Master's degree thesis

LOG950 Logistics

Title: A Simulation model for the assessment of the Northern Sea Route carrying capacity

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Preface

Master`s degree thesis is a final mandatory requirement for the Master of Science in Logistics program in Molde University College – specialized university in logistics. We were engaged in writing and researching this thesis from January – May 2017. The topic of the master thesis is the usage of the Northern Sea Route for cargo transportation from Northern Europe to Asia.

Our research was formulated together with supervisor PhD student Yauheni Kisialiou. And we would like to thank him for his support during the whole process of writing. Also, we want to thank him for patience and wish him clever students.

We are thankful to each other for the great cooperation and support in every difficult situation during writing.

Aleksandr Rozhdestvenskii,

Lidia Rybakova,

Molde, May 2017.

Summary

The purpose of the research is to estimate the throughput of the Northern Sea Route and define the factors that impact on the transit of vessels. To achieve this purpose our research will be divided into parts: data collection and general description part, simulation modeling part.

For the first part general overview of the organization transit of vessels in the arctic region needs to be done and discover what rules and principles are using by decision makers in this process. The following dimensions such as weather conditions, rules of navigation, the formation of caravans and icebreaker support requirements will be considered. The modeling part will be developed using the Discrete-Event simulation methodology. Many assumptions should be taken into account, that is why we need to find out what is the main factors influencing to the transit to implement them into the model in the first place. The result of the research will be analyzed and could be used for the further researchers and serve as a guide for interested in transition activities of the Northern Sea Route.

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1. Introduction

Through the last decade, the interest in transporting goods by the NSR (Northern Sea Route) has dramatically increased. The reason for that interest growth hides behind the effects of global climate change and following appearance of new economic possibilities. Northern Sea Route is a marine route starting in North Europe and going along Siberia to Asia.

Figure 2.1.1. NSR, Suez Route and Northwest Passage. Source: Ragner, 2000.

The economic benefits were generally motivations to navigate Northern Sea route considered by Liu at al. The NSR is rather attractive as it is 40% shorter than the Route going through Suez Chanel, so it is faster and cheaper. The different routes from Northern Europe to Asia are shown in figure 1.1. The distance from Rotterdam (Netherlands) to Yokohama (Japan) using the NSR is approximately 7200 nautical miles. The distance of the Suez Route is approximately 11400 nautical miles.

It has been used by USSR in the period from 1935-1991 because the USSR considered that the most part of the NSR passed through sovereign waters and due to it they protected their waters carefully from foreign vessels. After 1991 it became open for international sea shipping. Due to the global warming effect, the period of navigation extended from two to six months and opening good perspective for international cargo shipping between Asia and Europe (Mulherin et al., 1996).

US Geological Survey (Bird et al., 2008) the Arctic region contains around 22% of all unproved hydrocarbons deposits. Due to the continuous depletion of conventional oil and gas reserves, Russia has started to invest a significant amount of money in offshore Arctic projects (heli and air ports, search and rescue stations). The situation has changed now as oil prices dropped down and most projects are now economically non-feasible. No one is able to predict how oil prices will behave in the nearest future, so if these projects will be restarted, they will require developed infrastructure to supply installations and hereafter the transportation of produced hydrocarbons to consumers. In addition, a decline in oil and gas prices means the more efficient way transportation should be analyzed (Bird et al., 2008).

According to Russian legislation, vessels transiting the NSR require permission and in most cases should be escorted by nuclear icebreaker. Icebreakers support is required due to the presents of ice in the NSR waters and depends on the ice conditions and vessels ice class. Vessels ice class describes the vessels capability to withstand the ice of certain thickness. Each icebreaker can support one vessel or a group of them (these groups are usually called caravans or convoys). Group size depends on the ice conditions at the particular season. It can vary from two to four ships and its number is usually limited. Nevertheless, even taking into consideration that in the middle period of navigation the NSR waters are mostly free of ice, the beginning of the end navigation is characterized by rather harsh and uncertain ice conditions. Vessels with very low ice class still require the icebreaker support even in the middle of navigation. All the vessels transiting in the NSR have to meet the requirements of rules of navigation in the water area of NSR (Rules of navigation in the water area of the NSR approved by Ministry of Transport of Russia from 17 of January 2013). According to the information of the administration of the NSR, the number of operating icebreakers is four: «Vaygach», «Yamal», «Taymyr» and «50 Let Pobedy» (The NSRA, 2015).

We have searched the NSR condition and realized that there are some factors we have to consider in order to estimate the possibilities of the development of the NSR goods transportation. (The NSRA, 2016b). There are several icebreakers under construction. Icebreaker fleet of Russia replenished by three new nuclear icebreakers: «Arktika» (December of 2017), «Siberia» and «Ural» with the time of commissioning in 2019 and 2020 respectively (Rosatom flot, 2015).

The transit statistics of the previous years (2011-2016) shows that the flow vessels was not so high, maximum 71 number in the 2013 year (table 1.1).

Year	2011	2012	2013	2014	2015	2016
Number of transits	41	46	71	22	18	19

Table 2.1.1. Transit statistics. Source: NSR information office, "Transit Statistics", 2016.

Nevertheless, Russian Federation is heavily investing in coast infrastructure and satellites systems and thus creating the possibility for the high transit rate.

The number of transit vessels is directly related to the total quantity of icebreakers. Obviously, the large number of icebreakers provides higher transit rate and the opposite. There are some icebreakers under construction and some will be put out of operation due to their age. The situation is complicated by harsh and uncertain weather conditions (winds, fogs, icebergs). Here arises the question the NSR throughput capacity i.e. the number of vessels passing in the NSR during the navigation period. When all infrastructure along the NSR is developed, more transit orders may follow and it becomes unclear how many icebreakers is required and how customers will behave in case of delays. Another problem is that the NSR was not used on the large scale and the way the transit is organized may turn out not effective in the case for the high demand of the transit.

Considering uncertain factors such as ice conditions, a random number of incoming orders, icebreakers availability, the transit can be represented as a stochastic process. Therefore, for analysis and assessment, this process would be suitable to create a stochastic model, some tool which allows to analyze the throughput of the NSR and to take into account the most influencing factors. To realize this goal, we emphasize two main characteristics of the transit. One of them is the percentage of satisfied customers during the navigation period, and next one is average delay time from desired departure date of orders. These two characteristics depend on the above mentioned uncertainties.

Discrete-event simulation modeling is used in order to model the transit through the NSR. It involves probability and statistics and can be used to represent transportation systems and to describe the logic (Rosetti, 2015).

The research paper consists of seven main sections. The first section is introduction of the master thesis. The second section provides general information about navigation in the waters of the NSR including weather conditions and icebreaker support requirements. In section three, we define the problem, and after we make a short review of the relevant literature in the next section. In section five, we consider methodological approaches for solving the definite problem. Section 6 involves solution approaches in this study as well as the description of theoretical assumptions, simplifications and logic of simulation model. The last section is experimental part containing an analysis of the obtained results.

2. Problem description

In this section, we provide some information about the navigation in the North Sea Route waters, rules of navigation, icebreaker support requirements and weather conditions of the Arctic region.

2.1. General information

The Northern Sea Route takes its origins in the Kara Sea, either from Dezhnev Cape or from Kara gate and ends at the Bering Strait. The route lies across four Arctic seas: the Kara Sea, the Laptev Sea, the East Siberian Sea and the Chukchi Sea.

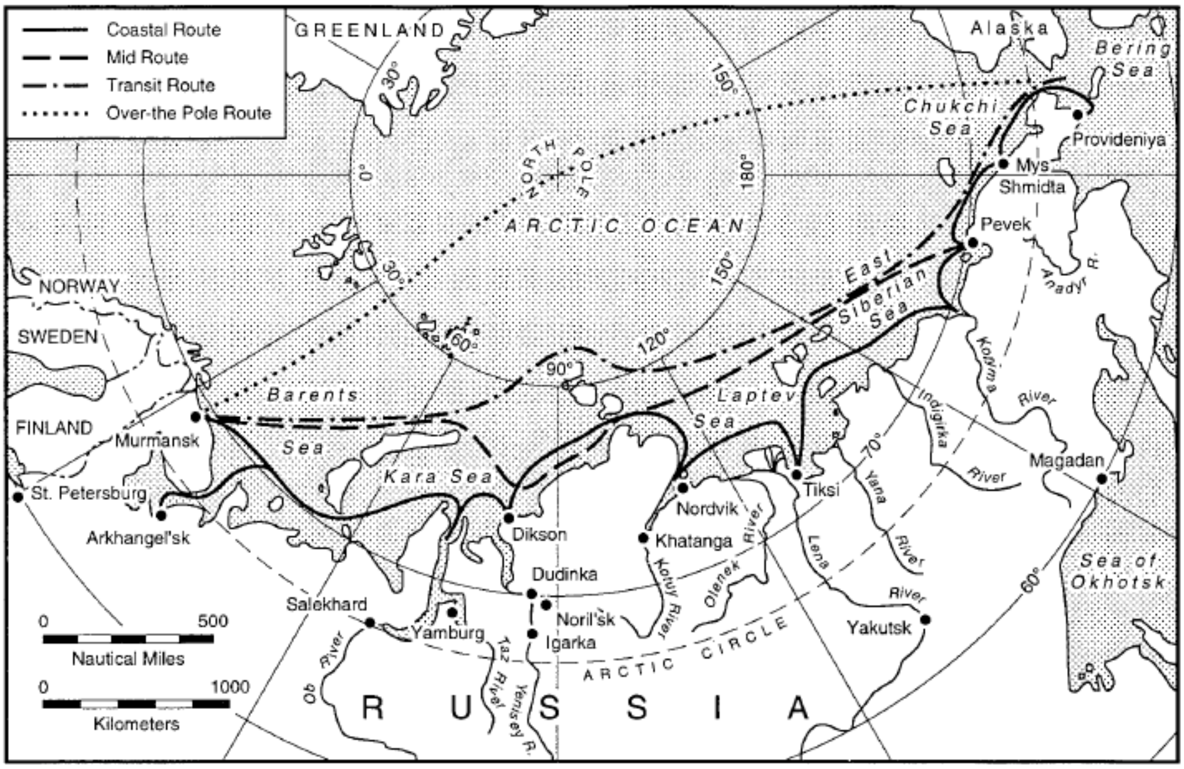


Figure 2.1.1. The various of ways in the Northern Sea Route waters. Source: Nathan, 1996.

Northern Sea Route provides the shortest path by sea from Northern Europe to the Far East. There is another way to Asia by sea using the Suez Canal. But the Northern Sea Route in comparison with the way through the Suez Canal is 35-60% shorter. The Northern Sea Route it is not the only one single path (figure 2.1.1), but there are many alternatives according to vessels characteristics, icebreakers support and ice conditions.

2.2. Weather conditions

The climate on the northern highway is quite severe. There are very low temperatures, strong winds, a high number of days with fog, snowstorms, drifting icebergs and long polar nights. Heavy ice of seas presents challenges for operation in the Arctic region. Annual navigation on the NSR has two main seasons: summer-autumn season and winter-spring – season of the rest when the coast is blocked by ice. The highest number of passages takes place during summer and autumn; it is five months period from mid-June to mid-November. On this interval, the ice coverage is the lowest and in some places the water is completely free of ice, for example, the Barents Sea.

There are two main characteristics of the ice conditions in the Arctic seas. One of them is square of solid ice and another is iciness. There are three criterions of conditions for each characteristic: light, middle and harsh. It can be described as a percentage where the hardest condition is 100% and the lightest is 0% (table 2.2.1 – 2.2.3, source: the NSRA, 2016b). It depends on which sea we consider in the moment.

		the West side		**the East side**	
		square of solid ice	iciness	square of solid ice	iciness
criterions	light	0%-35%	0%-45%	0%-10%	0%-45%
	middle	35%-60%	45%-60%	10%-45%	45%-60%
	harsh	60%-100%	65%-100%	45%-100%	60%-100%

Table 2.2.1. For the Kara Sea and the Laptev Sea.

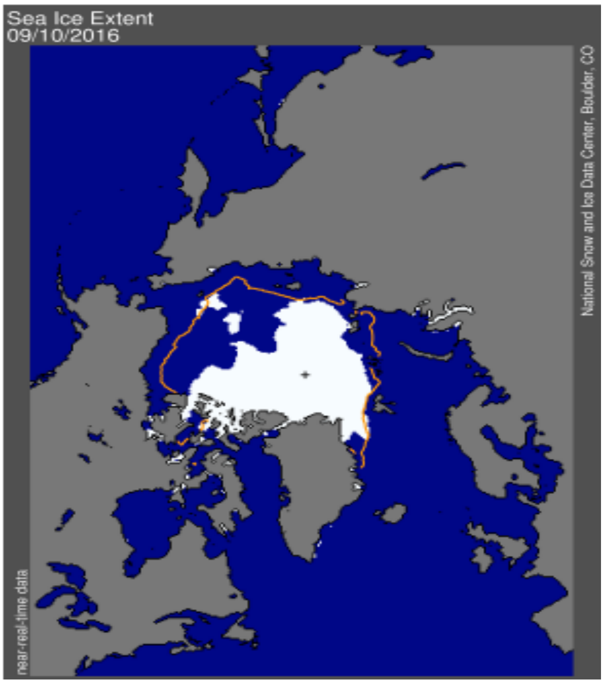
		the West side		**the East side**	
		square of solid ice	iciness	square of solid ice	iciness
criterions	light	0%-15%	0%-50%	0%-60%	0%-80%
	middle	20%-50%	50%-70%	60%-75%	80%-90%
	harsh	50%-100%	70%-100%	75%-100%	90%-100%

Table 2.2.2. For the East Siberian Sea.

		the South-West side	
		square of solid ice	iciness
criterions	light	0%-10%	0%-35%
	middle	20%-40%	35%-55%
	harsh	40%-100%	55%-100%

Table 2.2.3. For the Chukchi Sea.

From June it is mainly light conditions in all Arctic seas. The only obstacle that you can meet in the summer period is drifting icebergs and according to this condition you need to make a choice which route you prefer. In September and October, the conditions are even better, you can hardly meet with ice massifs on the route. In November the Laptev Sea and the Siberian Sea the conditions of ice become harder and it is impossible to pass without icebreakers.



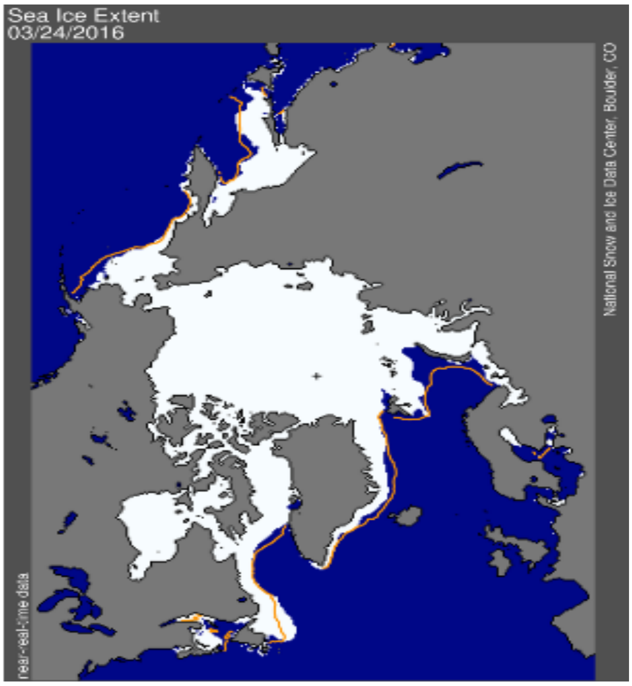


Figure 2.2.1. Arctic sea ice extent for September 2016. Source: NSIDC, 2010.

Figure 2.2.2. Arctic sea ice extent for March 2016. Source: NSIDC, 2010.

Figure 2.2.1. Arctic sea ice extent for September 10, 2016 was 4.14 million square kilometers (1.60 million square miles) according to the National Snow & Ice data center (the NSIDC, 2010). The orange line shows 1981 to 2010 median extent for that day. Satellite data show extensive areas of open water in the Beaufort and Chukchi seas and in the Laptev and East Siberian seas.

Figure 2.2.2. Arctic sea ice extent for March 24, 2016 was 14.52 million square kilometers (5.607 million square miles). The orange line shows 1981 to 2010 median extent for that day (NSIDC, 2010).

2.3. The NSR Administration

The Northern Sea Route Administration (NRSA) is responsible for navigation in the waters of Northern Sea Route. The Federal Government from 15 of March 2013 established the administration of the NSR. The Northern Sea Route Administration provides following functions:

- Receiving, considering of application and giving permissions for navigation.
- To make a recommendation how the route can be developed and to utilize icebreakers.
- To create information services considered the water conditions.
- To help in the organization of rescue and search operations.

“Rosmorrechflot” (managed by the Russian Ministry of Transport, from 2004) organizes rescue and search operations on the NSR. The coordination centers are located along the route (figure 2.3.1).

Marine Rescue Coordination Centre Dikson (MRCC) organizes during the whole year. Marine Rescue Sub-Center Tiksi (MRSC) and Marine Rescue Sub-Center Pevek (MRSC) organize during the navigation period (NSRA, “Search and rescue”, 2013).

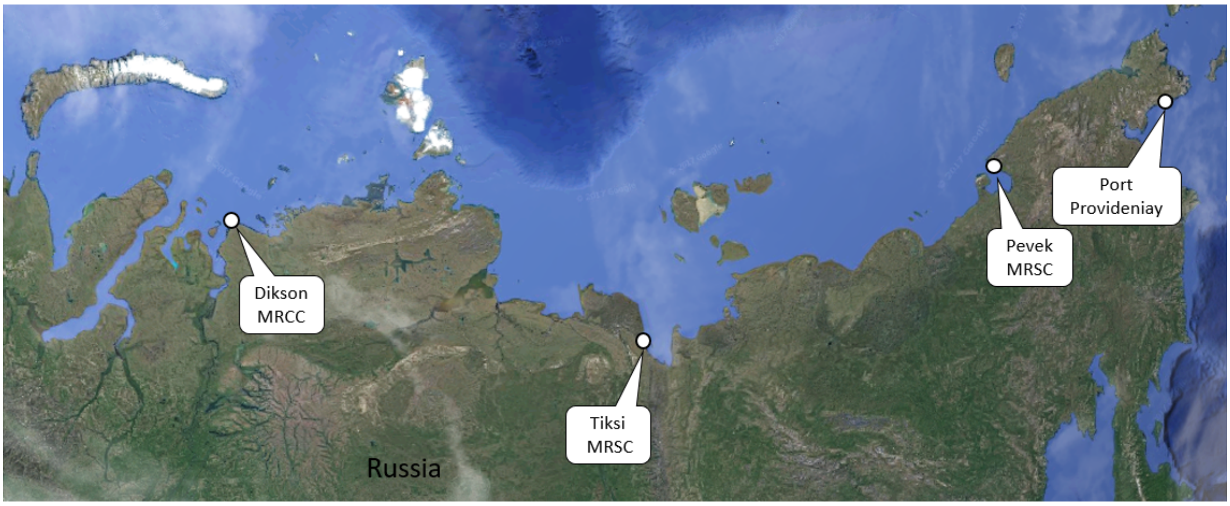


Figure 2.3.1. The map of Search and rescue coordination centers. Source: NSRA, 2016c.

The NSR administration does not manage the icebreaker fleet and not making decisions of their support, it only issues permissions for navigating via the route with or without icebreaker support. These functions of icebreakers assistance are divided among a few state and commercial organizations and one of the main players is the state “Atomflot” with the fleet of several icebreakers with different abilities.

The ship owner or the master of a vessel needs to have an agreement with icebreakers Support Company about the start time and place of navigation with the support of an icebreaker and also should have information on the vessel characteristics, flag, name, IMO number. To this agreement have to be attached such documents as ownership certificate, the classification certificate etc. The NSRA examines the application within 10 days and after that makes the decision. The application should be submitted not later than 20 days before the required date of the navigation through the NSR (Ministry of Transport of Russian Federation, 2013). The NSRA can refuse in a possibility to navigate in the NSR waters according to different reasons (ice class of the vessel does not satisfy current weather conditions; the ship owner didn’t provide all the required information about the vessel.

2.4. Icebreakers support requirements

The NSR is divided into seven zones by administration (figure 2.4.1): South West part of the Kara Sea, North East part of the Kara Sea, the Laptev Sea, the East Siberian Sea and the Chukchi Sea.

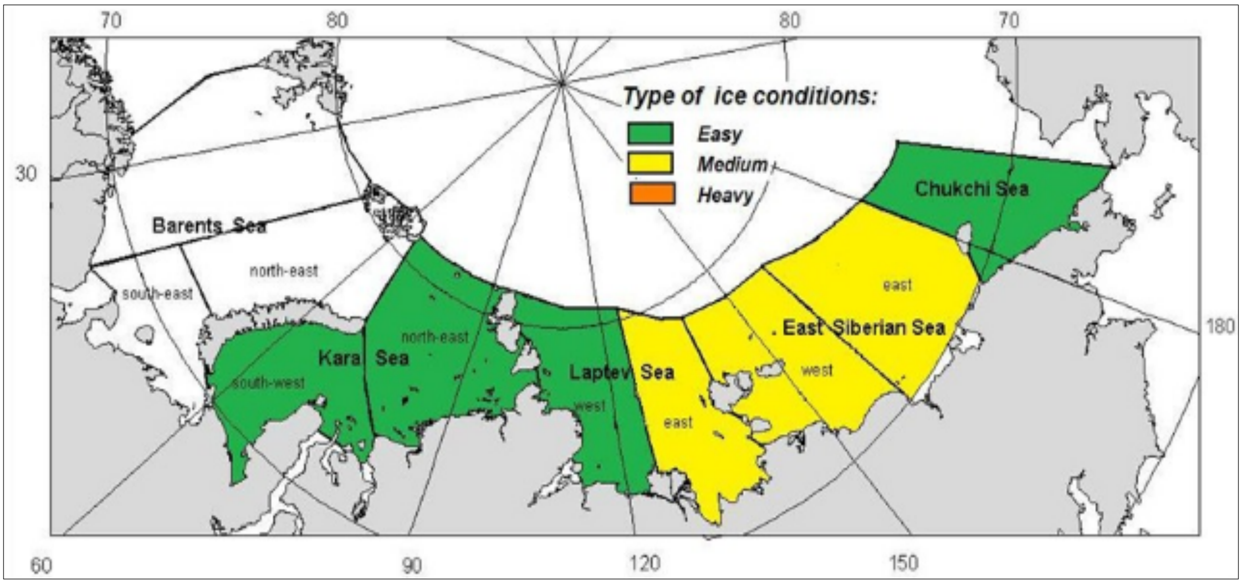


Figure 2.4.1. Chart-map of borders of the Russian Arctic seas and their main areas. Source: NSR information office, 2015b.

The icebreakers support provides safe navigation on aforesaid zones. The sailing period is from mid-June - mid-November. However, in the period from August - September the most part of the route is free of ice and the icebreakers support is required only for small ice areas.

The vessels have a different ability to navigate according to various ice conditions. It presents as a parameter and is called ice-classes. Different countries have their own marine classification societies with different systems of ice classes. The ice-classes are regulated by the Russian Maritime Register of shipping[1]. In the Ice Rules of the Russian Maritime Register, vessels are divided into nine categories (Ice1, Ice2, Ice3, Arc4, Arc5, Arc6, Arc7, Arc8, Arc9) for vessels and into four categories (icebreaker6, icebreaker7, icebreaker8, icebreaker9) for icebreakers. For each ice-class, there are different characteristics: maximum ice thickness, the conditions of water, the vessel can navigate.

The Northern Sea Route information office (NSRIO) presents the table of the Admittance criteria for navigation in the Northern Sea Route water area according to the vessel's ice-class. Vessels with ice-classes (Ice1, Ice2 and Ice3) are allowed to navigate in the rare ice non-Arctic seas and through ice in the canal behind the icebreaker when ice thickness up to 0.4 - 0.7 m, according to

[1] Russian Maritime Register of Shipping provides safe navigation of ships (www.rs-class.org , rules 2007)

the class. Vessels with ice-classes (Arc4, Arc5, Arc6, Arc7, Arc8, and Arc9) are allowed to navigate in the rare annual Arctic ice considering ice thickness (0.6; 0.9; 1.1; 1.4; 2.1; 3.5, according to the ice class) in the summer - autumn season; and to navigate behind the icebreaker. In addition, ships with categories (icebreaker6, icebreaker7, icebreaker8, icebreaker9) can perform icebreaker operations with an ice thickness of up to (1.5; 2.5; 3; 4 m., according to the ice class).

Ships ice reinforcement class	Ice navigation mode	The Kara Sea		The Laptev Sea		The East Siberian Sea		The Chukchi Sea
		South-West part	North-East part	South-West part	North-East part	South-West part	North-East part	
		S M L	S M L	S M L	S M L	S M L	S M L	S M L
Arc4	IN	- + +	- + +	- - +	- - +	- - +	- - +	- + +
	IS	+ + +	+ + +	- + +	- + +	- + +	- + +	- + +
Arc5	IN	+ + +	+ + +	- + +	- + +	- + +	- + +	- + +
	IS	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
Arc6	IN	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
	IS	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +

Table 2.4.1. Admittance criteria for navigation in the NSR water area. Source: NSRIO, 2015b.

Icebreakers with ice reinforcement class Icebreaker9 are not restricted in independent navigation in the Northern Sea Route water area (NSRIO, 2015b). Icebreakers with ice reinforcement class Icebreaker6 – Icebreaker8 are allowed to navigate independently during the navigation period July to November (Rules of navigation in the water area of the NSR, 2016). Notation description of the table 2.4.1: IN – independent navigation, IS – with icebreaker support, S – severe ice conditions, M – moderate ice conditions, L – easy ice conditions according to the "Rosgidromet" center official information, «+» – navigation is allowed, «–» – navigation is not allowed (Rosgidromet, 2015).

The main characteristics of the nuclear icebreakers (table 2.4.2.) according to the information of the "Rosatom" company (Rosatomflot, 2013).

Icebreakers	«Taymyr»	«Vaygach»	«Yamal»	«50 Let Pobedy»
Length, m	151.8	151.8	148	159.6
Width, m	29.2	29.2	30	30
Speed, knots	18.5	18.5	20.6	18.6
ice thickness, m	1.77	1.77	2	2.8

Table 2.4.2. Technical Data of Nuclear Icebreakers. Source: Rosatomflot, 2013.

The modern nuclear icebreaker “Yamal” (ice-class is Icebreaker9, figure 2.4.2.) has a length is 151.8 meters; the width is 29.2 meters. The speed of the icebreaker is 2 knots with the maximum thickness of the ice is 2.25 m. The speed of icebreakers in the clear water is 20.8 knots. The lifetime of icebreakers is around 40 years (Rosatomflot, 2013).

Figure 2.4.2. Nuclear icebreaker “Yamal”. Source: Rosatomflot, 2013.

2.5. Summary

The Northern Sea Route distance from Dezhnev Cape or from Kara gate to the Bering Strait is approximately 5600 kilometers (Schøyen, 2011). The icebreakers can navigate along the whole length. In most cases, the transit via the NSR requires icebreaker support. However, the number of icebreakers is limited (4 nuclear icebreakers). In case, if the demand for the transit through the Northern Sea Route is drastically increased, then the limited number of icebreakers will lead to the formation of queues where part of orders will be canceled by the customers or declined by the administration. The construction of new icebreakers is quite costly and time-consuming. The construction period of new powerful nuclear icebreakers is 5 years. It means, that some outdated icebreakers will be put out of operation while new nuclear icebreakers will be only projecting or building. Important to know icebreakers availability and we should make some assumptions about capabilities of the transit via the NSR on the large scale.

According to the statistics, the maximum flow of vessels was 71 (in the 2013 year). Each icebreaker can support from 2 up to 10 vessels. Convoy formation can be different in terms of vessels ice class that gives different ability to navigate according to various ice conditions. Due to this, a combination of vessels that can be assigned to the caravan is different depending on ice conditions.

Vessels ice-class and weather conditions influence on the decision of the icebreaker support requirement. The ice cover is different for each month and the NSR zone. The speed of vessels directly depends on ice condition during navigation. The average transit speed is 10-15 knots in different months. Therefore, the speed of vessels in the Arctic seas is a stochastic factor.

In addition to stochastic weather condition, the demand for the transit of the NSR is also stochastic. There are several requirements for the initiation of the transit of vessels. The master of a vessel needs to have a permission for a sailing via the Northern Sea Route, and if the transit is allowed, a ship owner will be notified of a date and place of meeting with an icebreaker. The question about the decision making logic (departure time, departure place, caravan size, composition) arises. How is it organized and will it be the same if the flow of orders will increase?

Some factors are difficult or impossible to describe. We just can make some assumptions about how the transit via the Northern Sea Route is organized based on these factors, and which it will be in the future. The current transit of vessels through the NSR can be represented as a tramp shipping system. In this case, icebreakers do not have a fixed schedule. Tramp shipping applies a situational approach. As soon as we have the number of vessels with close enough desired date of departure and acceptable ice class according to the weather conditions the convoy can be formed and assigned to the certain date for icebreaker support. The opposite of this system is a linear shipping; the ships depart exactly in time according to the timetable. The Suez Canal as an alternative for the NSR uses such a system. Two main convoys system is applied in the Suez Canal. The first of one is the Northbound convoy that starts at 04:00 hours and the second is the Southbound convoy that starts at 03:30 hours. The transit begins from two ports respectively: south Port Said and north Port Tewfik (Suez Canal Authority, 2008).

It is unknown, how the throughput capacity will change in case the number of the order will increase. We want to apply the tramp shipping system for the assessment the transit via the NSR.

3. Problem definition

The main task of this research is to develop a simulation modeling tool that allows for the assessment of the transit of vessels via the NSR. It should be able to simulate the transit via the NSR taking into account the number of available icebreakers, the number of orders for transit, average delay time, stochastic weather conditions, rules regulating the transit and the model of transit organization (tramp). The tool should provide the necessary output statistics for the subsequent analysis. As well, it should be designed so that it could be easily modified in case of possible changes in the principles or rules guiding the transit.

4. Literature review

In this section, we provide a short overview of the relevant literature dedicated to the shipment in the Arctic.

The comparison of the two possible ways of transportation from the Northern Europe to Asia. One of them is using the Suez Canal and another is the Northern Sea Route. In the article of authors Schøyen and Bråthen (2010), we can find some description about the maritime routes. In addition, they evaluated the potential risks and benefits of traveling via the Northern Sea Route. Buixade et. al. (2014) considered shipping routes through the Arctic zone and development during previous years. In the same time, it contends analyzes of the new opportunities which appear because of technological growth relatively the natural resources in the Arctic area. Miaojia Liu et. al. (2010) also estimate the economic reasonability of using the Northern Sea Route as an alternative route through Suez Canal from Europe to Asia. The authors describe many different factors, which influence to the navigation through the NSR and talking about the challenges, that company need to face navigating in this severe Arctic area. In article of Østreng et. al. (2013) is compared three possible Arctic corridors and covers many different factors like global warming, logistics in Arctic, ocean law and regulations, resources, economic trends.

Mikhaylichenko et. al. (2014) analyzed how was organized the transportation via the Northern Sea Route in the previous years. What kind of problems and challenges it faces. For example, the delays of the icebreakers and waiting of vessels in the queue. Another paper also considers the NSR navigation rules: Icebreaker support guarantees safe navigation of a group of vessels that called as convoys. Rules for the vessels and icebreakers regarded different weather conditions. Also the common rules of navigating by ship considered by Šarlaj et. al. (2016).

In these two articles, some modeling tools were developed. Choi et.al. (2015) developed a simulation model for ships traveling in the Arctic region that got into consideration uncertainties that sea ice could give. In the system, the model of ice condition simulates its behavior and using the results for planning optimization model (Nathan et. al., 1996). The authors of this article suggest the Monte-Carlo model, which was developed by them. This simulation model concerns the NSR transportation time and cost estimation and sensitivity analyses of these parameters.

5. Methodological approaches

Since our main goal is to assess the throughput of the NSR and it does not presume any optimization, the methodology dedicated to optimization modeling is not considered. On the other hand, the transit in seriously influenced by stochastic factors (such as weather conditions and human factor). For this reason, the transit can be represented as a stochastic process. In this case, simulation modeling could be the best approach to our problem.

Simulation modeling is an imitation of the operation of a system over time. Simulation modeling is represented by two main approaches: continuous simulation and discrete event simulation. (Bernard et. al., 1976) Continuous Simulation refers to a computer model of a physical system that continuously tracks system response according to a set of equations. For instance, the amount of liquid in a tank and or its temperature. Such a system can be described by differential equations (Rossetti, 2015). On the contrary discrete event simulation produces a system, which changes its behavior only in response to specific events and typically models changes to a system resulting from a finite number of events distributed over time (Fishman, 2001). An example of such a system is the number of customers in the post office: the number of customers is discrete and the system changes when someone enters to the office or finishes its business (Rossetti, 2015). Discrete event simulation usually faster than continuous simulation and more suitable for large complex problems. It is convenient to present the transit as a sequence of events such as arriving an order, assigning a ship to a caravan, starting convoy. Therefore, discrete event simulation suites to analyze throughput in the NSR.

6. Solution approach

Discrete-Event Simulation (DES) is a modeling method that can be used in operations research. It allows building a model based on theoretical assumption and empirical observations about systems behavior. It enables to deduce the logic of organization of systems (Fishman, 2001).

6.1. Assumptions

In this part, we make some assumptions about how the transit of vessels can be represented. We assume only one single path along the NSR and don't use the route selection procedure to simplify the simulation model. The route is open for transit in both directions. All available icebreakers can navigate from three points on the West side and three points in the East. Those points were defined according to the division of Arctic seas into seven zones, with different ice conditions in particular month. Each point starts from another region according to the NSR administration (NSRA, 2015b). All these points could be at the same time starting point of navigation and finishing point, so we can consider them in some cases as origins and in some cases as destinations.

For simulation purposes, we consider that the number of orders for a whole navigation period is known. According to the NSR administration, the required departure date in the application for transit could be not later than three months from the date of application arrival and not earlier than two weeks before required departure. We use inter-arrival rate between orders and probability distribution to represent departure date for every application.

For simplification purposes, we consider that weather conditions during each month are constant and represented by the distribution of speed of the caravan which doesn't change from the beginning until the end of the month. These speed limitations based on Liu and Kronbak (2010) article. The second main thing connected with the weather in the NSR area is the ice thickness influences not only on the speed of the caravan but also to the ability to pass through the route with or without icebreaker support in the particular area. That influence appears in our model with three different ice classes for the vessels. According to the NSRA, there are more of them but we assume only three for simplicity.

As we mentioned above about particular areas of the NSR for which ships need or don't need icebreakers support, it is assumed in our model the subdivision the NSR region to several areas according to the NSRA. We have three potential start points on the east side of the NSR and three potential start points on the west side and the matrix of distances between them. Month weather conditions and the ice-class regulate the distance that caravan of vessels must be provided with icebreaker`s support.

All this weather and areas restriction of cause have the influence to caravans' formation. For simplification purposes, each caravan provides with only one icebreaker and has minimum and the maximum amount of vessels. Formation of the caravan depends on the ice-class of vessels and current month.

Taking into account all the previous factors and uncertainties in most of them such as weather conditions, ice thickness and human factor, the caravan dates of departure can have many differences and can not be predicted clearly. The customer desired departure date may differ significantly with an actual date which is suggested to the ship's owner. Some of the ship owners decide according to their personal desires and needs if they will use the NSR in spite of some probable delay or they will refuse and find another way to deliver their goods. We provide some assessments for the possible delay which customers are going to satisfy on average.

6.2. Description of the model

The NSR transit of vessels is represented as a stochastic system and relationships between elements of this system, such as transit orders, destinations, icebreakers and caravans of vessels. Every entity is considered as an application in the first part of the simulation and as a vessel inside of the caravan in the second part. State of the discrete event system determines in the discrete moments of time and causes with special occurs or events. In our model, we can distinguish such events as order arrival, month creation, the start of the caravan, the formation of the caravan, releasing from the queues. To make experiments we define the number available icebreakers and the number of transit orders during the navigation period and according to this input data formulate difference scenarios.

The objective is to simulate the transit of vessels along the NSR during the period of navigation in order to define the throughput of the system. We want to assess the percentage of satisfied orders changing the flow of vessels. To achieve these purposes, taken into consideration all assumptions above we want to present the logic of our simulation model starting with parameters description.

The table 6.2.1 describes parameters that necessary for the simulation model. Set of parameters was defined before the simulation model was created, and in the model building phase based on assumptions.

Deterministic parameters	**Description**
Departure point	Set of origins (destinations) from which icebreakers start to lead caravans. There are three points on the West side and the same number of points on the East side. The points are defined by the NSR information office (NSRIO, 2015).
Distance	The shortest route between possible origins (destinations) between Kara Gate and Bering Strait. The distances between points were calculated taking into account their location. Measured in kilometers.
Navigation period	The period when navigation through the NSR is possible. According to the NSR informational Office (NSRIO, 2015b), the standard navigational period is from mid-June till mid-November. In our experiments, we take a six-month period from beginning June until the end of November. Measured in month/days.
Pre-navigation period	The period when only applications come, and when there is no vessel navigation via the NSR. Three months of the non-navigational period from Marsh till May when a caravan of vessels is not sailing through the NSR. Measured in month/days.

Stochastic parameters	Description
Inter-arrival rate	Rate between arrivals of applications. Given by probability distribution.
Request departure time	A time when vessel desires to depart from the Port. Given by triangular probability distribution with minimum, maximum and mode values.
Ice-class of vessels	Different vessels ability to navigate according to various ice conditions. We assume all vessels have classes: Ice2 – Arc5, according to ice-class criteria's (NSRIO, 2015c). Arc-type of vessels is represented by a discrete probability distribution.
Icebreaker speed	The speed of icebreakers according to the ice condition (light, middle or harsh) in the particular navigation month (NSRA, 2016b). The parameter is given by triangular probability distribution with minimum, maximum and mode values.
Caravan size	The number of vessels that one icebreaker leads. Given by triangular probability distribution with minimum, maximum and mode values and measured in units.
Maximum delay time	The average time that each particular ship owner is going to postpone the order till it will be canceled.

Table 6.2.1. List of parameters.

6.3. Logic of the simulation model

The conceptual logic of the simulation model is visualized in the figure 6.3.1 and presented by a scheme which consists of numbered blocks. To describe the logic of our model we will follow the block numbers and will reveal them step by step.

The first step is input generating and it is like pre-simulation phase where we specify parameters and initial conditions for them. Some input data are deterministic parameters, for instance, departure point and navigation period. Other parameters are stochastic, for example, inter-arrival rate and ice-class of vessels.

The model logic branches into two ways: transit modeling (block 2) and month modeling (block 3). Transit modeling starts from the creation of orders for transit with exponential distributed inter-arrival rate (block 4). In the same time, month modeling branch creates month with the certain number of days. Here we determine pre-navigation and navigation period of the simulation. Orders arrive in a way the flow of orders of first three months comes to three initial months of the navigation period. According to the NSR administration´s rules, the order cannot be placed earlier than 3 months before desired navigation date. To make the flow of orders spread evenly for the first navigation month and further months we provide significantly larger arrival rate for the first and second months.

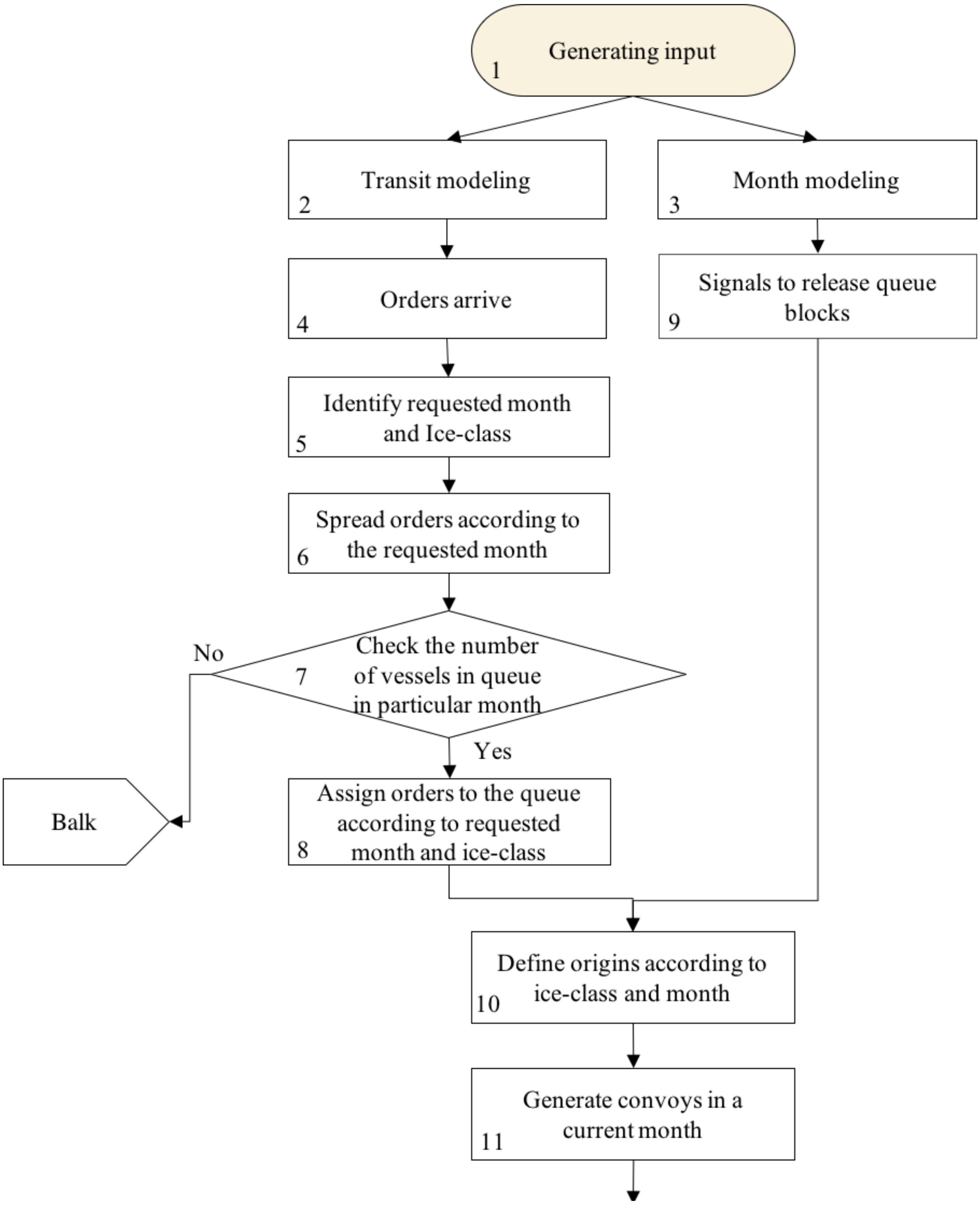
Orders arrive from West and East sides of the Northern Sea Route. Each order arrives has a desirable departure date and an ice-class of vessels. According to the NSR administration, desirable date of navigation in the received application must not be less than two weeks after application date and not more than three months. Therefore, the first order may arrive 3 months before the start of navigation, and that is why three months of the simulation are non-navigational. Then in this step, we identify requested a month of departure and vessel`s ice-class (block 5).

The next step is distributing of orders to the six navigational months according to their desired date of departure (block 6). All orders are going to be sent to the queues specified to each month of navigation and divided by three ice-classes. But starting from a certain number of order rest of them should be canceled due to a limited number of icebreakers. The next model block (block 7) checks the number of orders in the queues and if it is too many for the particular month, an incoming order balks. For the orders which desirable month is already started, we have another decision logic that checks queues of the caravans before the transit, and an order would be balked if the number of caravans in that queue is not reasonable.

In the next stage of our simulation model, collected orders should be released from the queues to start a current month of navigation period (block 9). When the simulation month has started the flow of the orders goes to assign to one of the origins or starting points according to the vessel ice-class and the current month (block 10). After that, the orders flow is divided into three ways in the West and in the East in the same way. In each branch, caravans are formed according to first in first out rule. The orders with the close desirable date of departure forms to the caravan (block 11).

In case, during the caravan forming, the maximum delay time of one of the orders exceeded then the order balks and goes out of the system (block 12).

After a convoy was formed it was assigned to an icebreaker (block 13) and if there were available at the moment. In case, all icebreakers are busy, the caravan goes to the queue. Then the icebreaker is assigned to the caravan. In the next step, a caravan leading with icebreaker is assigned to the destination point. A further logical block of the simulation model transports a caravan from the selected origin to destination (block 14). After the transportation is finished, the icebreaker is free and can be used by another convoy. Before the caravans released from the system, they separated into particular vessels to count the number of orders passed (block 15). To analyze how many orders were bulked we count them before bulking to collect output statistics (block 16). In addition, we are interested in average delay time of the vessel before shipping in the model. We talk about output statistics in detail in the experiments and results chapter.



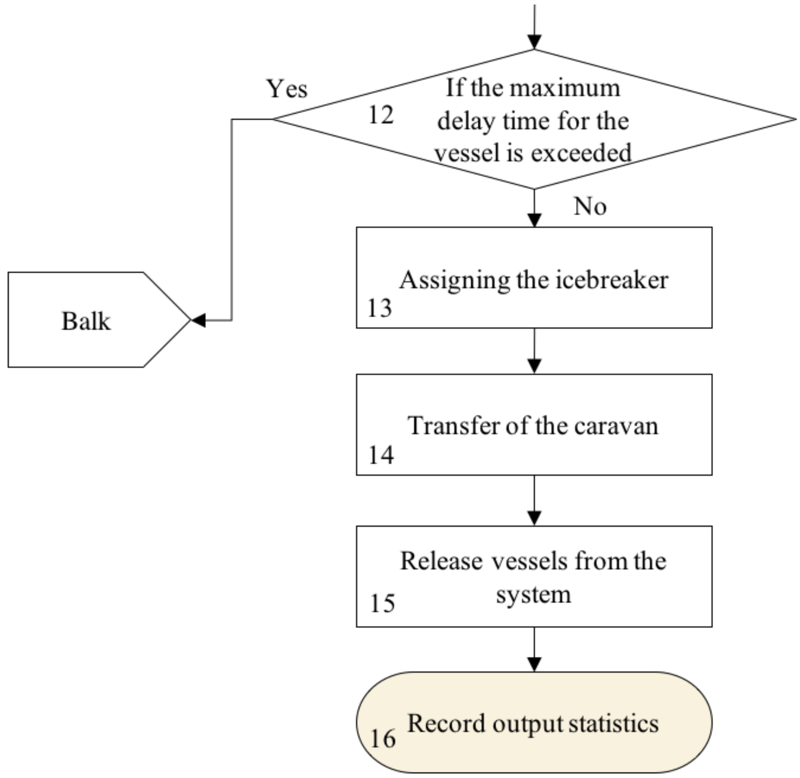


Figure 6.3.1. The conceptual logic of the simulation model for assessment of transit via the NSR.

7. Experiments and results

In this section, we describe input data, consider different scenarios for experiments and analyze obtained output results.

The simulation program was built employing Arena Discrete-Event Simulation Software (version 14.7), developed by Rockwell Automation, which has the following main features (Arena Simulation Software, 2017):

- Flowchart modeling methodology includes a large library of pre-defined building blocks to model your process without the need for custom programming;
- Complete range of statistical distribution options to accurately model process variability;
- Ability to define object paths and routes for simulation;
- Statistical analysis and report generation;
- Performance metrics and dashboards.

In **Appendix A,** the constructed simulation model with Arena modules can be found.

7.1. Data

This section is focused on the generation of the input data.

Navigation period

In our experiment, we have considered two periods: pre-navigation and navigation. Pre-navigation period is a time when the transit of vessels is not carried out but orders can be accepted. It is three months, from Marsh till May. The second period is navigation period that begins from June and ends in November. In this case, icebreakers start to support vessels through the NSR and orders also can be accepted.

Ice-class of vessels

Ice-class of the vessel is defined based on statistical analysis of the previous years (NSRIO, 2013) and given by discrete probability distribution. We consider three ice-classes: Arc1, Arc3, Arc5, where 20% of the vessel have ice-class is Arc1 of the total number of vessels passed the Northern Sea Route, 30% of Arc3 and 50% of Arc5.

Set of origins

Every vessel desired to transit the NSR has an ice-class. And according to the NSR administration criteria has restricted areas where icebreakers support is required taking ice-classes into account (NSRA, 2015b). The month of navigation period also should be considered. For every ice-class and navigation month, we define an origin and destination points as to points between which icebreaker support is required (**Appendix F).**

Distances

We consider the shortest way between Kara Gate and Dezhnev Cape. The distances between intermediate points of this route were calculated according to the location of these origins (NSRIO, 2015b). Distance matrix table is shown in **Appendix B**, includes distances between origins and destinations.

Inter-arrival rate

The statistic data for the inter-arrival rate was received from previous years' statistics of monthly demand of the vessel transit from Northern Europe to Asia through the Suez Canal route (Suez Canal Authority, 2016). And it is implemented as a proportion of the inter-arrival rate for each month of navigation and non-navigation period (**Appendix C).**

Request departure time

Each order that arrives at the system has the attribute of desired departure date. Each departure date defines as a triangular distribution number with minimum 14 days from arrival and maximum 90 days. For the first three months, we provide floating minimum days from arrival value in order to provide that navigation period starts from the fourth month.

Icebreaker speed

Speed of icebreakers in each navigation month is provided in **Appendix D**. The speed table is from Schøyen and Bråthen (2011) article. It was given by triangular probability distribution: TRIA (13.2, 13.89, 14.01) with lower limit 13.2, upper limit 14.01 and mode 13.89 is most likely value.

Caravan size

Convoy formation can be different in terms of vessels ice-class (Šarlaj, 2016). Relying on this data, we can describe caravan size using the triangular probability distribution in the range of two finite numbers: minimum, maximum; and most probable value: ANINT (TRIA (2, 3, 5)). Caravan size computations are shown in **Appendix E**.

7.2. Scenarios

The maximum transit order number passed through the NSR in previous years was 71 in 2013 (NSR Information office, 2016). So, we can say that the route was not used on the large scale. In order to assess the throughput, we decided to provide different possible scenarios of the total number of vessels to pass the NSR. Starting from 70 vessels and increasing that number to extra 70 units till it reaches 700 (table 7.2.1).

Scenarios										
Total number of orders to pass	70	140	210	280	350	420	490	560	630	700

Table 7.2.1. Combinations of scenarios for a different number of orders.

Also, an important thing is the number of icebreakers operating. The number of icebreakers limits the possibility to pass the NSR for a significant amount of the ships. The icebreakers have their own time of service and when it passed, they are out of operation, but in the same time, new icebreakers are under construction. So we consider that it is reasonable to use not only different a total number of orders but also a different number of icebreakers in operation (table 7.2.2).

Scenarios				
Icebreakers number	3	4	5	6

Table 7.2.2. Combinations of scenarios for a different number of icebreakers.

The total number of scenarios that we provide, will be 4 different icebreakers multiplied by 10 various total number of orders: 40 different scenarios as a result.

7.3. Results

In the results section, we implemented all the scenarios to our simulation model and obtained a number of vessels passed through the NSR for each scenario. The numbers are shown in the table 7.3.1 and in order to discover some trends from this data we also put this data to the graph which is represented here bellow.

	Number of orders (passed)									
Number of Icebreakers	70	140	210	280	350	420	490	560	630	700
3	27,37	65,21	94,24	111,6	115,36	118,11	119,3	119,72	120,29	120,89
4	26,97	67,56	103,24	131,63	151,72	156,16	160,44	162,4	163,82	169,04
5	27,13	75,22	112,18	152,49	178,07	195,28	204,27	206,13	210,37	213,13
6	27,07	77,56	124,89	162	195,56	223,19	241,88	253,22	255,22	258,84

Table 7.3.1. Vessels passed for different scenarios.

On the figure 7.3.1, we can see the trends of a number of vessels passed if the orders arrival rate increasing partially. There is a similar thing among the curves with a different number of icebreakers, all of them first grow rapidly and then comes some kind of breaking point after which the growth almost stops. The reason for such behavior is obvious and hides above the icebreaker limitation. When it faces with route capacity the increasing of the number of satisfied orders almost stops and the point after which it occurs depends on a number of icebreakers operating. For less number of icebreakers, it comes earlier and later when these number growths.

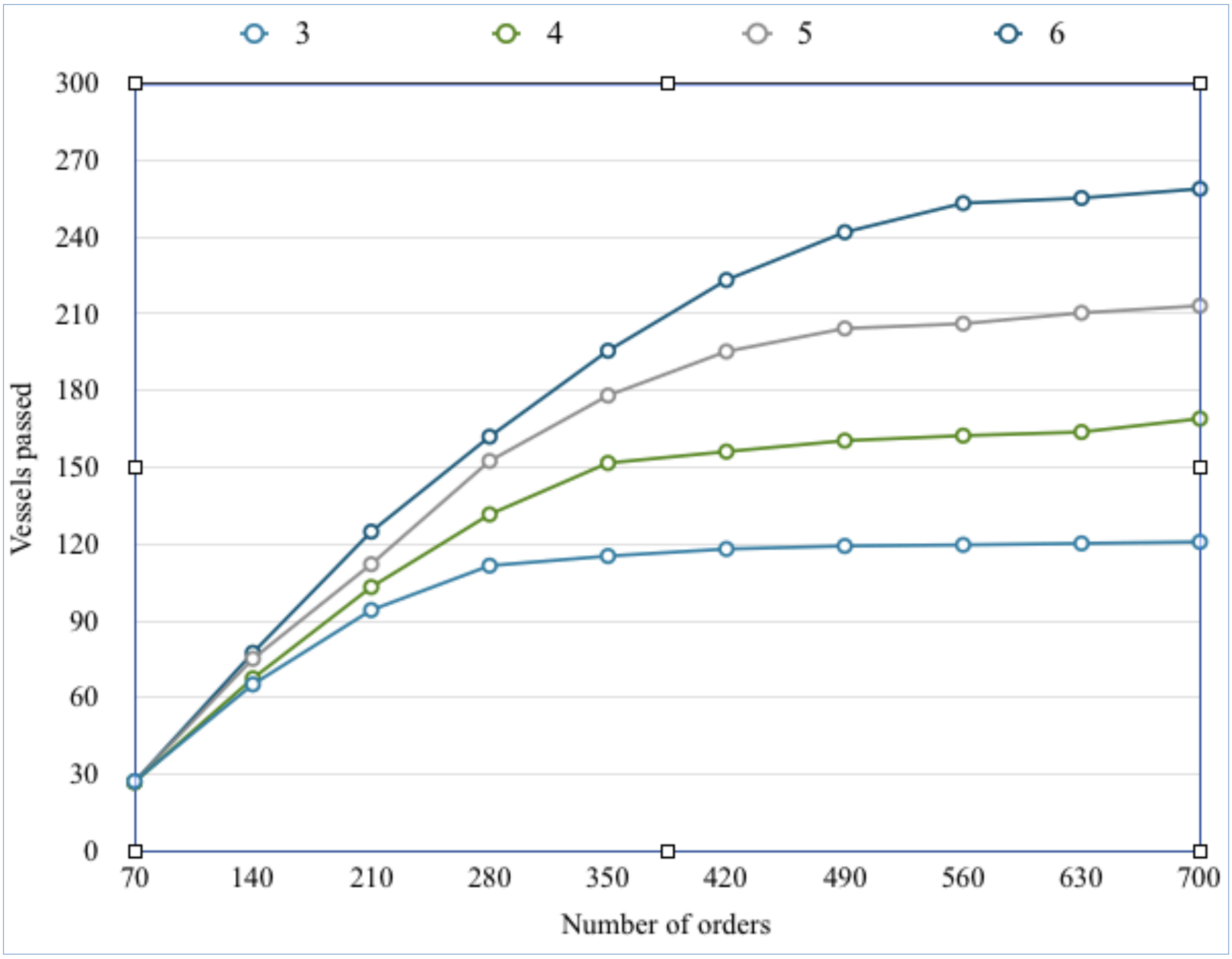


Figure 7.3.1. The number of vessels passed the NSR for each number of icebreakers.

The figure discussed above gives rather obvious information and don’t allow as to analyze sufficiently the system actual trends. That is why we provide first experimental design factor as the percentage of orders satisfied during navigation period. (Figure 7.3.2). From this graph, we can see a trend which we didn’t expect to discover from the beginning. The percentage of satisfied orders starts to growth, increasing at some point and start decreasing after that. It can be caused by some reasons which are not so obvious from the first glance. As one of them, we can name the fact that if the number of orders is relatively small it is harder to find the number of vessels which can form the caravan because the maximum delay which vessel is going to wait before the shipment. During caravan generation, the planned convoy start dates can deviate significantly from requested transit start dates, resulting in many orders being canceled due to the exceeded limit on maximum delay. Figure 7.3.2 shows as the maximum number of orders satisfied are 60 percent for 6 icebreakers with 210 orders in the navigation period and around 18 percent for 3 icebreakers and 700 orders.

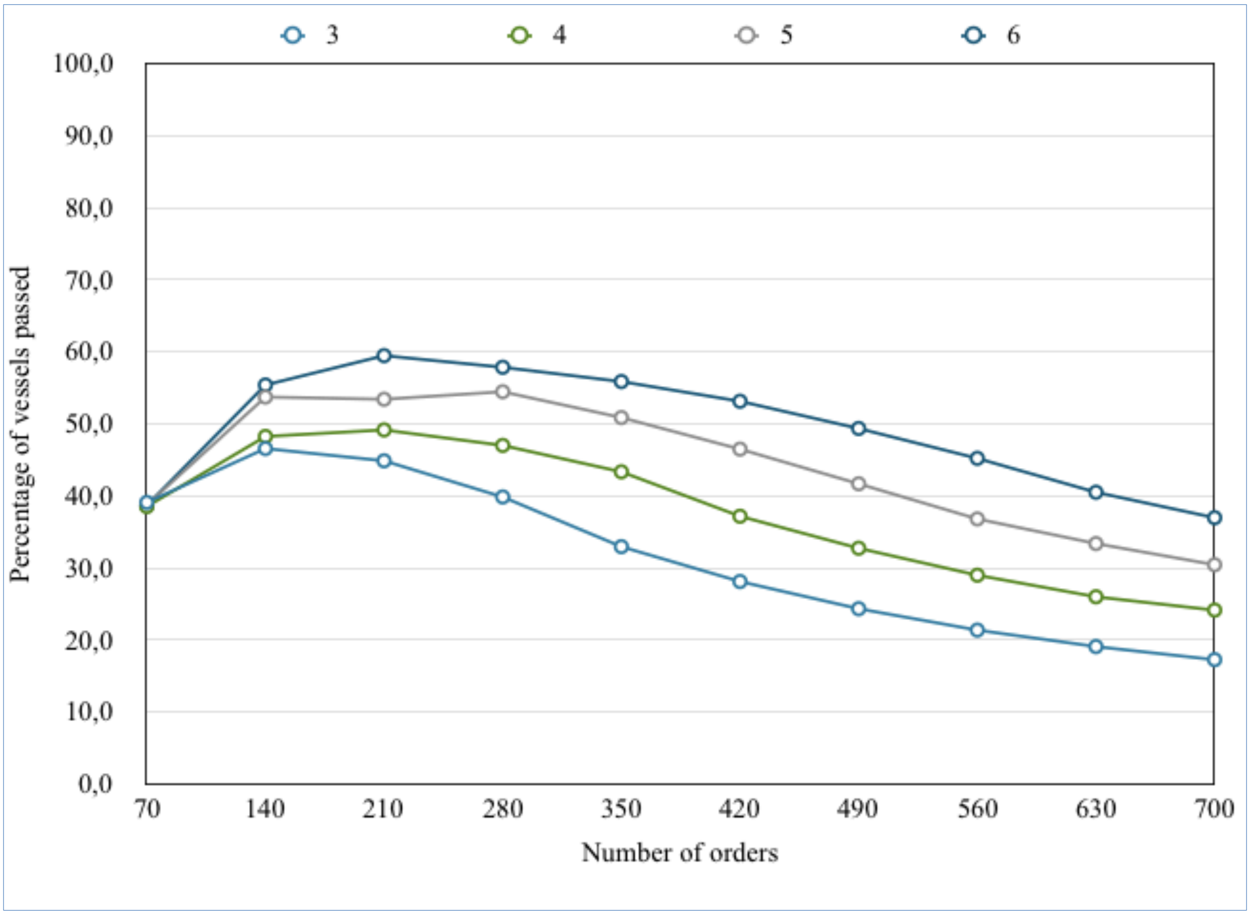


Figure 7.3.2. Percent of satisfied orders for each scenario.

Second experimental design factor is average waiting time. This is an average time in the system that vessel is waiting for an icebreaker to lead. Figure 7.3.3 shows us a strong trend of decreasing customers waiting time in the beginning, but then it stops to decline and even shows a slight trend of growth. There are some of the reasons causes such behavior. The main reason of so large average waiting time for the small number of vessels going to pass the NSR is that the shipments appear quite rarely. For instance, all the icebreakers located in the west or in the east part of the NSR then caravan needs to wait for a shipment from the other side of the NSR and it could be quite a long time to wait. But, when the number of orders becomes larger, a system is more stable and not showing any significant changes in the average waiting time. It represents a just slow trend for increasing due to a number of orders in the system growing. It is not showing any significant grow because the system organized in a way to avoid a large queue of caravans.

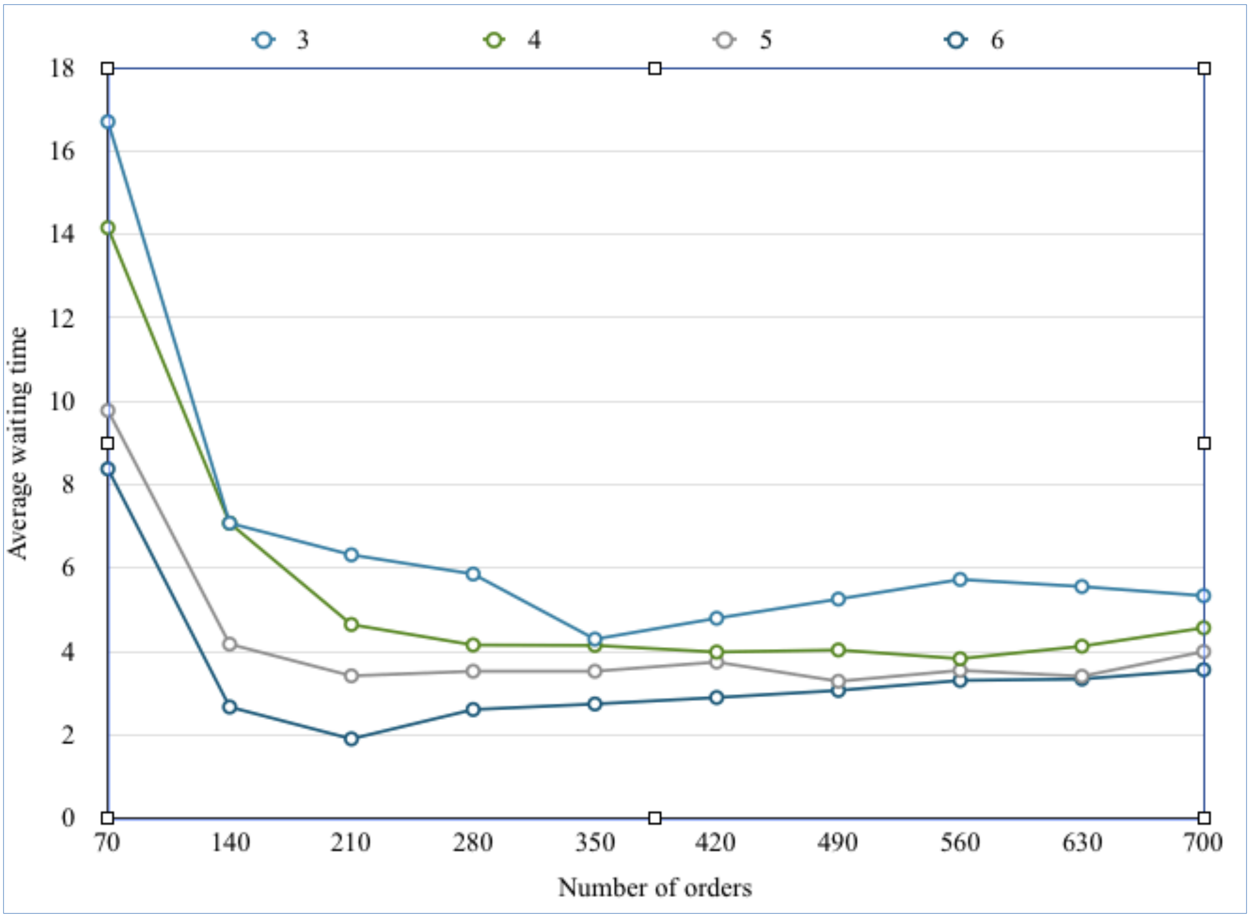


Figure 7.3.3. Average waiting time of caravans for each scenario.

8. Conclusion

This section provides conclusions based on experimental results and possible ways for future research in this area.

The main purpose of this thesis was to analyze the throughput capacity of the NSR. We defined factors affecting the throughput, such as uncertain weather and ice condition, limited number of icebreakers, ice-class of vessels, speed of vessels, caravan formation, delay time, decision logics. As methodology for solving this task, we use discrete-event simulation, due to uncertain factors.

To make analysis, different scenarios was implemented through different number of icebreakers and different number of orders for transit through the NSR. Results of experiments demonstrate that increasing in the total number of orders lead to essential increase in the fraction of order satisfy and average waiting time diminution. Further growth in the total number of orders changes the trend to the opposite. We have conformation of our expectations that increase in the number of icebreakers in operation leads to a greater fraction of the satisfied order and shorter average waiting time.

The created simulation model may be used for the throughput assessment in terms of different fleet of icebreakers and growing demand. It can help shippers and transit providers operating in the NSR area.

For the future research, we recommend to incorporate more advanced weather conditions data, to explore decision making logic process in detail.

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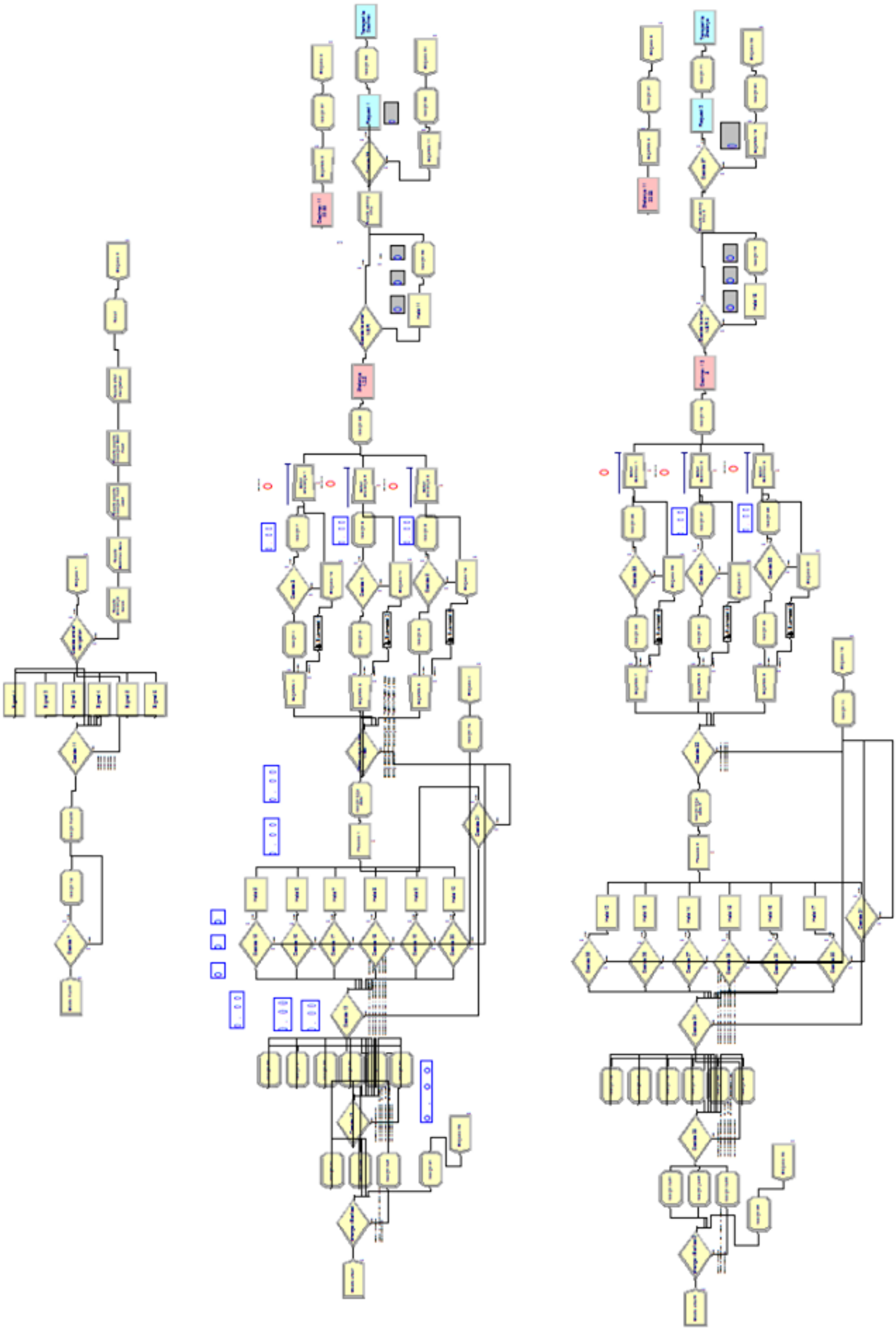
Appendix A

The simulation model in a general view.



Appendix B

The distance between possible origins and destinations. Measured in kilometers.

Starting station	Ending station	Distance
Zhelanya1	Zhelanya 11	0
Zhelanya1	Zhelanya2	2050
Zhelanya1	Zhelanya 22	2050
Zhelanya1	Zhelanya3	1550
Zhelanya1	Zhelanya 33	1550
Zhelanya1	Dezhnev 1	5600
Zhelanya1	Dezhnev 11	5600
Zhelanya1	Dezhnev 2	3550
Zhelanya1	Dezhnev 22	3550
Zhelanya1	Dezhnev 3	4050
Zhelanya1	Dezhnev 33	4050
Zhelanya2	Zhelanya1	2050
Zhelanya2	Zhelanya 11	2050
Zhelanya2	Zhelanya 22	0
Zhelanya2	Zhelanya3	500
Zhelanya2	Zhelanya 33	500
Zhelanya2	Dezhnev 1	3550
Zhelanya2	Dezhnev 11	3550
Zhelanya2	Dezhnev 2	1500
Zhelanya2	Dezhnev 22	1500
Zhelanya2	Dezhnev 3	2000
Zhelanya2	Dezhnev 33	2000
Zhelanya3	Zhelanya1	1550
Zhelanya3	Zhelanya 11	1550
Zhelanya3	Zhelanya2	500
Zhelanya3	Zhelanya 22	500
Zhelanya3	Zhelanya 33	0
Zhelanya3	Dezhnev 1	4050
Zhelanya3	Dezhnev 11	4050
Zhelanya3	Dezhnev 2	2000
Zhelanya3	Dezhnev 22	2000
Zhelanya3	Dezhnev 3	2500
Zhelanya3	Dezhnev 33	2500

Starting station	Ending station	Distance
Zhelanya 11	Zhelanya1	0
Zhelanya 11	Zhelanya2	2050
Zhelanya 11	Zhelanya 22	2050
Zhelanya 11	Zhelanya3	1550
Zhelanya 11	Zhelanya 33	1550
Zhelanya 11	Dezhnev 1	5600
Zhelanya 11	Dezhnev 11	5600
Zhelanya 11	Dezhnev 2	3550
Zhelanya 11	Dezhnev 22	3550
Zhelanya 11	Dezhnev 3	4050
Zhelanya 11	Dezhnev 33	4050
Zhelanya 22	Zhelanya1	2050
Zhelanya 22	Zhelanya 11	2050
Zhelanya 22	Zhelanya2	0
Zhelanya 22	Zhelanya3	500
Zhelanya 22	Zhelanya 33	500
Zhelanya 22	Dezhnev 1	2050
Zhelanya 22	Dezhnev 11	2050
Zhelanya 22	Dezhnev 2	1550
Zhelanya 22	Dezhnev 22	1550
Zhelanya 22	Dezhnev 3	2050
Zhelanya 22	Dezhnev 33	2050
Zhelanya 33	Zhelanya1	1550
Zhelanya 33	Zhelanya 11	1550
Zhelanya 33	Zhelanya2	3550
Zhelanya 33	Zhelanya 22	3550
Zhelanya 33	Zhelanya3	0
Zhelanya 33	Dezhnev 1	3550
Zhelanya 33	Dezhnev 11	3550
Zhelanya 33	Dezhnev 2	4050
Zhelanya 33	Dezhnev 22	4050
Zhelanya 33	Dezhnev 3	2500
Zhelanya 33	Dezhnev 33	2500

The distance between possible origins (destinations). Measured in kilometers.

Starting station	Ending station	Distance
Dezhnev 1	Zhelanya1	2000
Dezhnev 1	Zhelanya 11	2000
Dezhnev 1	Zhelanya2	3550
Dezhnev 1	Zhelanya 22	3550
Dezhnev 1	Zhelanya3	4050
Dezhnev 1	Zhelanya 33	4050
Dezhnev 1	Dezhnev 11	0
Dezhnev 1	Dezhnev 2	2050
Dezhnev 1	Dezhnev 22	2050
Dezhnev 1	Dezhnev 3	1550
Dezhnev 1	Dezhnev 33	1550
Dezhnev 2	Zhelanya1	3550
Dezhnev 2	Zhelanya 11	3550
Dezhnev 2	Zhelanya2	1500
Dezhnev 2	Zhelanya 22	1500
Dezhnev 2	Zhelanya3	2000
Dezhnev 2	Zhelanya 33	2000
Dezhnev 2	Dezhnev 1	1550
Dezhnev 2	Dezhnev 11	1550
Dezhnev 2	Dezhnev 22	0
Dezhnev 2	Dezhnev 3	500
Dezhnev 2	Dezhnev 33	500
Dezhnev 3	Zhelanya1	4050
Dezhnev 3	Zhelanya 11	4050
Dezhnev 3	Zhelanya2	4050
Dezhnev 3	Zhelanya 22	2000
Dezhnev 3	Zhelanya3	2500
Dezhnev 3	Zhelanya 33	2500
Dezhnev 3	Dezhnev 1	1550
Dezhnev 3	Dezhnev 11	1550
Dezhnev 3	Dezhnev 2	500
Dezhnev 3	Dezhnev 22	500
Dezhnev 3	Dezhnev 33	0

Starting station	Ending station	Distance
Dezhnev 11	Zhelanya1	5600
Dezhnev 11	Zhelanya 11	5600
Dezhnev 11	Zhelanya2	3550
Dezhnev 11	Zhelanya 22	3550
Dezhnev 11	Zhelanya3	4050
Dezhnev 11	Zhelanya 33	4050
Dezhnev 11	Dezhnev 1	0
Dezhnev 11	Dezhnev 2	2050
Dezhnev 11	Dezhnev 22	2050
Dezhnev 11	Dezhnev 3	1550
Dezhnev 11	Dezhnev 33	1550
Dezhnev 22	Zhelanya1	3550
Dezhnev 22	Zhelanya 11	3550
Dezhnev 22	Zhelanya2	1500
Dezhnev 22	Zhelanya 22	1500
Dezhnev 22	Zhelanya3	2000
Dezhnev 22	Zhelanya 33	2000
Dezhnev 22	Dezhnev 1	2050
Dezhnev 22	Dezhnev 11	2050
Dezhnev 22	Dezhnev 2	0
Dezhnev 22	Dezhnev 3	500
Dezhnev 22	Dezhnev 33	500
Dezhnev 33	Zhelanya1	4050
Dezhnev 33	Zhelanya 11	4050
Dezhnev 33	Zhelanya2	2000
Dezhnev 33	Zhelanya 22	2000
Dezhnev 33	Zhelanya3	2500
Dezhnev 33	Zhelanya 33	2500
Dezhnev 33	Dezhnev 1	1550
Dezhnev 33	Dezhnev 11	1550
Dezhnev 33	Dezhnev 2	500
Dezhnev 33	Dezhnev 22	500
Dezhnev 33	Dezhnev 3	0

Appendix C

Inter-arrival rate of orders.

Month	Number of orders									
	70	140	210	280	350	420	490	560	630	700
1	16,02	8,01	5,34	4,02	3,21	2,67	2,28	2,01	1,77	1,59
2	8,01	4,01	2,67	2,01	1,605	1,335	1,14	1,01	0,885	0,795
3	5,34	2,67	1,78	1,34	1,07	0,89	0,76	0,67	0,59	0,53
4	5,34	2,67	1,78	1,34	1,07	0,89	0,76	0,67	0,59	0,53
5	5,34	2,67	1,78	1,34	1,07	0,89	0,76	0,67	0,59	0,53
6	5,34	2,67	1,78	1,34	1,07	0,89	0,76	0,67	0,59	0,53
7	8,01	4,01	2,67	2,01	1,605	1,335	1,14	1,01	0,885	0,795
8	10,68	5,34	3,56	2,68	2,14	1,78	1,52	1,34	1,18	1,06
9	5,34	2,67	1,78	1,34	1,07	0,89	0,76	0,67	0,59	0,53

Appendix D

Icebreakers speed probability distribution.

Navigation Month	Speed
4	TRIA(13.2,13.89, 14.01)
5	TRIA(18.1,18.5, 18.8)
6	TRIA(20.3, 20.74, 20.9)
7	TRIA(20.3, 20.74, 20.9)
8	TRIA(19.1,19.63, 20.2)
9	TRIA(16.2, 16.85, 17.21)

Appendix E

Caravan size for Western origins.

Set of origins	Batch size
Zhelanya 1	ANINT(TRIA(2,3,5))
Zhelanya 2	ANINT(TRIA(3,5,8))
Zhelanya 3	ANINT(TRIA(4,7,10))

Caravan size for Eastern origins

Set of origins	Batch size
Dezhnev 1	ANINT(TRIA(2,3,5))
Dezhnev 2	ANINT(TRIA(3,5,8))
Dezhnev 3	ANINT(TRIA(4,7,10))

Appendix F

Eastern origins for each month and type of vessel.

Month	Ice-class of vessels		
	Arc1	Arc3	Arc5
1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	0.0	0.0	0.0
4	Dezhnev 1	Dezhnev 2	Dezhnev 2
5	Dezhnev 1	Dezhnev 2	Dezhnev 3
6	Dezhnev 3	Dezhnev 3	Dezhnev 3
7	Dezhnev 3	Dezhnev 3	Dezhnev 3
8	Dezhnev 2	Dezhnev 2	Dezhnev 3
9	Dezhnev 1	Dezhnev 1	Dezhnev 2

Western origins for each month and type of vessel.

Month	Ice-class of vessels		
	Arc1	Arc3	Arc5
1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	0.0	0.0	0.0
4	Zhelanya1	Zhelanya2	Zhelanya2
5	Zhelanya1	Zhelanya2	Zhelanya2
6	Zhelanya3	Zhelanya3	Zhelanya3
7	Zhelanya3	Zhelanya3	Zhelanya3
8	Zhelanya2	Zhelanya2	Zhelanya3
9	Zhelanya1	Zhelanya1	Zhelanya2