower), one nuclear lighter aboard container ship (power capacity – 40,000 horsepower), and five maintenance vessels. In 2015-2016, Russia launched three diesel icebreakers (power capacity – 16 MWT each). Eight icebreakers of different power capacity from 6.8 MWT up to 60 MWT are being constructed, including three nuclear-powered icebreakers: "Arctic", "Siberia", and "Ural". The construction is scheduled to be completed in 2019, 2021, and 2022. One linear diesel-electric icebreaker is under construction too but its launch has been postponed several times due to technical problems.

Both nuclear-powered icebreakers in operation and those under construction may be operated year-round in the western parts of the NSR only, in the Kara Sea and the Barents Sea. In the eastern sections of the NSR, they may be operated during summer navigation. In other seasons, their operation makes no economic sense because of the low speed in difficult ice conditions. That is why, in addition to the three nuclear-powered icebreakers which are under construction, "Rosatomflot", a Russian operator of a nuclear-powered fleet, plans to launch two universal nuclear-powered icebreakers (power capacity 60 MW), four LNG-powered icebreakers (power capacity 40 MW), and three nuclear-powered icebreakers of Leader type. There is a necessity in tug vessels of high ice classes and of different size and capacity to ensure ice routing in the frozen water areas at the seaports. Mining companies require specialized vessels and marine equipment for the exploration of the continental shelf. By 2035, they will need about 140 units of various equipment, including large-capacity transport vessels, tankers, and oil-and-gas carriers (up to 40 vessels), Aframax and Shuttle tankers (7 vessels), maintenance ships of ice and non-ice class, as well as rescue vessels. Also, there is a need for new research vessels – up to 90 by 2035, including various types of research vessels for the Russian Academy of Science, Ministry of Environment, Federal Service for Hydrometeorology and Environmental Monitoring of Russia, and Federal Agency for Fishing.

The average age of port and support vessels is 27 years, but the fleet is now under modernization, particularly in relation to tugboats. Russia's primary need in this sphere is shallow-draught and low-capacity icebreakers. Currently, to ensure ice-routing in the ports, Russia uses icebreakers produced in Finland in the 1970-1980s. A new port icebreaker is under construction to the order of Rosmorport, a Russian operator of river and seaports. Its launch is scheduled for 2021. “Atomflot”, a national operator of nuclear-powered icebreakers, ordered two ice-class tugboats (power capacity 5 MWT), two ice-strengthened tugboats (power capacity 7 MWT), and one port icebreaker (power capacity 12 MWT). “Gazproneft”, one of Russia’s leading oil and gas companies, is constructing two icebreakers for the use at the Arctic terminal of Novoportovskoe oil deposit.

Russia’s mixed river-sea fleet is decreasing, particularly bulk carriers of mixed and middle-water operation. By 2020, the number of river-sea vessels is expected to drop down to 623, by 2025 – to 276 vessels constructed before the year of 2000, or only 32% of the current number of vessels. To keep the volume of dry cargo on the current level, by 2022, Russia needs at least 130 new bulk carriers, 60 dry cargo lighters, and 20 push towboats. 28 bulk carriers of mixed river-sea type are now under construction at the Russian shipyards, including ten multipurpose bulk carriers (deadweight – 7500 tons), eight bulkers (deadweight – 8000 tons), and 18 vessels of lower capacity.

In the sphere of construction and assembling, the major needs are large-size section assembly of ships and vessels; real-size production of hull structures and elements in a unified system of fits and tolerances; usage of electro-optical computer-aided instrumentation systems; automation in shipbuilding and robotic application; 3D modelling in marine engineering; additive technologies for assembling of machinery and equipment aboard a ship; naval mechanical engineering (power installations, ship propulsors, active control units); and shipbuilding materials and coatings (highly corrosion-resistant and low-alloy steel, resistant and antifriction materials for use in saltwater).

Fifteen liquefied gas carriers for Yamal LNG are being constructed at DMSE shipyards in the Republic of Korea. Currently, Yamal LNG is served by seven gas tankers, but only one of them sails under the Russian flag. The remaining six are owned by Canadian Teekay, Greek Dynagas, and Japanese Mitsui. Three more LNG carriers will be launched in 2019, five more will be launched in 2020. However, that is not enough. Accelerated expansion of the Yamal LNG project along with the construction of new LNG facilities in the North require more gas tankers. Since January 2019, the Russian government requires that all new vessels operated by Russian companies in the Russian Arctic have to be constructed at Russian shipyards. In 2016, Russia launched a new shipyard near Vladivostok. Novatek company, the one that owns and operates Yamal LNG facilities, has already placed an order for the construction of fifteen LNG carriers to be launched in 2022, 2024, and 2025. Sovkomflot, one of the leading shipping companies in Russia, also ordered three product carrier tankers (deadweight 51,000 tons, MR type) for the carriage of petroleum products and gas condensates and two crude oil tankers of Aframax type.

In the sphere of science, technology, and engineering, prospective areas for collaboration between China and Russia include engineering projects of marine vessels and technical equipment (robotic engineering for the exploration of continental shelf, marine platforms and terminals, subsea production units and systems) and digital technologies (augmented reality technologies, 3D modeling, application of industrial robots with the use of the Internet of Things, swarm intelligence technologies for ship underwater surveys) (see Figure 6).

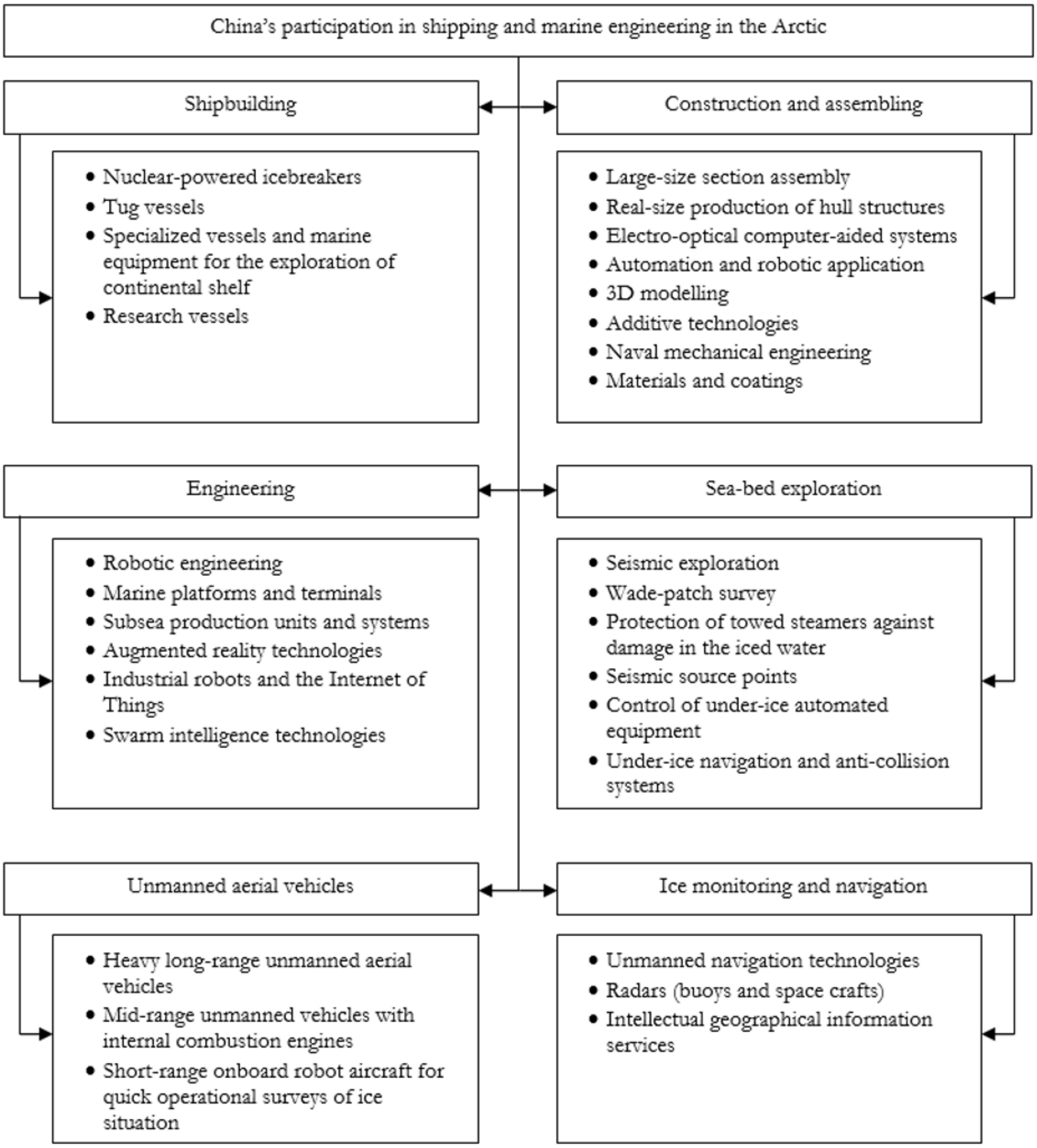

Figure 6. Prospective directions of China's participation in shipping and marine engineering in the Arctic
Source: Authors' development

Among Russia's seaports on the Arctic Ocean coast, only Dudinka can receive vessels all year-round. All ports need dredging to be able to receive modern large-capacity vessels. The dredging fleet operated in the Russian Arctic consists of only six vessels, including five self-propelled and one non-propelled dredger. Their average age is over 40 years. Because of the small number of available vessels and their obsolescence, Russia engages foreign dredgers primarily from the Netherlands and Belgium. The most demanded ones are trailing suction hopper dredgers, cutter-dredgers, and mud scows. Russia tries to localize the construction of dredgers but it lacks technologies required for the engineering and construction of trailing suction hopper dredgers.

Several shipyards are trying to start production of bucket dredgers, universal dredgers of Watermaster and Amfibex types, as well as various support equipment.

Due to the insufficient exploration of the sea bottom along the NSR and harsh climate and ice conditions, Russia needs advanced technologies and equipment for seabed exploration. This is one of the most crucial issues today in the Russian Arctic in terms of improvement of navigability of the NSR, prospecting of oil and gas deposits in the continental shelf, as well as the replacement of western companies which left joint exploration projects in the Russian Arctic because of sanctions. Russia is heavily dependent on foreign technologies and equipment for subsea exploration. One of the most problematic areas is seismic exploration. Annually, Russia needs up to 250km of towed streamers. Also, there is a need for 3D wade-patch survey, technologies for protection of towed streamers against damage in the iced water, and seismic source points to improve the accuracy of streamers' positioning. For Chinese companies, there is another prospective area of collaboration with Russia in subsea exploration in the North which is the engineering of automated unmanned equipment. Russia needs advanced technologies of handling and control of under-ice automated equipment; under-ice navigation and anti-collision systems; and equipment (multichannel high-capacity telemeters for recording of geophysical data with high sampling frequency, geophysical equipment constructed with the use of superconducting quantum interference devices).

Use of unmanned aerial vehicles for various purposes, including ice monitoring, navigation, geophysical and meteorological surveys, and delivery of cargo to remote areas is a developing sector in the Arctic. In the last decades, emergency preparedness resources in the Arctic have been significantly strengthened through the addition of available vessels and helicopters. However, the response time may still be long and the capacity limited if major incidents occur (Marchenko et al, 2018). China is one of the leading countries worldwide in terms of unmanned aerial solutions but Russia lacks such technologies. Specifically, Russia needs the technologies of engineering and construction of heavy long-range unmanned aerial vehicles which are required for the monitoring of long-distance high-latitude routes of the NSR. Also, there is a demand for mid-range unmanned vehicles with internal combustion engines and short-range onboard robot aircraft for quick operational surveys of the ice situation.

Chinese companies may also participate in the (1) development of unmanned navigation technologies which have started in Russia recently, including computer vision, automatic navigation, technical verification and data recording; (2) replacement of the US and European radar equipment on the Russian market (meteorological buoys, small low-altitude space crafts for monitoring of climate, ice conditions, and navigation); and (3) intellectual geographical information services for data analysis and visualization of navigational charts.

Conclusion

In the Russian sector of the Arctic Ocean, an increase in commercial shipping activities requires substantial investment in the development of infrastructure for cargo shipping, icebreaking assistance, safer navigation and rescue, and the creation of new materials and technologies to construct enforced vessels that are able to operate in polar waters. For China, an acceleration of collaboration with Russia in the spheres of Arctic shipbuilding and marine engineering to cover the current gap in icebreakers' assistance and navigation and support services is clearly a high priority. Both countries need each other to clear the existing economic, technological, and even climate thresholds in the way of potential convergence of the NSR and Polar Silk Road initiative and the establishment of secure navigable maritime routes in the North. Meanwhile, China's activities in the NSR need to be well balanced with Russia's interests in the region, current and future technological needs, as well as special regulatory rights under the current international legal regimes, recognizing special conditions of navigation risks.

Unpredictable ice, wave, and wind conditions, varying routes, high environmental risks, and lack of qualified and experienced staff to facilitate safe sailing in polar waters are just a few security-related challenges to the intensification of commercial shipping in the NSR (Erokhin et al, 2018; Fisenko, 2014). In light of the establishment of more secure and stable navigation along the NSR, the identification of water areas suitable for the development of deep-water shipping and the operation of large-tonnage tankers and icebreakers should be supplemented by investigation of major technological, engineering, and economic factors affecting China-Russia collaboration. China has both expertise and money to offer to Russia, which is currently nearly fenced off from formerly used western technologies due to the sanctions. The adoption of Chinese technologies and engineering solutions, however, first requires Russia's openness to accept them and thereby tolerate China's rising presence in the Russian sector of the Arctic, and second, substantial changes to the Russian less-than-perfect import-substitution policy, as well as custom, tax, and financial legislation. Ultimately, the intensification of shipping and securitization of the NSR for international transit largely depends on Russia's willingness to modernize national legislation and create favorable conditions for collaboration with China and other partners in the spheres of maritime engineering, shipbuilding, ice and weather monitoring, and navigation services.

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References

ABS. (2016). *Navigating the Northern Sea Route: Status and Guidance*. Houston, TX: ABS.

Afonin, A., Olkhovik, E., & Tezikov, A. (2019). Conventional and Deep-Water Shipping Passages Along the Northern Sea Route. In V. Erokhin, T. Gao, & X. Zhang (Eds.), *Handbook of Research on International Collaboration, Economic Development, and Sustainability in the Arctic* (pp. 314-337). Hershey, PA: IGI Global.

Afonin, A., & Tezikov, A. (2017). The Concept of Development of Shipping Routes along the Northern Sea Route. *The Scientific Journal "Vestnik Gosudarstvennogo Universiteta Morskogo i Rechnogo Flota imeni Admirala S.O. Makarova", 9*(1), 81-87.

Ananyeva, E. (2019). Russia in the Arctic Region: Going Bilateral or Multilateral? *Journal of Eurasian Studies, 10*(1), 85-97.

Arctic and Antarctic Research Institute. (n.d.). *Handbook on Ice Conditions in the Northern Sea Route (NSR). General Information about NSR.* Retrieved from: http://www.aari.ru/projects/ECIMOt/Docs/reports/21/html/main.html.

Bennett, M. (2017). *China Plans Arctic Belt and Road Initiatives.* Retrieved from: http://www.maritime-executive.com/editorials/china-plans-arctic-belt-and-road-initiatives.

Blaxekaer, L. Ø., Lanteigne, M., & Shi, M. (2018). The Polar Silk Road and the West Nordic Region. In L. Heininen & H. Exner-Pirot (Eds.), *Arctic Yearbook 2018* (pp. 437-455). Akureyri: Northern Research Forum.

Drewniak, M., Dalaklis, D., Kitada, M., Ölçer, A., & Ballini, F. (2018). Geopolitics of Arctic Shipping: The State of Icebreakers and Future Needs. *Polar Geography, 41*(2), 107-125.

Dumanskaya, I. (2016). Some Tendencies in Change of Ice Parameters of the Arctic Seas in the 21st Century. *Proceedings of Hydrometcentre of Russia, 362*, 129-154.

Ehret, M. (2019). *Silk Road Expands to Arctic and Beyond.* Retrieved from: https://www.asiatimes.com/2019/05/opinion/silk-road-expands-to-arctic-and-beyond/.

Erokhin, V., & Gao, T. (2018). Northern Sea Route: An Alternative Transport Corridor within China's Belt and Road Initiative. In J. Chaisse & J. Gorski (Eds.), *The Belt and Road Initiative: Law, Economics, and Politics* (pp. 146-167). Leiden: Brill Nijhoff.

Erokhin, V., Gao, T., & Zhang, X. (2018). Arctic Blue Economic Corridor: China's Role in the Development of a New Connectivity Paradigm in the North. In L. Heininen & H. Exner-Pirot (Eds.), *Arctic Yearbook 2018* (pp. 456-474). Akureyri: Northern Research Forum.

Fisenko, A. (2014). Prospects and Problems of Development Sea Freight Transport and Icebreaker Support Northern Sea Route. *Contemporary Problems of Science and Education, 2*, 450.

Friedlander, B. (2018). *Recent Russian Arctic Glacier Loss Doubles from the Previous 60 Years*. Retrieved from: http://news.cornell.edu/stories/2018/04/recent-russian-arctic-glacier-loss-doubles-previous-60-years.

Gao, T. (2019). Going North: China's Role in the Arctic Blue Economic Corridor. In V. Erokhin, T. Gao, & X. Zhang (Eds.), *Handbook of Research on International Collaboration, Economic Development, and Sustainability in the Arctic* (pp. 133-161). Hershey, PA: IGI Global.

Górski, J. (2019). Northern Sea Route: International Law Perspectives. In V. Erokhin, T. Gao, & X. Zhang (Eds.), *Handbook of Research on International Collaboration, Economic Development, and Sustainability in the Arctic* (pp. 292-313). Hershey, PA: IGI Global.

Government of the Russian Federation. (1998). *Federal Law from July 17, 1998, "About Internal Sea Waters, Territorial Sea, and Contiguous Zone of the Russian Federation".* Retrieved from: http://docs.cntd.ru/document/901714424.

Guo, P., & Guan, Q. (2009). An Analysis of Political and Legal Problems of the Northern Sea Route. *Journal of the Ocean University of China (Social Sciences), 4*, 1-5.

Hong, N. (2012). The Melting Arctic and its Impact on China's Maritime Transport. *Research in Transportation Economics, 35*, 50-57.

Hong, N. (2018). *China's Interests in the Arctic: Opportunities and Challenges*. Washington, DC: Institute for China-America Studies.

Huang, L., Lasserre, F., & Alexeeva, O. (2015). In China's Interest for the Arctic driven by Arctic Shipping Potential? *Asian Geographer, 32*(1), 59-71.

Kelmelis, J.A. (2011). Arctic Warming Ripples through Eurasia. *Eurasian Geography and Economics, 52*, 56-78.

Landy, J., Babb, D., Ehn, J., Theriault, N., & Barber, D.G. (2016). Sea Ice Thickness in the Eastern Canadian Arctic: Hudson Bay Complex & Baffin Bay. *Remote Sensing of Environment, 200*, 281-294.

Lasserre, F. (2018). Arctic Shipping Traffic: More Ships Will Come, but not for Transit. In T. Bell & T. Brown (Eds.), *From Science to Policy in the Eastern Canadian Arctic* (pp. 509-521). Quebec City: ArcticNet.

Lenta.ru. (2015). *Rogozin Suggested Creation of "Cold Silk Route" through the Arctic*. Retrieved from: https://lenta.ru/news/2015/12/07/rogozin/.

Li, Z. (2009). Analyzing China's Strategy with Respect to the Northern Sea Route. *China Soft Science, 1*, 1-7.

Li, Z., & Tian, Y. (2009). Research on Arctic Route Issue Basin Based on KJ Method. *World Regional Studies, 18*(3), 97-102.

Li, Z., Sun, Y., & Wei, B. (2018). Car Following Model for Navigation Safety on "Polar Silk Road". *Journal of Dalian Maritime University, 44*(3), 22-27.

Lind, S., Ingvaldsen, R.B., & Furevik, T. (2018). Arctic Warming Hotspot in the Northern Barents Sea Linked to Declining Sea-Ice Import. *Nature Climate Change, 8*, 634-639.

Liu, N. (2016). *China's Emerging Arctic Policy*. Retrieved from: https://thediplomat.com/2016/12/chinas-emerging-arctic-policy/.

Liu, N. (2017). China's Emerging Arctic Policy: What Are the Implications for Arctic Governance?. *Jindal Global Law Review, 8*(1), 55-68.

Liu, N., Lin, L., Kong, B., Wang, Y., Zhang, Z., & Chen, H. (2016). Association between Arctic Autumn Sea Ice Concentration and Early Winter Precipitation in China. *Acta Oceanologica Sinica, 35*(5), 73-78.

Liu, Q., Babanin, A.V., Zieger, S., Young, I.R., & Guan, C. (2016). Wind and Wave Climate in the Arctic Ocean as Observed by Altimeters. *Journal of Climate, 29*(22), 7957-7975.

Marchenko, N., Andreassen, N., Borch, O.J., Kuznetsova, S., Ingimundarson, V., & Jakobsen, U. (2018). Arctic Shipping and Risks: Emergency Categories and Response Capacities. *International Journal on Marine Navigation and Safety of Sea Transportation, 12*(1), 107-114.

Mao, R., Gong, D., Bao, J., & Fan, Y. (2011). Possible Influence of Arctic Oscillation on Dust Storm Frequency in North China. *Journal of Geographical Sciences, 21*(2), 207-218.

Mayorova, V., Grishko, D., Chagina, V., & Khardaminova, S. (2013). Possibilities of Using Dynamical Local Sinusoids for Short-Term Forecast of Ice Condition in the Kara Gate Strait from Space-Based Radar Imaging. *Herald of the Bauman Moscow State Technical University. Series Natural Sciences, 1*, 117-128.

Meng, Q., Zhang, Y., & Xu, M. (2017). Viability of Transarctic Shipping Routes: A Literature Review from the Navigational and Commercial Perspectives. *Maritime Policy and Management 44*(1), 16-41.

Moe, A., & Stokke, O.S. (2019). Asian Countries and Arctic Shipping Policies, Interests and Footprints on Governance. *Arctic Review on Law and Politics, 10*, 24-52.

Mokhov, I., & Khon, V. (2015). The Duration of the Navigation Period and Changes for the Northern Sea Route: Model Estimates. *Arctic: Ecology and Economy, 18*(2), 88-95.

National Petroleum Council. (2015). *Arctic Potential. Realizing the Promise of U.S. Arctic Oil and Gas Resources*. Washington, DC: National Petroleum Council.

National Snow and Ice Data Center. (2016). *Arctic Sea Ice News and Analysis*. Retrieved from: https://nsidc.org/arcticseaicenews/2016/10/.

Østreng, W. (2010). *The Russian Federation's Arctic Policy*. Retrieved from: http://www.arctis-search.com/The+Russian+Federation%E2%80%99s+Arctic+Policy.

Paris, C., & Chiu, J. (2015). *Chinese Shipping Group Cosco Planning Regular Trans-Arctic Sailings*. Retrieved from: https://www.wsj.com/articles/chinese-shipper-cosco-to-schedule-regular-trans-arctic-sailings-1446133485.

Parkinson, C.L. (2014). Spatially Mapped Reductions in the Length of the Arctic Sea Ice Season. *Geophysical Research Letters, 41*(12), 4316-4322.

RIA News. (2015). *Centers of Arctic-Related Decision-Making May Move from Moscow*. Retrieved from: https://ria.ru/20150319/1053487104.html.

Shalina, E., & Bobylev, L. (2017). Sea Ice Transformations in the Arctic from Satellite Observations. *Current Problems in Remote Sensing of the Earth from Space, 14*(6), 28-41.

State Council of the People's Republic of China. (2018). *China's Arctic Policy. The State Council Information Office of the People's Republic of China*. Beijing: The State Council of the People's Republic of China.

Sun, K. (2014). Beyond the Dragon and the Panda: Understanding China's Engagement in the Arctic. *Asia Policy, 18*, 46-51.

Shyu, W., & Ding, J. (2016). Key Factors Influencing the Building of Arctic Shipping Routes. *Journal of Navigation, 6*(1), 1-17.

Tillman, H., Jian, Y., & Nielsson, E.T. (2018). The Polar Silk Road: China's New Frontier of International Cooperation. *China Quarterly of International Strategic Studies, 4*(3), 345-362.

Wang, Y., & Shou, J. (2013). Economic Analysis and Navigation Feasibility Probe into Sino-Europe Maritime Transport Route of Northeast Navigation Route. *Marine Technology, 2*, 21-24.

Xiao, Y. (2012). Game Theory of the National Interest in the Arctic Navigation: China Position and Policy. *Peace and Development, 3*, 42-47.

Xinhua. (2017). *"Silk Road on Ice" to Enhance Russia-China Cooperation in Arctic: Russian Expert*. Retrieved from: http://english.scio.gov.cn/beltandroad/2017-11/29/content_50075864.htm.

Xu, S. (2013). How Should Chinese Enterprises Take a Share of North Pole Shipping? *Journal of China Transport, 24*, 7-8.

Zhang, J., Peng, J., Huang, M., & Zhang, S. (2006). Are Dust Storm Activities in North China Related to Arctic Ice-Snow Cover? *Global and Planetary Change, 52*(1), 225-230.

Zhang, X. (2019). Regional Aspects of the Arctic Ice Silk Road: Case of Heilongjiang Province, China. In V. Erokhin, T. Gao, & X. Zhang (Eds.), *Handbook of Research on International Collaboration, Economic Development, and Sustainability in the Arctic* (pp. 370-394). Hershey, PA: IGI Global.

Zhang, X., Shou, J., & Zhou, H. (2013). Studies on North Pole Maritime Shipping Commodity Types and Related Economy Scale. *Chinese Journal of Polar Research, 25*(2), 66-74.

Zysk, K. (2010). Russia's Arctic Strategy: Ambitions and Constraints. *Joint Force Quarterly, 57*, 104-110.