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Risk-Based Design Methodology for an Ice-Classed Multipurpose OSV

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Abstract

According to US Geology Survey of 2009, 30 % of the world's undiscovered gas and 13% of the world's undiscovered oil may be located in the Arctic area. Due to a high demand for energy resources and a reduction trend in the ice covered area in the Arctic Seas, more attention is paid to the oil and gas exploration in the high north. Several oil and gas fields have been explored and more are under development in the Barents Sea. In order to ensure safe and economic oil and gas production in this region, highly specialized vessels are needed. This thesis considers the problem of developing a methodology for an ice class offshore supply vessel.

The purpose of the study was to evaluate the effect of Arctic related challenges on the ship design methodologies and to find a suitable ship design method. Three ship design methodologies have been studied and developed to meet Arctic challenges related to the Barents Sea. By evaluating the qualitative aspects of each design, one ship design method (Risk Based Design) was recommended involving potential of solving all the selected Arctic challenges. A case study, given for a particular part of the Barents Sea has been studied and risk based design methodology has been successfully utilized for this particular part of the Barents Sea. Also, a code has been developed to provide quick solutions to the designer particularly for this case. Solutions have been provided with different ice class vessels with their cost assessment and it has been found that with a high ice breaker fee, the total life cycle cost difference between ICE 1C and ICE 1B is marginal.

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Task Description

THESIS WORK 2013
For
A.D. M. Abdur Rahman

A risk-based design methodology for an ice-classed multipurpose OSV

It is estimated that 22% of the world's undiscovered petroleum resources are located in the Arctic, 84% projected to be offshore, majority in West and Eastern Siberian Basin (US Geology Survey, 2008). Hence, this project concerns the design of OSVs in view of the continuous movement towards the northern Arctic, which will be ice covered for a majority of months per year in the future. Hence, in order to ensure safe and economic oil and gas explorations and production in these regions highly specialized vessels are needed. Therefore, this project is concerning with the development of a risk-based design methodology for a multipurpose ice-classed OSV to identify the sensitivity of the design variation to CAPEX, OPEX and VOYEX.

The following aspects shall be considered for the risk-based design methodology concept:
--- Design drivers concerning safe operations in the high north
--- Multi-purpose nature of the OSV (transport, oil spill response, EER and SAR)
--- Relevant-actions and their future perspective in view of the operational window
--- OW-base case assessment for comparison of the expenditure shares.

The work shall be carried out in the following steps
1) Literature review of different ship designs including risk-based design method to identify one optimal design solution for arctic ship design
2) Familiarization with the Arctic Sea region, especially the Barents Sea (infrastructure, inhabitants, general conditions)
3) Literature review of OSV concepts (design methods, criteria and constraints incl. polar codes)
4) Literature review of cost assessment methodologies for CAPEX, OPEX and
VOYEX
5) Utilization of merit factors to perform the design comparison and sensitivity study
6) Presentation of the findings and results, both on a generally applicable level as well as with the use of a case study
7) Development of the risk-based design methodology suitable for the conceptual design of ice-classed vessels
8) The required conditions shall be discussed which make your findings feasible considering the stakeholder preferences today and in the short- and long-term future
9) The conditions, assumptions and limitations of your study shall be discussed with respect to physical relevance
10) Conclusions and recommendations for further work

Literature studies of specific topics relevant to the thesis work may be included.

The work scope may prove to be larger than initially anticipated. Subject to approval from the supervisors, topics may be deleted from the list above or reduced in extent.
Theories and conclusions should be based on mathematical derivations and/or logic reasoning
Theories and conclusions should be based on mathematical derivations and/or logic reasoning identifying the various steps in the deduction.
The candidate should utilize the existing possibilities for obtaining relevant literature.

Thesis format
The thesis should be organized in a rational manner to give a clear exposition of results, assessments, and conclusions. The text should be brief and to the point, with a clear language and the objective to be published in a conference article and/or scientific journal. Telegraphic language should be avoided.
The thesis shall contain the following elements: An executive summary, list of symbols and acronyms, followed by the main body of the thesis consisting of a brief background introduction, a state of the art defining the knowledge gaps defining the scope or work and limitations, the actual contribution chapters, conclusions with recommendations for further work, references and (optional) appendices. All figures, tables and equations shall be numerated.
The supervisors may require that the candidate, in an early stage of the work, presents a written plan for the completion of the work. The plan may include a budget for the use of computer and laboratory resources if applicable, which will be charged to the department. Overruns shall be reported to the supervisors.
The original contribution of the candidate and material taken from other sources shall be clearly defined following basic academic principles and an acknowledged referencing system, which includes the name of the referred authors followed by the publication year in the text. The subsequent reference list can thus be alphabetical.
The report shall be submitted in two copies:
- Signed by the candidate
- The text defining the scope included
- In bound volume(s)
- Drawings and/or computer prints, which cannot be bound should be organized in a separate folder.
- The report shall also be submitted in PDF along with essential input files for computer analysis, spread sheets, MATLAB files etc. in digital format.

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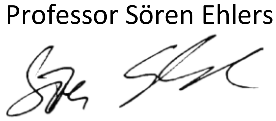
Deadline: June 10, 2013

Thesis supervisors
Professor Sören Ehlers



Trondheim, June 7, 2013

Preface

This Master Thesis completes the work of my *Master of Science* degree in Marine Technology at the Norwegian University of Science and Technology (NTNU), and is the result of the work carried out during the spring semester of 2013.

The objective of this work has been to develop a risk-based design methodology for an ice-classed OSV to identify the sensitivity of the design variation to CAPEX, OPEX and VOYEX. The thesis project is completed step by step towards the objective. The main focus was on the Arctic challenges related to the Barents Sea, different types of ship designs and implementation of the most suitable one for Arctic ship design.

First of all, I would like to thank my responsible supervisor at NTNU, Professor Sören Ehlers for valuable input, discussions, help and guidance throughout the work of this thesis. It has been highly appreciated. I would also like to thank Professor Tor Einer Berg for help and guidance with the wave analysis. Lastly, I would also like to thank my friend Edward Medvedev for helping me with the code. Writing a thesis can be a very solitude process, but thanks to the support of above mentioned supervisors, family and friends, it has been a very pleasant journey for me, here in Norway.

Trondheim, 10th June, 2013.

A.D.M. Abdur Rahman

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Nomenclatures

Loa =Length Overall

Lpp =Length between Perpendicular

B = Breadth

D=Depth

T (max) = Draft Maximum

T (Design) = Design Draft

DWT = Deadweight Tonnage

C_b – Block Co-efficient

S – Stiffener Spacing

P_s – Machinery Output

t- Plate Thickness

σ -Yield Strength

h_o - Maximum Ice Height

h - Design Ice Height

p- Ice Pressure

Rch - Resistance of the Ship

D_p -Diameter of Propeller

k_e, f_2,c_i, c_d, a, b – Different Factors

Acronyms

IMO – International Maritime Organization

ISO – International Organization for Standardization

OSV- Offshore Supply Vessel

PSV-Platform Supply Vessel

EU-European Union

SOLAS – Safety of Life at Sea

MARPOL – Prevention of Pollution from Ships

AFS – Anti-Fouling system

BWM – Ballast Water Management (Not yet in force) Convention on Load Lines

STCW – Standards of Training, Certification and Watchkeeping

COLREG –Preventing Collisions at Sea

RBD – Risk Based Design

UR IACS – Unified Requirements of International Association Classification Societies (Draft)

CASPPR – Canadian Arctic Shipping Pollution Prevention Regulation

FSR – Finnish-Sweden Rules

LR – Lloyd's Register

GL – Germanisher Lloyd

DNV – Det Norske Veritas

ABS – American Bureau of Shipping

RR – Russian Register

SMF – Ship Merit Factor

1. INTRODUCTION

According to US geological survey 2008, Arctic area is rich in oil and gas. By using probabilistic survey, the United States Geological Survey assessed the area north of the Arctic Circle. It was concluded that around 30% of the world's undiscovered gas and 13% of the world's undiscovered oil may be found there, mostly offshore and under less than 500 meters of water. [2] Besides these facts, the amount of ice is decreasing and more oil and gas exploration works are going on in Arctic areas (Figure 1). Hence, in order to ensure safe and economic oil and gas explorations and production in these regions highly specialized vessels are needed.

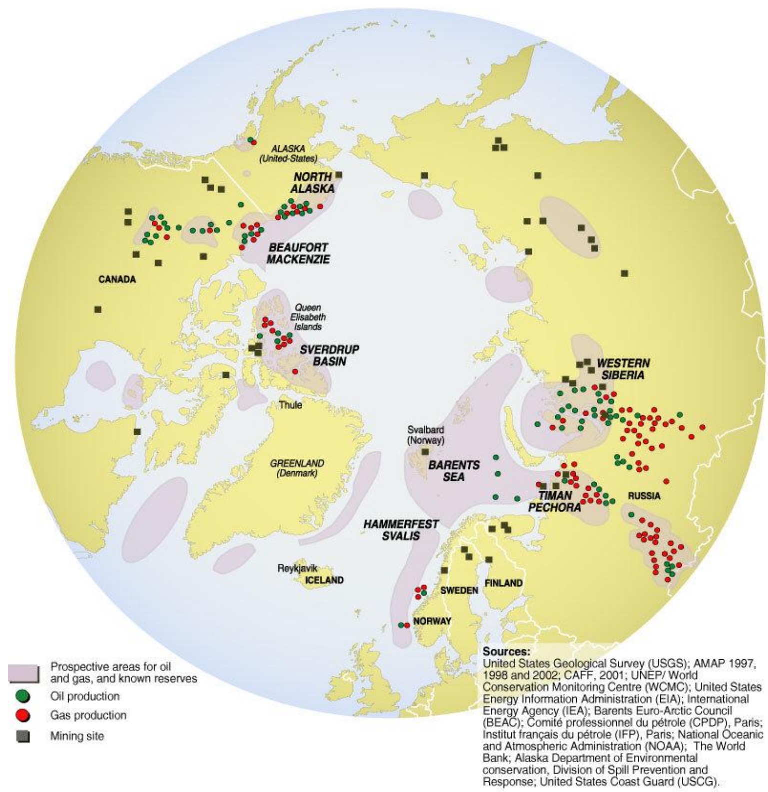


Figure 1: Fossil fuel resources and oil and gas production in the Arctic[1]

The general mission of the thesis is to identify a suitable conceptual design method for offshore supply vessel which is applicable to Arctic areas. Different Arctic Seas offer different ice and weather conditions. The challenges are related to harsh polar weather conditions, selection of appropriate ice class which will give economic success. For safe and economic success, robust ship design methodology is required for specific Arctic operation.

So far, there is no specified guideline for Arctic ship design. Existing ship design methods are mainly developed for open water operation; not for Arctic water. Some ship design methods are based on rules and these rules are developed in the wake of major accidents which happened mostly in open operator. Some ship design methods are based on existing successful merchant vessels database which are mainly non ice class. Some ship design methods covers novel design supports by providing risk analysis. For example, while developing risk based ship design in SAFEDOOR project (2005-2009), three applications of risk based ship design were elaborated. [3] First one was a RoPAX vessel, second one was an AFRAMAX tanker and the third one was a Ferry. While in the system based ship design method book several vessel designs are described such as Container vessel, RoRo, Ferry, Bulk carrier, Tanker etc. [4] However, all the design methods show how the vessels should be built in open, ice free water. None of them provides clear methodology to surpass the distinct Arctic challenges and to ensure a safe and economic feasibility. This identifies the lack of a ship design methodology for Arctic operation.

Therefore those methods are needed to be analyzed and developed for Arctic challenges. The hypothesis of this thesis is the evaluation of different ship design methods to identify their suitability in the integration of Arctic design requirements and the application of the most suitable method in a case study to justify it.

To do so, this study focuses on the following points, which coincide with the chapters of the report. Firstly, different types of ship designs will be analyzed. Secondly, the challenges offered by one of the Arctic Seas, such as harsh weather conditions, infrastructure and communication problems will be discussed. Thirdly, different ship design processes will be evaluated for arctic challenges and suitable design process will be selected for further study. Fourthly, a case study will be evaluated for a specific area of the selected Arctic Sea by using the selected design. Cost assessment of the OSV will be done to get the idea of economic success for the alternatives vessels. Finally, a code will be developed to using risk based design for the particular area to find vessel information.

2. Ship Design

Ship design is a complex, creative and iterative process serving a bounded objective. Ship design process follows a series of iterative tasks. Naval Architects require the discipline of a well-defined objective to meet the owner's need. Moreover, it has to be bounded; that is to say the limits to which the designer may need stating. Having defined what is the designer is to address and the limits within to work, creative activity can start. This whole design process is a circular process, a first shot, corrected and re-created often many times until it satisfies the objective. [5]

There are several types of ship design process.

a. Conventional ship design with design spiral

b. System based ship design

c. Risk based ship design

2.1. Conventional ship design:

Conventional ship design is popular among the designers. It follows a design spiral. It is the graphical representation of ship design which captured the basic tenets of a widely accepted approach to ship design (See Figure 3).

Before starting the design spiral the design statement is required to finalize the design statement. The Design Statement is a short document which is used to clarify the purpose and goals of the vessel. It is also used to determine the requirements of the owner and to guide the designer in making rational choices between design trade-off during the design process.

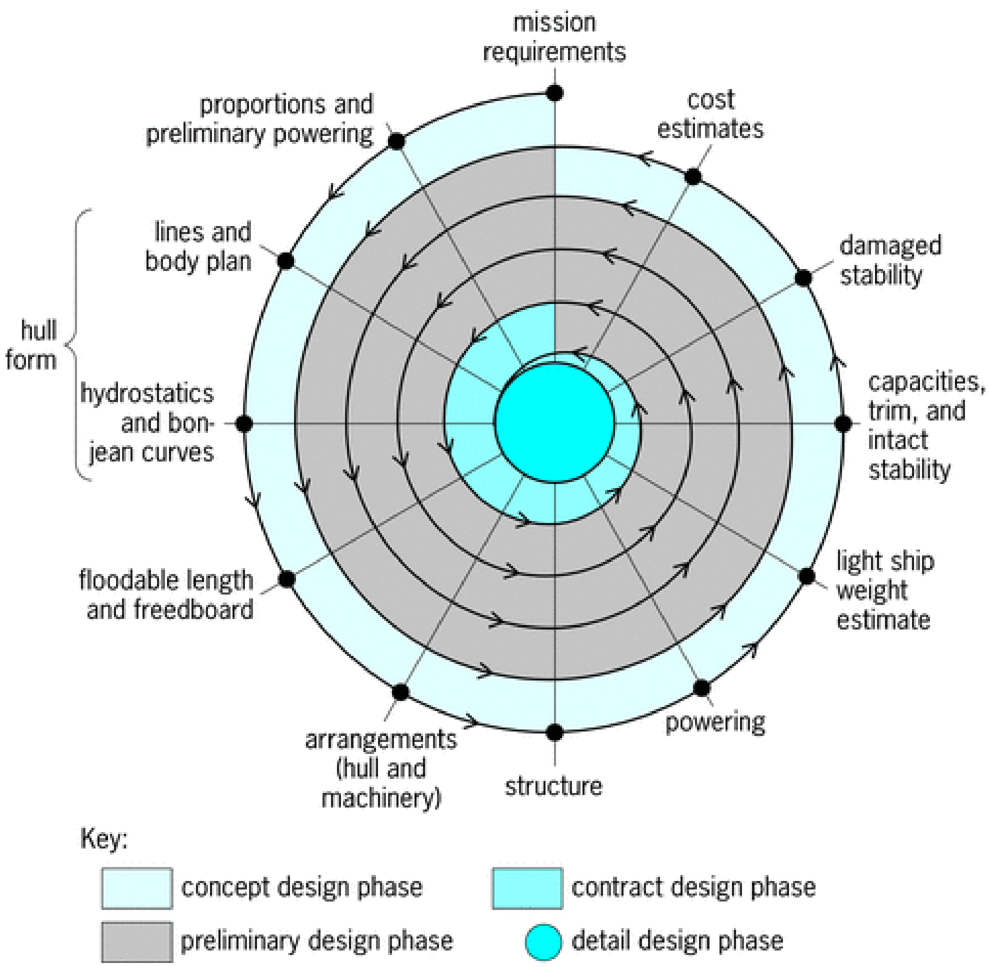


Figure 2: Ship Design Spiral [6]

Ship design spiral has three main phases

1. Concept design phase
2. Preliminary design phase
3. Detail design phase

Each and every design phase has to follow the steps circle showed in Figure 2. The steps are mission requirement, proportions and preliminary powering, hull form, floodable length and freeboard calculations, arrangements, structure, powering, light ship weight estimate, capabilities Trim and Intact stability and Cost estimation. According to Stephen M. Hollister the design phases are described. [7]

2.1.1 Concept design phase:

The Conceptual Design Phase determines whether the boat described in the design statement is feasible and how the stated goals in the Design Statement must be modified to achieve a feasible and successful design. It is important for the designer to strive for an optimal design, rather than just a feasible solution. Principal dimensions, general arrangements, major weights items, and powering options are chosen, and concept drawings are produced and included in a concept statement or design proposal which is then submitted to the client or prospective client. This step is often done on speculation in the hopes that a client will select the design for construction.

All designers have their own ways to approach this design phase depending on their experience and the type of boat being designed. One effective approach is given below

1. Classify the cost for the new design compared to other boats of the same type
2. Identify all major design trade-offs
3. Select an iterative process which will create a feasible design
4. Create a measure of merit (analytic or subjective) for the design
5. Optimize the principal dimensions of boat
6. Optimize the details of the boat

2.1.2 Preliminary Design Phase:

Once the Concept Design is complete, it is ready to take to the next level of design specification and detail: hull shape is finalized, interior arrangements are finalized, all weights are calculated or estimated, the structural analysis is performed, and the performance prediction is recalculated and verified. If the results of the Concept Design stage are accurate and there aren't any last-minute design changes, one should not run into any large trade-offs problems which require you to re-evaluate your whole design concept.

The Preliminary Design phase is characterized by the following steps

1. Complete the hull shape definition
2. Perform a detailed structural analysis for the boat
3. Finalize the interior arrangements
4. Determine hydrostatic and stability requirements
5. Re-evaluate resistance, powering, and performance of the boat
6. Calculate detailed weights to determine an accurate draft and trim for the boat
7. Calculate detailed costs for the boat

3. Detailed Design Phase

2.1.3. Detailed Design Phase:

The Detailed Design phase is that portion of the design involved with producing the design "deliverables": the drawings, the templates, and the specifications. What designer includes in this design package depends on the needs of the builder. This raises a couple of interesting design process considerations which must be dealt with well before you get to this point in the design. [7]

2.2 Systems Based Ship Design

System based ship design is like a checklist that reminds the designer of all the factors that affect the design and record his choices. It gives the possibility to compare the selections with statistical data derived from existing, successful designs. The result is a complete system description for new ship, which will act as the base for further design work. [4]

This system based design can be described through the following figure

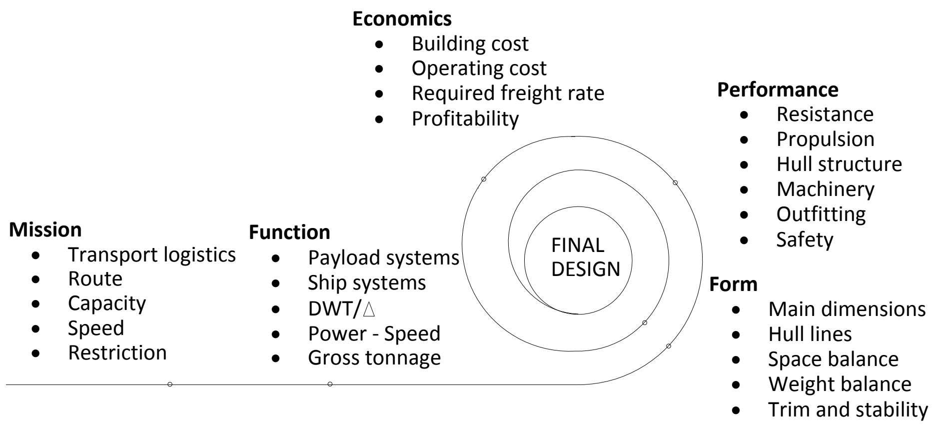


Figure 3: System Based Ship Design [4]

The starting point of this ship design process is the mission and the function of the ship. All systems needed to perform the defined tasks are first listed. The areas and volumes demanded in the ship to accommodate all systems are then calculated. This design method does not need pre-selected dimensions, hull lines or standard layouts.

The design phases are:

1. Mission
2. Function
3. Form
4. Performance
5. Economics

2.2.1. Mission

The mission description defines the transport task of the ship. The operational area, cargo and cargo capacity are defined. Type of machinery, rules and regulations and other preferences of the owner are defined. Special limitations such as breadth or draft are recorded in this step. In the operation description the route and operating schedule is specified. Length of the route is given together with the time at sea and port. From this average speed, round trip time can be calculated. These are very important for cargo carrying capacity and economic evaluation. A workbook based on Microsoft Excel is used for system based design.

To sum up the topics which are needed to define in this phase are

-Transport logistics

-Route

-Capacity

-Speed

-Restrictions

2.2.2 Function

Main topics of this design phase are:

-Payload systems

-Ship systems

-DWT/Δ

-Power – Speed

-Gross tonnage

The next step in system based design is to define all functions needed in the vessel and divide them into payload related functions and ship related functions. For each function the "space" demanded in the ship is calculated. All spaces are defined "steel to steel" and include the space needed for frames, deck beams or bulkheads. The total volume of all spaces onboard defines the ship size. Here SI units are used. If a spreadsheet is used then it is easy for the designer to change names, add or delete spaces to suite the concept and layout of his mind. So the ship function can be shown:

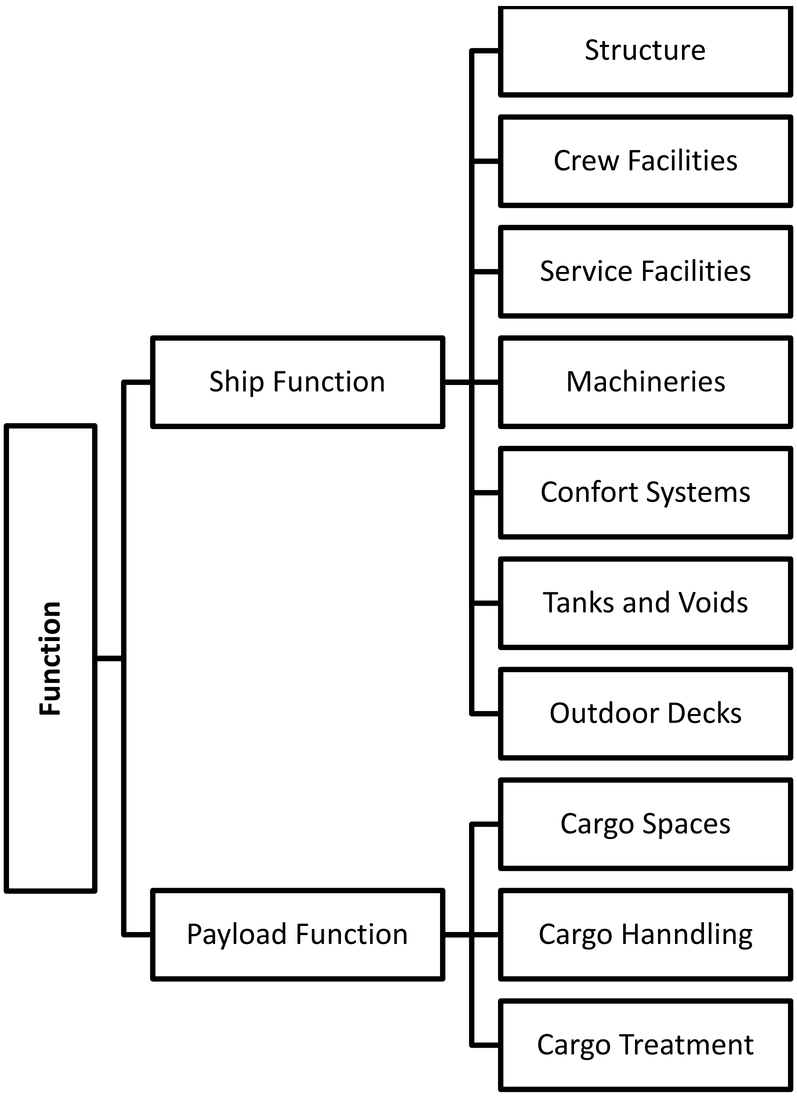


Figure 4: Function phase of system based design[4]

The first weight estimate can be done based on the information in the system summary. In the concept design phase it is sufficient to divide the lightweight into 6-10 main groups. Also deadweight can be calculated from the operation data in mission description. Previous data is a great source of determining all the weight estimation. Total displacement of ship is the summation of lightweight and deadweight.

2.2.3. Form

Next phase of system based design is “Form”. Here main dimensions of the ship, its hull lines, space, weight and stability are selected.

For main dimension selection the statistics of previously built ships is a good starting point for selecting suitable main dimensions of the vessel. The designer must consider any special features planned for this ship. Speed of the vessel must be considered when selecting the main dimensions. A hull with suitable form parameters is needed to keep the power demand at a competitive level. When main dimensions have been selected also the hull form parameters, like slenderness, block coefficient, midship area coefficient, waterplane area coefficient, length/breadth, and breadth/draught can be calculated and evaluated against the Froude Number. Slenderness ratio, prismatic co-efficient CP has great influence on the resistance of the hull. Section area curve for the hull is well defined from the block coefficient and midship area coefficient. It is important to remember that the selection process is based on the recommendation table of previous data.

The transverse stability and trim resulting from the hull form and lay out proposal is checked at this stage. The center of gravity is calculated for the ship based on the weight groups used in lightweight calculation. The vertical center of gravity for each weight group is estimated in relation to the depth of the hull. Geometric definition is used.

In total main topics of this step are

-Main dimensions

-Hull lines

-Space balance

-Weight balance

-Trim and stability

2.2.4. Performance

In this phase the designer needs to define the following topics

-Resistance

-Propulsion

-Hull structure

-Machinery

-Outfitting

-Safety

The resistance of the hull form and efficiency of the selected propulsion arrangement can be calculated using the methods presented by Guldhammer-Harvald, Holtrop or other available model test data. The influence of the selected main dimensions should always be checked. The length of the vessel has greatest influence on the resistance. If the length is increased both Froude Number and the block coefficient decreases and slenderness ratio increases, which all contribute to lower resistance.

Resistance and propulsion power is calculated for trial condition, assuming no speed reduction due to wind, waves or shallow water. The trial speed is reached with machinery power at the maximum continuous rating (100% MCR). In practical case speed is reduced due to winds and waves. A sea margin of 15-25% is added to the power calculation for trial condition. In service the machinery is operated at lower power of 80-85% MCR. The operating schedule for the ship should be based on the service speed so the schedule can be kept also in bad weather condition maintaining the safety of the ship.

2.2.5. Economics

Last stage in system based design is economics. Here building cost and other costs of ship are calculated. To determine the building cost system description and the weight calculation are needed. The main cost factors are design, material and production labor. In the system based ship design process the material cost and the production man-hours are calculated for the same items as those in the weight calculation. Design man-hours are calculated for the whole ship based on the lightweight. The whole process is done on a prescribed platform.

In this phase the final outcomes are:

-Building cost

-Operating cost

-Required freight rate

-Profitability

2.3. Risk Based Ship Design

Due to high pace in scientific and technological developments now people have improved technical capability. This is motivating innovation in the shipping sector. The shipping industry is still fragmented, undermanned and intensely competitive. Modern society is also very demanding on human life safety and environmental issues. Safety could easily be undermined and disaster could happen. This is particularly true for knowledge intensive and safety critical ships. For giant cruise vessels innovation is very important but it sometimes creates safety challenges. In this case, a new design paradigm needs to take which treats safety as a design objective not as constraint. This also formalized the methodology which capable of adapting innovation through routine utilization of first-principles tools and leads to cost-effective ways of dealing with safety (Risk Based Design). This was advocated by EU maritime industry. "The future is Risk-Based" was proclaimed by the international Maritime Organization and new rules for damage stability, SOLAS Chapter 2-1 came in 2009. Now this rule has almost become a routine task for the yards and design offices and goal based standards are too trendy to resist. The adoption of risk based approaches in the maritime industry is not as straight forward as it was thought and risk-assessment not as amenable to traditional naval architecture tools as rule compliance. [3]

2.3.1 Motivation of Risk-Based Design:

Owners and operators benefit from improved economics of novel solutions

- Example: more cabins with balcony on a cruise ship with fewer but larger than prescribed lifeboats

Yards and suppliers benefit from sustaining their competitive position

-Example: offer innovative layouts for cruise ship and ferry super structures

Classification societies benefit from improved client relations

- Risk-based approval offers planning reliability for novel concepts
- Fast technological development: Prescriptive rules quickly outdated

Link between Risk based design and Approval can be shown by the following formula

$$R_{\text{Design}} \leq R_{\text{acceptable}}$$

“R Design” is the risk of considered ship. It is typically sum of partial risks coming from different accident categories like, e.g., collision or fire. Each partial risk can be computed with the help of risk models.

“R acceptable” is specified by the approval authority, such as flag state administrator and/or classification society.

To make risk based design and approval work the following steps are required which are described in Risk Based Design book written by Papanikolau.

1. Regulatory framework
2. Design Framework and Tools
3. Qualified Engineers

2.3.1.1 Regulatory Framework:

The regulatory framework comprises IMO regulations, classification societies' rules, regional and national regulations and industry standards. To facilitate risk-based design and approval, three main elements are needed.

• Provisions for risk-based designs: SOLAS I/5 and MARPOL Annex I, I/5 have the necessary provision to allow alternative designs and arrangements. In addition, alternatives are possible related to fire safety and in the near future for electrical systems and lifeboats.

• Approval procedures: A number of IMO documents exist to guide the approval process for alternative designs. In addition, SAFEDOR developed a high-level approval process and a system-level approval process for risk-based designs.

• Risk evaluation and acceptance criteria: The FSA guidelines detail criteria related to human life safety, addressing individual and societal risks. [3]

Key to understand RBD is the integration of risk assessment in the design process and decision-making towards achieving the overall design goals but also as part of a parallel iteration within the safety assessment procedure to meet safety-related goals, as showed in the following figure

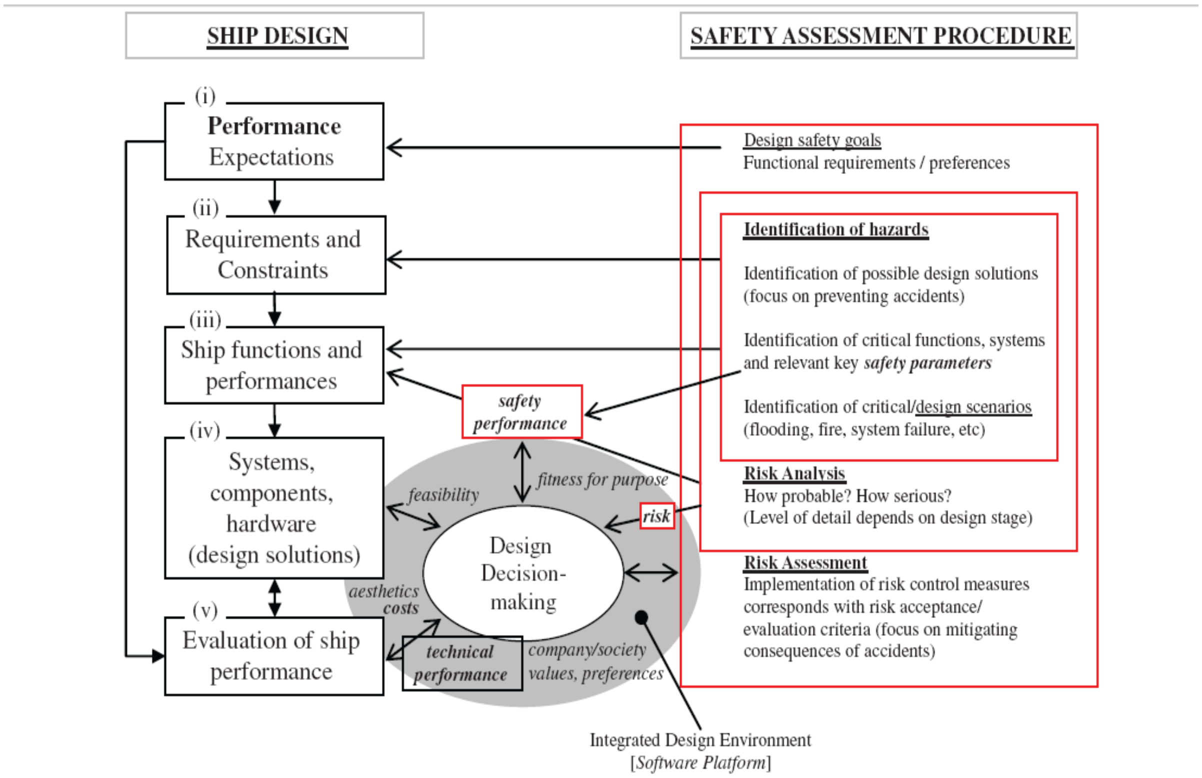


Figure 5: A high level framework for risk-based design [3]

2.3.1.2 Design Framework:

The design framework couples traditional design with risk-based thinking. It describes the integration of safety as an additional design objective.

The toolbox of the engineer engaged in risk-based designs should comprise

• Safety-performance prediction tools: The necessary software tools derive from the actual application. In general, tools to predict frequency and consequences for all accident categories are needed.

• Risk models: These models also depend on the actual application. In general, fault trees may be used for system analysis, event trees and Bayesian networks in FSA studies, and risk models expressed by mathematical formulae for fast design optimization.

• Optimization platform: As for the traditional design, optimization is required to achieve best designs.[3]

3. Challenges in Arctic Seas

Arctic region offers different types of challenges. Most of the Arctic seas offer harsh condition for any kind of operation. For this thesis, the Barents Sea related Arctic challenges will be analyzed.

For shipping operation the main Arctic challenges are:

1. Temperature
2. Ice
3. Icing/Winterization
4. Icebergs
5. Wave
6. Communication
7. Uncertainty about future weather condition and past and future ice thickness etc.

3.1 Challenges:

All the selected seven challenges will be discussed for the whole Barents Sea.

3.1.1 Temperature

In Arctic Seas the variation of temperature is large. For example in the Barents Sea water temperature varies from +3 to +12 degrees. In figure 4, Monthly mean temperature at 1 m and 250 m depth at the fixed station Ingøy, northern Norway, situated in the Coastal Current at the entrance to the Barents Sea. Vertical axis is temperatures (^{0}C) and horizontal axis is month. The green areas are the long-term mean for the period 1936-1944 and 1968-1993 +/- one standard deviation and represent the typical variations.

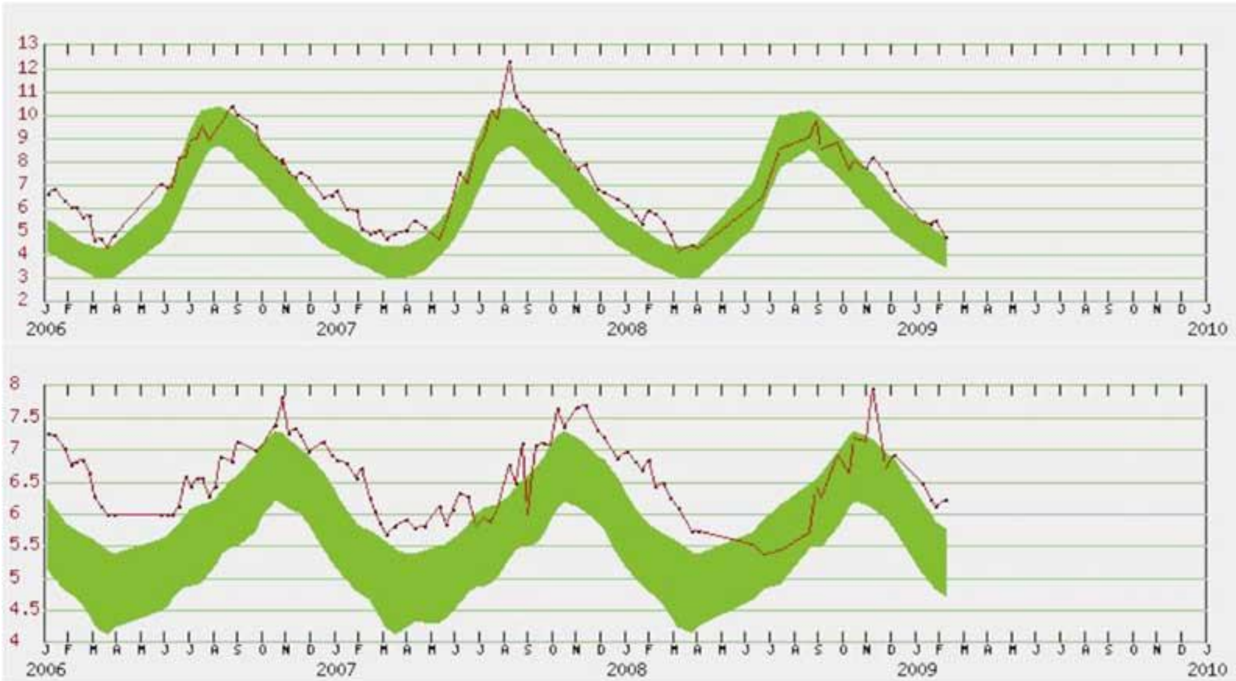


Figure 6: Temperature Variation[8]

In wind the change in temperature is also harsh. It changes from -1,9 to +6,2 Degree (Table 1). Mean air temperature anomalies at weather stations around the Barents Sea in December 2007- December 2008, yearly mean anomaly in 2008, maximum anomalies and years when they were observed.

Table 1: Mean Temperature Anomalies[8]

Station	Year/Month 2007 Dec	2008 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2008 mean	Max/Year
Svalbard airport	3.7	6.2	5.3	-1.2	-0.2	1.3	0.5	-0.2	-0.4	2.3	-0.5	0.1	3.8	1.1	4.3 2006
Bear Island	5.3	5.7	4.3	-0.4	0.3	1.2	0.5	0.2	-0.1	1.7	0.4	2.0	5.1	1.8	2.9 2006
Tromsø	4.0	1.6	1.8	-1.4	-0.9	-0.8	-1.0	1.8	-1.1	0.0	0.9	0.4	2.5	0.2	1.5 1938
Vardø	4.1	2.7	2.2	0.2	-0.1	0.1	-0.1	-0.5	-1.1	0.3	1.4	1.2	3.3	0.9	1.5 1937/2005
Murmansk	7.1	5.2	3.3	-1.3	-0.6	-0.7	-0.2	-0.8	-1.9	-0.4	1.8	1.4	4.4	1.1	2.0 2005
Kanin Nos	4.4	6.2	3.4	-0.4	0.3	-0.4	0.2	0.2	-0.2	0.1	1.6	1.5	4.7	1.3	2.5 1937

This type of wide temperature change has effect on ship design. For crew area additional isolation of superstructure is required. Additional heating is required for air and water. In cargo space additional heating is also required.

3.1.2 Ice

Ice is one of the biggest challenges in the Arctic seas. Barents Sea is covered with ice for a certain period of the year. In figure 5, it is seen that northern part of Barents Sea is covered with ice in February. From the same data source (nesrc.no) of the Figure 2 it has been found that this continues for the whole winter. [9] Southern part is mainly ice free for the whole year. Whole Barents Sea is usually ice free in August and September. According to polar code to operate a vessel in any Arctic sea, the vessel has to be ice classed.

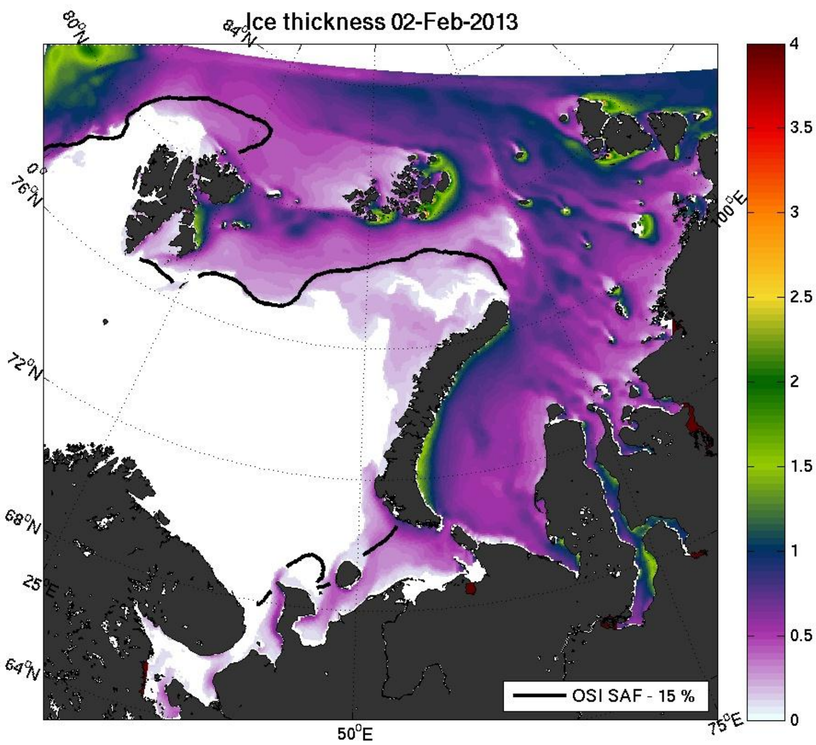


Figure 7: Ice Cover [9]

In ship design for ice several areas are required to be changed.

Structure: Ice breaking bow, knife rudder, ice belt, sheltered forecastle etc. are needed.

Machinery: Additional engine power is required to go through ice. In engine, pump room and thruster areas inlets for cooling must be placed well stern.

Trim and Stability: During trim and stability calculation ice interaction must be required to take into account. Due to ice interaction special trim requirements are needed to fill up.

Resistance: Due to ice the resistance of the ship is changed. For different ice thickness different resistance appears.

3.1.3 Icing

This is another big challenge in the Arctic sea. In vessel icing is a severe hazard of high latitude waters. Icing refers to the accumulation of ice on ships and offshore structures due to the freezing of impinging sea spray or precipitation. Icing can lead to reduced operability, since the ice may accumulate on operational equipment or communication antennas, rendering them temporarily unusable. Even more serious, there is numerous safety hazards connected to icing, such as slippery rails, ladders or decks, unusable lifeboats and fire equipment or blocking of air vents. In the worst case scenario, the weight of the ice may even threaten the stability or integrity of the vessel.

There are several source of icing.

1. Atmospheric icing

2. Sea spray icing (wind spray and wave spray)

Atmospheric icing refers to icing due to the freezing of precipitation, such as rain or snow. This is not a serious problem for ships or offshore structures. Sea spray icing causes serious problem. Wind and wave sprays both are the causes of sea spray icing. [10]

Effects of icing on protection of personnel, safety of vessels are:

– Stability of vessel due to icing

– Operability and adequacy of evacuation equipment

– Stability and operability of support vessels

– Unpredictable weather forecasts in case of polar low pressures

– Operability and adequacy of cargo handling equipment

[11]

Working climate requirements are:

– Needs for enclosed space

– Concerns regarding ventilation requirements when hydrocarbons can get locked into enclosed space

– Large energy requirements

– Ergonometric design, danger of slips and falls

[11]

3.1.4 Icebergs

Icebergs are hazardous for shipping and offshore activities. Icebergs in the Barents Sea originate from glaciers on Franz Joseph Land, Novaya Zemlya and Spitsbergen (Figure 8). They are usually rather smooth, less than 100m thick and with a horizontal extension of maximum 300-400m. A number of giant icebergs have, however, been observed. Apart from these instances no icebergs have been observed south of 72,5°N. [12]

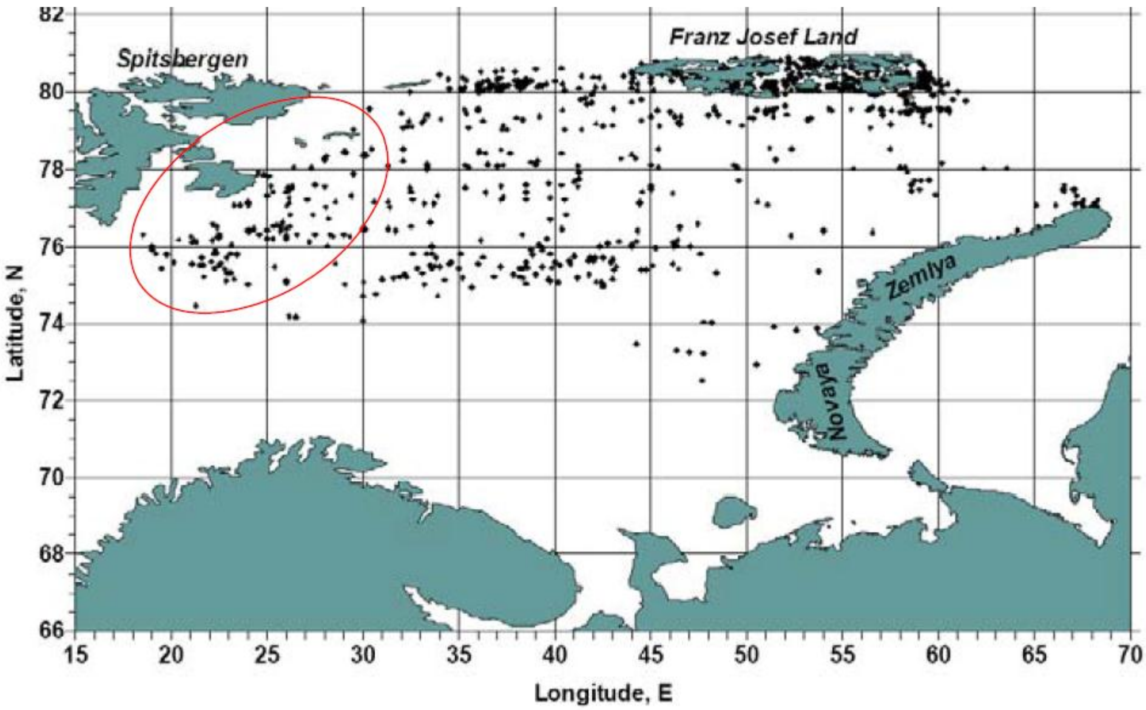


Figure 8: Location of icebergs [8]

The amount of kinetic energy is calculated from an average iceberg [13].

L=91m, B= 64m, H=15m, M≈1million tons, velocity, v=0.25m/s

Kinetic Energy= ½ x M x v^2= 31250 KJ

Icebergs can create an accidental event for any vessel with this amount of energy. It is important to avoid icebergs. Speed of icebergs is slow but large in size. It is important to identify them as early as possible. Good communication equipment is required for that purpose.

3.1.5 Wind and Wave

High wind speed and high wave together can create serious problems. From Figure 9, it is found that wind speed up to 8 m/s is found in 50% time in Barents Sea which is quite high. From Figure 10, it can be seen that the average wave height is 2m. In Barents Sea there are three major mass flows. One from warm, salty Atlantic water from the North Atlantic drift, cold Arctic water from the north and Warm, but not very salty coastal water. From Figure 11 (Location 77^{o} N, Olga basin), it can be seen that Barents Sea has wave from different direction. This may create fetch. High wind speed creates high wave and accelerates icing. Wave height also determines operational condition and some design features of the vessel. In Figure 11, wave from different directions are shown. It shows that in one point waves from different direction can appear which may create fetch.

Designers require considering the following things:

Freeboard: Comparatively higher freeboard due to high waves
Cargo handling equipment: Operability and adequacy of cargo handling equipment
Cargo Space: Additional heating system

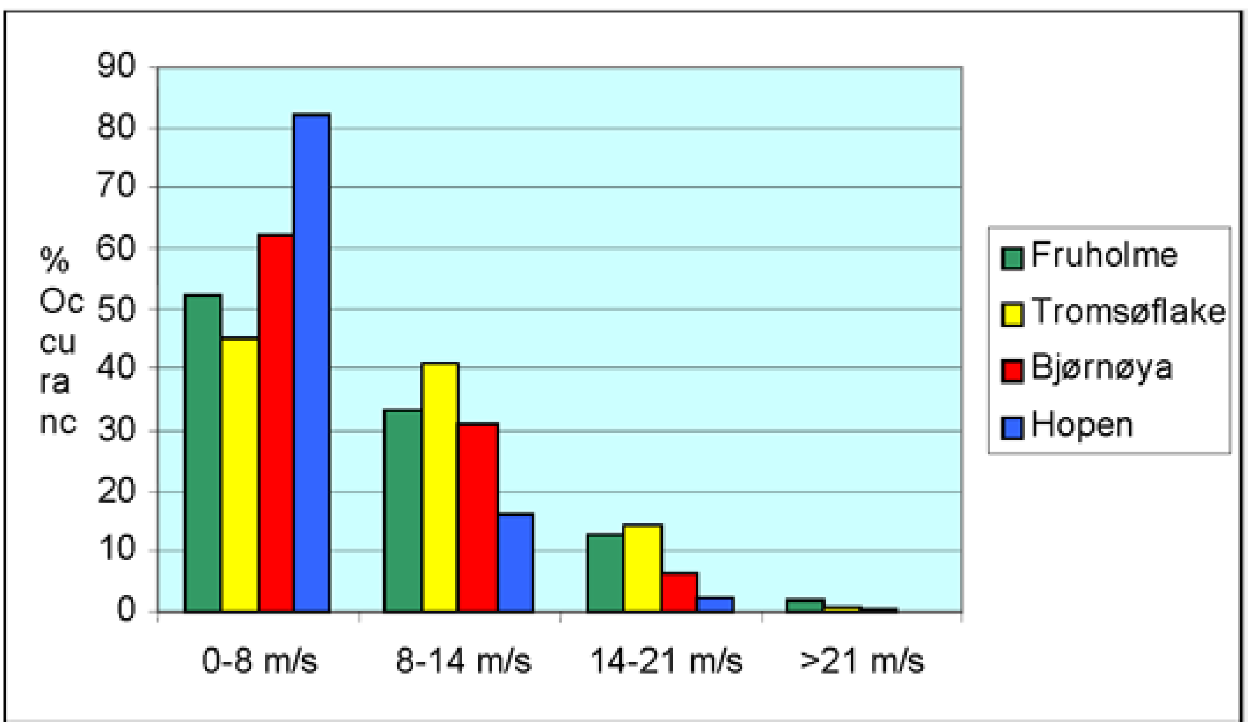


Figure 9: Wind speed[14]

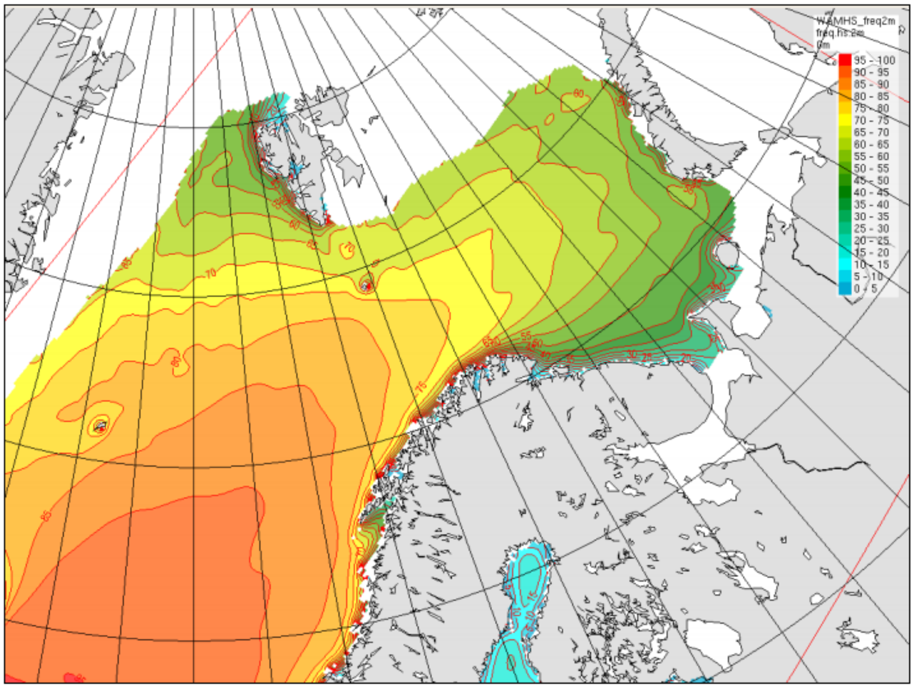


Figure 10: Significant wave height, Hs>2m in percentage[15]

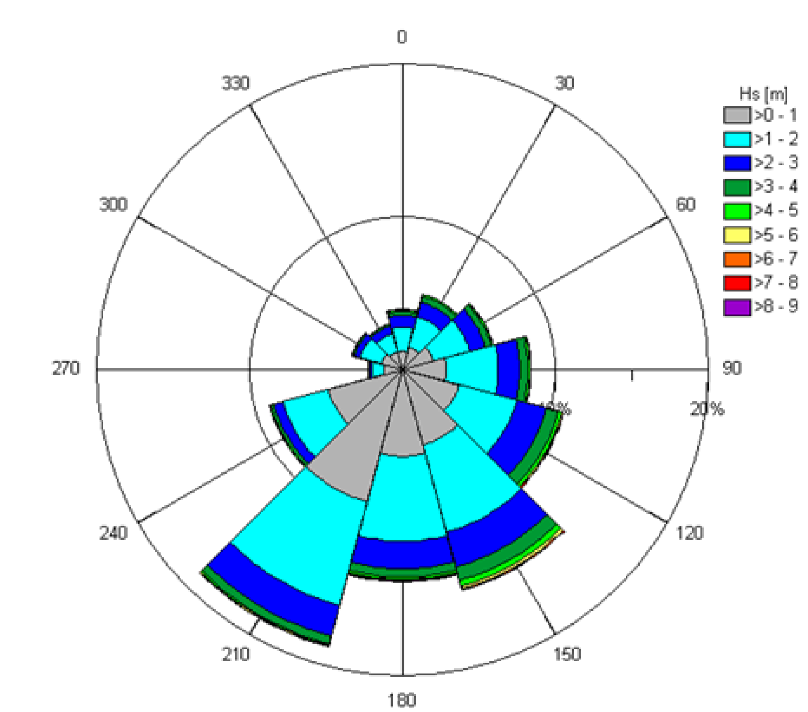


Figure 11: Wave height in Barents Sea[16]

3.1.6 Communication

Arctic area is not under proper satellite communication system. According to Rodseth and Kvamstad's model [17], the Barents Sea is in the polar and sub-polar zone (Figure 12). This region is not totally under the stable communication zone. As most of the offshore supply vessels are equipped with DP system so the satellite communication is very important. In the projected area GEO and LEO both satellites have potential problem with quality. It is important to improve the communication as soon as possible. HEO satellite could be a good solution. The whole communication scenario is presented below.

It is important to consider communication related challenges in the early design stage. Best quality with high range equipment is required.

	System	Characteristics	Polar (>80°N)	Sub-Polar (70°N - 80°N)	Other (<70°N)
Terrestrial systems	HF, MF	Safety related messages and voice communications	OK, but unsuitable for digital communications	OK, but unsuitable for digital communications	OK, but unsuitable for digital communications
Terrestrial systems	VHF, digital VHF, GSM, 3G	Line-of-sight, voice and low data rate communications	No base stations, ship-to-ship OK	Few base stations, ship-to-ship OK	VHF is OK close to the coast, GSM/3G limited coastal coverage
Satellite systems	GEO satellites, including Inmarsat.	Medium capacity. Low to medium latency.	Not available	Potential problems with quality and availability	OK (except in fjords and similar special areas)
Satellite systems	LEO satellites; Iridium OpenPort	Currently max. 128 kbps. High and variable latency.	Potential problems with quality	Potential problems with quality	OK, except for areas around equator
Satellite systems	HEO satellites	Properties comparable to GEO. Currently unavailable.	Expected to provide good coverage, capacity and quality in the Polar and Sub-Polar areas. Spare capacity can be used in other sea areas. Not yet implemented.		

Figure 12: Communication System [17]

3.1.7 Uncertainty

Weather condition is changing in the Barents Sea area. Amount of ice is varying in different years. Due to rise in temperature amount of ice is decreasing in an arbitrary way. From uncertainty analysis it is found that there is uncertainty in previous ice data and there is no reliable future ice data.

Designer has to make his own decision based on owner's requirement and economic evaluation and prediction on future ice condition.

3.2 Design Considerations

Now it is required to find out which ship items are affected for the Arctic challenges. Here challenges are accumulated and added them into Borch's design consideration table (Table 2)

Table 2: Arctic Ship Design Considerations[18]

Arctic challenges	Item	Considerations
Ice	Structure (hull, forecastle, poop, deckhouse)	Ice-breaking bow, ice knife at the rudder for conventional rudders, sheltered forecastle to prevent icing, deckhouse allowing a close-range view
Temperature, Icing, Ice	Crew facilities (crew spaces, service spaces, stairs and corridors)	Additional isolation of the superstructure and crew area, crew spaces located in areas of low vibrations
Ice, Icing	Machinery (engine and pump rooms, engine casing, funnel, steering and thrusters)	Inlets for cooling must be placed well stern
Temperature	Tanks (fuel oil, lube oil, water, sewage, ballast, voids)	Additional capacity required waste- and bilge water-collecting tanks with capacity for 30 days or a cleaning system for sewage and domestic water. Ballast tank heating system
Temperature	Comfort systems (air condition, water and sewage)	Additional heating
Wind, Icing, Temperature	Exterior decks (mooring, lifeboat, etc.)	Additional heating
Temperature	Cargo spaces	Additional heating if needed
Icing	Cargo handling (hatches, ramps, cranes, pumps)	Must comply with cold climate to prevent icing or fracture

Ice, Icing, Wave	Trim and stability	Stability must take ice interactions into account and specific trim requirements must be met
Ice	Resistance	Requirements according to target ice class to satisfy performance criteria
Ice	Propulsion	Ice class determines propeller design and material as well as main machinery output
Ice, Iceberg	Hull scantlings	Strengthening according to ice class
Communication, Iceberg	Communication system	For low visibility additional sensors, light, camera area required. Upgrading satellite communication.

3.3 Influence of Arctic Challenges in Different Ship Design Processes

Now all this Arctic related design considerations will be put into different types of ship design.

3.3.1 Ship Design Spiral with Arctic Design Considerations

The Arctic design considerations are put into the conventional ship design spiral. The following figure (Figure 13) shows how different Arctic challenges can be fit within conventional ship design.

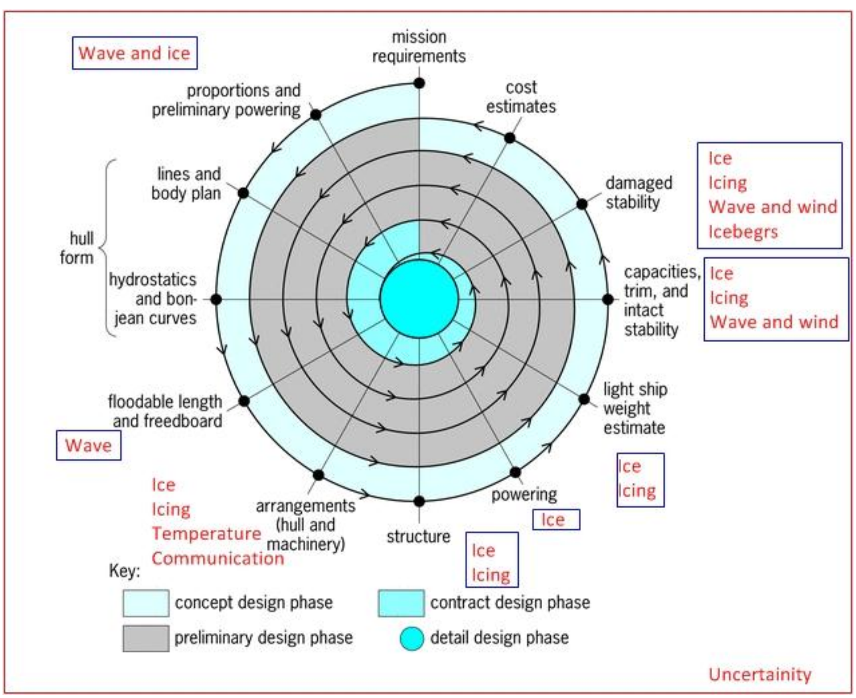


Figure 13: Spiral with Arctic design considerations

Wave can be put into the second step of design process, proportions and preliminary powering. Wave data is also required to calculate preliminary dimensions such as draft. It is also required to find floodable length and freeboard calculation. Wave and wind are placed in intact stability and damaged stability stage because of their effects.

Ice data can be fit into the preliminary powering calculation. It helps to define the resistance and powering. Ice data is also required for other steps as well such as hull and machinery, structure, powering, light ship weight estimation, trim and intact stability, and damaged stability. With ice data, the required hull strength, plate thickness, lightship weight and some important data for stability can be generated. From the same data power required for transit operation in ice can be determined. Therefore ice is placed in different locations of this type of ship design.

Icing is placed in arrangements (hull and machinery), structure, light ship, intact stability and damaged stability steps. Icing influences stability. Quick icing can change stability and trim rapidly which might lead to an accidental event. To avoid icing, designers require thinking about it in other steps such as hull, structure design also.

Temperature and communication are placed in arrangement step. Arctic operations require equipment which can withstand in cold temperature. In Arctic communication system is still under development and visibility is low during certain period of year. These things are important to consider during this stage.

Uncertainty is the item which is difficult to put in this type of ship design process which encircles the whole design process.

Main pitfalls of using design spiral for Arctic areas:

1. Change in one step requires full iteration of the whole process.
2. There is no step where “uncertainty” criteria can be fit.
4. This type of ship design might not give any competitive advantage to the owner

5. The task structure is "design-evaluate-redesign" which easily locks designer to patch with only one design rather than generate alternatives.

3.3.2 System Based Design with Arctic Design Considerations

In the following figure (Figure 14) different Arctic design considerations are placed in different stages of system based design.

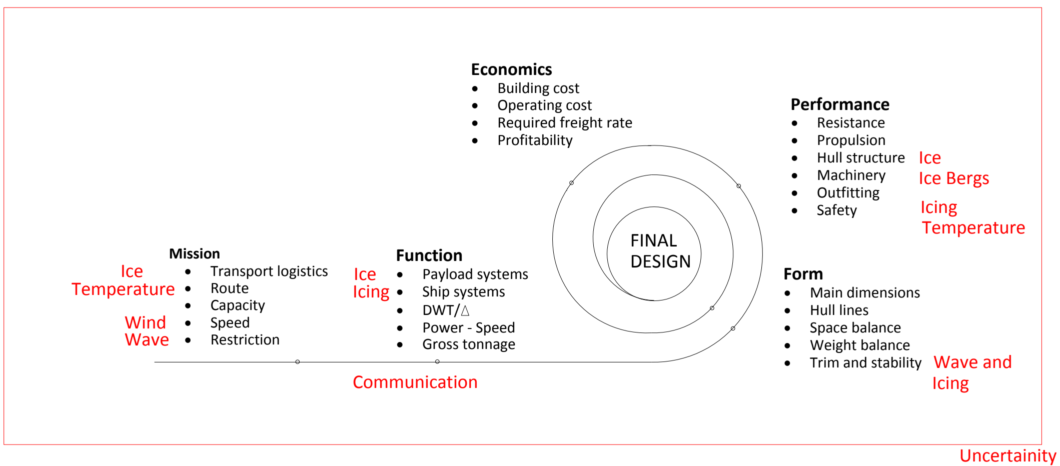


Figure 14: System based design with Arctic design considerations

Ice can be placed in the three stages. For example, in Mission stage ice has effect on the route selection and speed calculation. In Function stage, it has effect on power-speed and displacement calculation. In Performance stage it is required to know the ice condition for resistance calculation and machinery selection.

Icing can also be placed in three stages. In Function stage it has effect on ship systems selection. Ship systems have to be capable of working if icing occurs. Icing may cause change in trim and stability so it is also placed in Form stage. In Performance stage it is important to consider the effects of icing on safety, machinery and outfitting.

Temperature can be placed in Mission and Performance stages. Temperature creates restriction on mission stage. Temperature plays an important role while selecting machinery and outfitting.

Wave has effect on Mission and Form stages. It is important to consider wave while selecting the route and calculating the dimensions of the vessel. Wind has effect on Mission stage too.

Communication can be placed in Function stage. It is required to know communication related challenges, to set up ship's communication systems.

Uncertainty cannot be placed in any stage.

Main Pitfalls:

1. There is no step where "uncertainty" criteria can be fit.

2. There is insufficient successful data source for vessels those are operating in Arctic seas.

3.3.3 Risk Based Design with Arctic Design Considerations

The Arctic design considerations are put into the conventional risk based design. The following figure (Figure 15) shows how different Arctic challenges can be fit within risk based ship design.

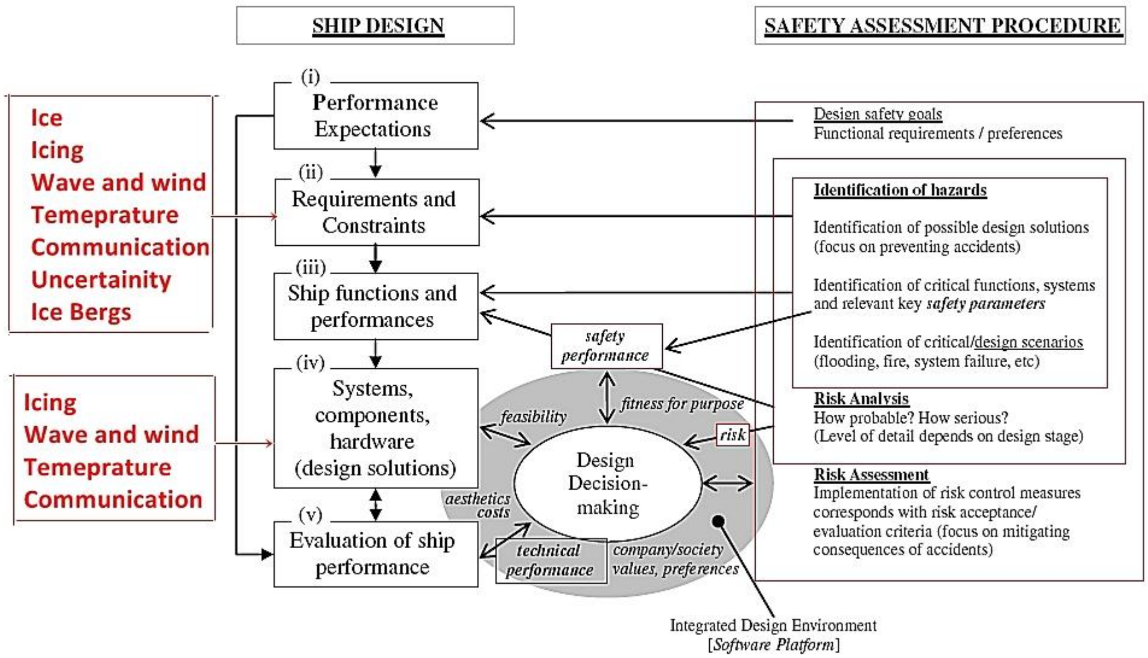


Figure 15: Risk based design framework with Arctic design considerations

Risk based ship design has five steps. Second step is Requirements and Constraints. Here possible design solutions, critical functions and design scenarios are identified. This is a very good place where all the Arctic design criteria can be fitted.

Weather condition is changing in the Arctic areas. Amount of ice is decreasing but still it is uncertain what will happen in future. There is certain amount of chance of uncertainty about ice and weather related information. In this step all the possible solutions can be identified and analyzed. Wave and wind have effect on ship dimensions, so for different wave condition different design solutions can be found. Temperature, iceberg, icing provide some additional constraints in design process. They can lead to critical situation, so it is important to reduce the risk. Adequate design and system related solutions can be identified in this design step. Communication is also an important challenge in the Arctic region which can also be placed in this step.

In fourth step systems, components, hardware related decisions are made. Here several Arctic designs related challenges can be placed again. Vessels are needed to be equipped with systems and hardware which can be used in low temperature.

Main pitfalls:

1. RBD will take longer time in design stage
2. Assumptions will be required for risk analysis.
3. Insufficient relevant data.

Main advantages:

1. All the features could be placed in early stage
2. Effect of "Uncertainty" can be measured and taken care of.
3. Owner can make profit from competitive design solution.

3.4 Selection of Ship Design Process

The selected Arctic related challenges can be dealt with risk based design in the early stages (Figure 15). It is possible to analyze risks related to those constraints and uncertainties before decision making. This is a great advantage of risk based ship design.

In other two ship design processes most of the selected artic related challenges can be dealt with except uncertainty (Figure 13 and Figure 14). In system based ship design most of the challenges can be dealt with also in the early stage before dimension selection and it is possible to make the design process suitable for specific type of ship design. For Arctic operation most of the supply vessels have different features according to the owner's specification. These ships are somehow different than each other. As number of vessels operated in this region is very low, so there is not enough successful vessel database for system based ship design.

In Arctic region, competitive design is required for operational and economic point of view. Conventional ship design takes time to complete and it is tough to accommodate new idea in this process. This might be a serious disadvantage in the competitive ship design world. It can be said that conventional ship design might not provide good solution. Based on these analysis, it can be said that risk based design should provide optimal design solutions for the Arctic region. The case study will be evaluated with risk based design.

4. Case study

The Arctic region is located at the northern-most part of the Earth. The Arctic consists of the Arctic Ocean and parts of several countries. The Arctic Ocean is one of the most discussed areas for oil and gas. The Barents Sea is a marginal sea of the Arctic Ocean, located north of Norway and Russia. Significant amount of oil and gas exploration work is going on in the Norwegian part of the Barents Sea. The main reason is the amount of ice is decreasing and several oil and gas fields are discovered in this sea. Few of the oil and gas fields are under development. They will require specialized offshore supply vessel for the whole year.

For understanding purpose a general case study is prepared. A multipurpose platform supply vessel will operate its year round operations from Hammerfest to upto 300 nautical miles into the Barents Sea. It will carry up to 5000 DWT and required deck area is up to 800 m^2. The vessel has to operate in this region for all seasons.

Find out the Arctic challenges in this region and their effect on ship design. Finally show the vessel particulars by a simple program.

Then show what will happen with vessel particulars if the weather conditions change.

4.1 Overview of the Case Study:

To solve the problems of the case study, part of risk based design will be used. The first step of risk based ship design is to find out the key performance expectations of the vessel. Then in the second step relevant requirements and constraints will be identified to provide possible design solutions.

Step 1: Performance Expectation

The platform supply vessel (PSV) will operate from Hammerfest to up to 300 nautical miles. It will be in operation throughout the whole year. The expected deadweight capacity is up to 5000 tons and expected deck area is 800 m^2.

It is expected that the operational days are 360 days and off hire days are 5 days. The vessel will be able to operate 300 nm that means in the Barents Sea it will operate within 70° N to 75° N. The expected cargo carrying capacity is approximately 5000 DWT. This means it has to carry fuel oil, fresh water, ballast water, drill water, brine, liquid mud, base oil, dry bulk tank, especial products etc. The required deck area is around 800 m^2. The deck has to carry around 10 t/ m^2. T

Table 3: Performance Expectations table

Criteria	Expectation
Operational area	300 nm
Operational days	360 days
Capacity	Up to 5000 DWT and 800 m^2 Deck Area

Step 2: Requirements and Constraints:

In this part of design stage it is required to identify relevant design requirements and constraints. From this stage different design solutions will be identified based on different constraints.

The main constraints are

1. Area and Route
2. Challenges for Barents Sea Operation
3. Infrastructure related to Communication

First, area related characteristics are needed to be identified and analyzed for possible solutions. After that it is required to focus on weather related challenges such as ice, icing, wind and wave, ice berg etc. These challenges have influence on ship's dimension selection. Then communication related problems have to identified and analyzed.

Elaboration of this step is done later in chapter 4.2 Problem Identification and Analysis).

Step 3: Program

A program will be developed based on the given input data to find out possible principal particulars and some other relevant data.

Step 4: Scenarios

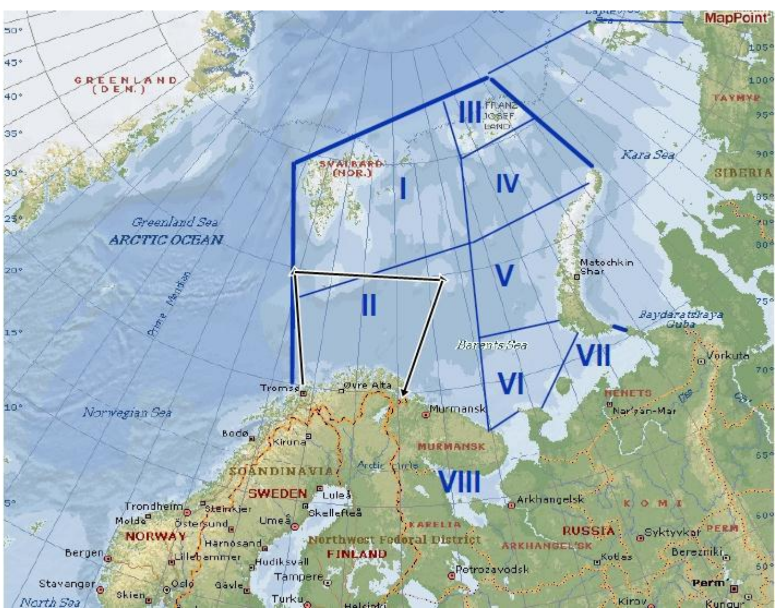
It is needed to find out the possible scenarios if the weather condition changes.

4.2 Problem Identification and Analysis

In this part all the relevant constraints related to the case study will be discussed.

4.2.1 Route and Area:

The platform supply vessel will operate from Hammerfest to 300 nm. It is assumed that the vessel's operational area is from 70⁰N to 75⁰N. According to DNV Barents 2020 HSE project the Barents Sea is divided into eight regions according to different ice conditions (Figure 16). Norwegian waters are in Sector I & II. This selected region for this case study is also marked in the following figure. It is shown that the selected region covers sector I and part of sector II.



I Spitsbergen, usually ice every winter
II Norwegian, generally ice free
III Franz Josef Land, usually ice every winter
IV Northeast Barents Sea, usually ice every winter
V Novozemelsky, in-between
VI Koala, in-between
VII Pechora, usually ice every winter
VIII White Sea, usually ice every winter

Figure 16: Barents Sea[19]

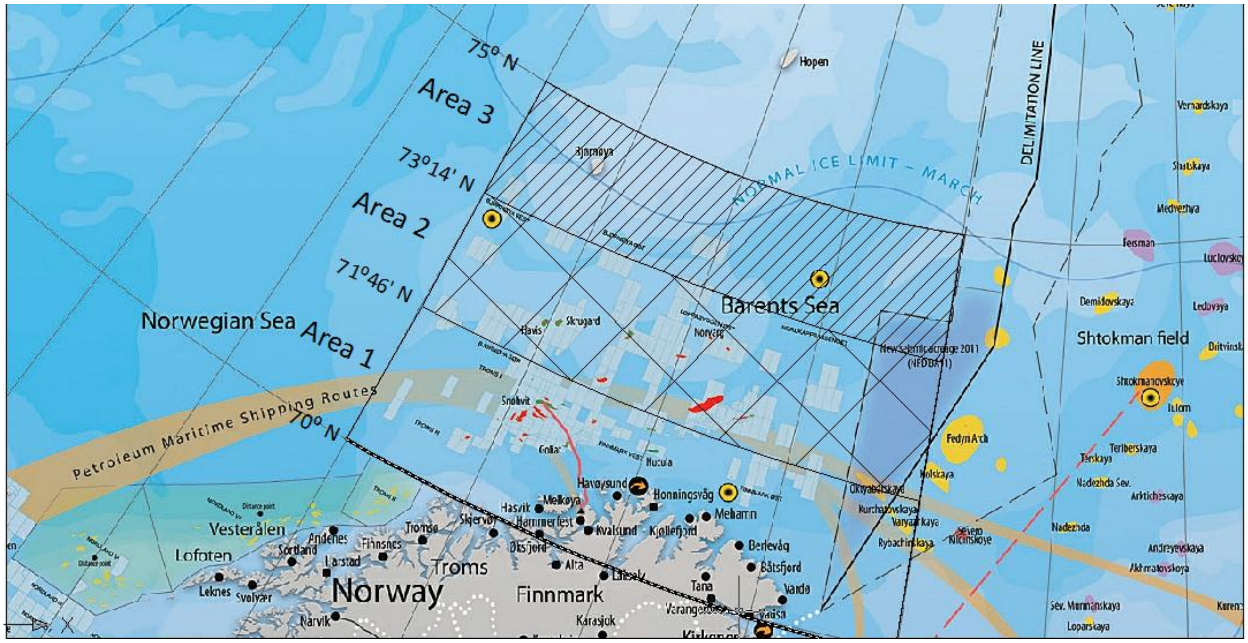


Figure 17: Area Selection [20]

For better regional analysis, the area is divided into three parts (Figure 17 and Table 4).

Area 1 covers from 70⁰ N -71⁰46’ N. There are some oil and gas fields in this region such as Goliat and Snøhvit. From Hammerfest distance of Goliat is 43 nm (nautical miles) and Snøhvit is 84 nm. Snøhvit is the first offshore development in the Barents Sea. Goliat field is under development. Vessel has to operate around 100 nm in this region from Hammerfest.

Area 2 covers from 71⁰46’ N to 73⁰14’ N and also covers 100 nm. In this area there are some oil and gas fields (red marks in the following figure). The newest discovery in this area is Skrugard which is 54 nm North of Snøhvit field. Vessel’s operational distance for this area is between 100-200 nm from Hammerfest.

Area 3 covers from 73⁰14’ N to 75⁰ N. This area is under oil and gas exploration. There is possibility to find new oil and gas field in this region. Vessel’s operational distance for this area is between 200-300 nm.

The area can be shown in the following table:

Table 4: Area distribution

	Location
Area 1	70^{o} N -71^{o}46’ N
Area 2	71^{o}46’ N to 73^{o}14’ N
Area 3	73^{o}14’ N to 75^{o} N

4.2.2 Challenges for Barents Sea Operation

In chapter 4, challenges for Barents Sea are identified and explained generally. Now operational area is selected for particular part of Barents Sea, so it is required to look more deeply into the challenges. Specific data is needed to analyze for specific operational window. Challenges are described below.

4.2.2.1. Temperature:

In chapter 3.1.1 Temperature at different depth and temperature anomalies are shown for the whole Barents Sea. Now it is required to see surface temperature and air temperature for the selected areas only, not for the whole sea. From osisaf.met.no website surface temperature is collected from graphical display. Sample figure is given in Figure 18.

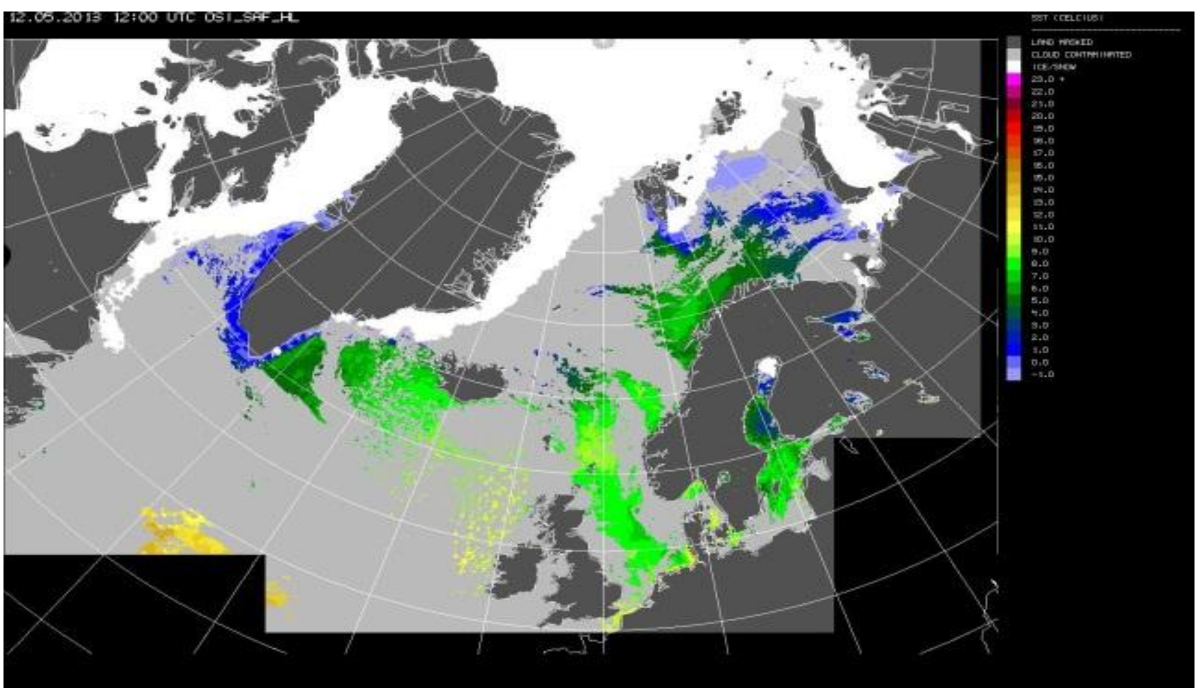


Figure 18: Sea surface temperature (14 May 13) [21]

Figure 18 shows different colors for different temperature such as dark green color represents 4^{o}C. For last two years data is collected for area 1, 2 and 3 for every month and three times of a day and then a table is made based on the data. From those data mean temperature is generated for each month for each three areas. In Table 5, it is visible that temperature changes from -1 to 8 ^{o}C. Here variation is about 9^{o}C.

Table 5: Surface Temperature

	Area 1, (^{o}C)	Area 2, (^{o}C)	Area 3, (^{o}C)
January, 2012	-1	4	-1
February	4	4	-1
March	5	5	0
April	1	0	0
May	-1	-1	-1
June	-1	-1	-1
July	0	0	0
August	8	7	0
September	0	0	0
October	-1	-1	1
November	7	6	3
December	5	5	2
January, 13	5	6	4
February	5	5	2
March	-1	-1	-1
April	0	0	0
May	-1	4	-1

For air temperature, measurement data is collected from different points for cross check of data for the same region. The graph is shown in Figure 19. It has been found that temperature changes from -9^{o}C to 12^{o}C. Air temperature variation is quite large. It also means that the ship's systems and equipment have to meet this temperature endurance range. For example different tanks need to have heating system so that the liquid does not solidify. For calculating vessel's principal particulars temperature has no effect but it has effect on systems and equipment selection.

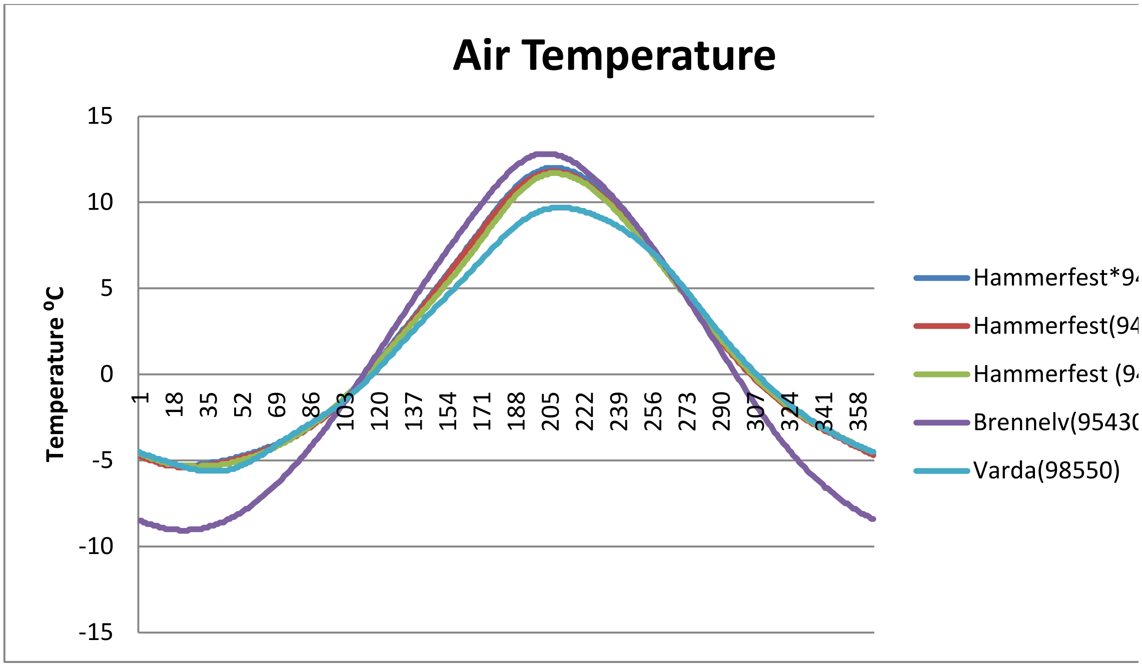


Figure 19: Air Temperature[16]

4.2.2.2. Ice

In chapter 3.1.2 Ice, general ice condition of Barents Sea is described. A specific location is selected for the case study, so ice data for that particular location is required. A table (Table 6) has been prepared with the ice information of the three selected areas from 2009-2013. Data has been taken for different days of the month from two sources.

1. "Arctic and Antarctic Research Institute" from Russia

2. "The TOPAZ project" funded by the 5th framework EC Commission Research program.

Ice condition is analyzed for different days of one month from the first source. For example: In Figure 20, it is visible that ice covers some part of area 3. Ice color is pink which means that it is young ice of 10-30 cm thickness. Then the data is cross checked with the second source. The maximum ice thickness is taken into consideration and presented in the table. At the end of the table (Table 6), the decision of the five year data is presented for each month.

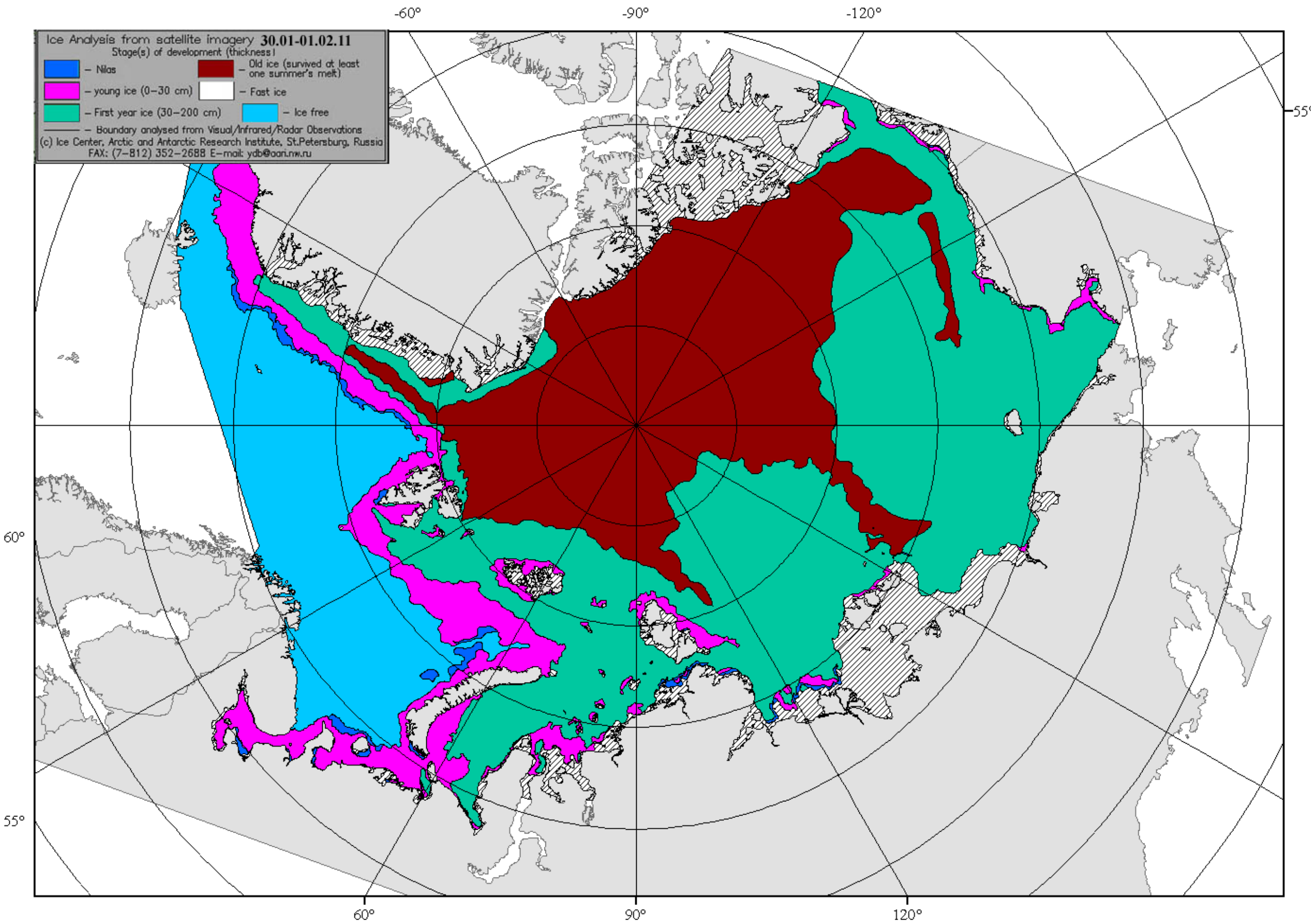


Figure 20: Ice condition in February 2, 2011 [22]

Table 6: Ice Data [22]

		January	February	March	April	May	June	July	August	September	October	November	December
2013	Area 1	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free							
	Area 2	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free							
	Area 3	Young Ice (10-30 cm)	Young Ice (10-30 cm)	Young Ice (10-30 cm)	First Year Ice (30-200 cm)	Ice Free							
2012	Area 1	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free
	Area 2	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free
	Area 3	Young Ice (10-30 cm)	Nilas (0-10cm)	Nilas (0-10cm)	Young Ice (10-30 cm)	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free
2011	Area 1	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free
	Area 2	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free
	Area 3	Young Ice (10-30 cm)	Young Ice (10-30 cm)	Young Ice (10-30 cm)	Young Ice (10-30 cm)	First Year Ice (30-200 cm)	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free

2010	Area 1	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free
	Area 2	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free
	Area 3	Ice Free	Young Ice (10-30 cm)	Young Ice (10-30 cm)	Young Ice (10-30 cm)	Young Ice (10-30 cm)	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Young Ice (10-30 cm)
2009	Area 1	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free
	Area 2	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free
	Area 3	Young Ice (10-30 cm)	Young Ice (10-30 cm)	Young Ice (10-30 cm)	Young Ice (10-30 cm)	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free
Expected Ice Condition	Area 1	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free
	Area 2	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free
	Area 3	Young Ice (10-30 cm)	Young Ice (10-30 cm)	Young Ice (10-30 cm)	First Year Ice (30-200 cm)	First Year Ice (30-200 cm)	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Young Ice (10-30 cm)

Table 6 shows that area 1 and 2 is ice free for the whole year. Area 3 has ice from December to May. Maximum ice thickness is from 30-200 cm. The severest ice conditions are summarized in Table 6, followed by the expected ice conditions based on the presented data. The expected ice conditions (the last row of Table 6) have been estimated rather simple instead, following the obvious trend of decreasing of the ice extent in the High North caused by the global warming. Average ice conditions do not represent the design criteria. Thus, averaging of ice conditions is highly recommended to be avoided. The ice-capable ship must be designed to withstand not the average ice conditions but the most severe ones, to a desired extent of course.

For robust decision, old data from 1958-1998 is also analyzed. Data table (Table 7) is shown below. From this table it is found that area 3 was covered by ice for the whole year. Maximum ice thickness was from 30-200 cm first year ice. This means that in last 50 years area 3 observes first year 30-200 cm ice. In area 2, maximum ice thickness was from 0-10 cm only for three months. Area 1 was ice free in that period. All these data are important to select ice class of the vessel.

Table 7: Ice Data 1950-1998[22]

		January	February	March	April	May	June	July	August	September	October	November	December
1950 - 1998	Area 1	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free
	Area 2	Ice Free	Nilas (0-10 cm)	Nilas (0-10 cm)	Nilas (0-10 cm)	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free	Ice Free
	Area 3	First Year Ice (30-200 cm)	First Year Ice (30-200 cm)	First Year Ice (30-200 cm)	First Year Ice (30-200 cm)	First Year Ice (30-200 cm)	Young Ice (10-30 cm)	Young Ice (10-30 cm)	Young Ice (10-30 cm)	Young Ice (10-30 cm)	Nilas (0-10 cm)	Young Ice (10-30 cm)	Young Ice (10-30 cm)

Ice classification

Vessels intended to navigate through more or less ice-infested water in Arctic Seas are obliged to be built to an appropriate ice class. The design must satisfy certain requirements such as hull strengthening, sufficient draft in ballast condition etc. are normally some of the requirements. Detail design considerations are given in Table 2.

Vessel's operational profile can serve as a basis for decisions on hull strengthening level and class notation. Operational profile can include a number of days sailing in ice vs. open water operation, expected ice type, infrastructure of the area (availability of icebreaker assistance), etc. The result of the contradictory design requirements is always a compromise between economy and ship performance in ice. Extra cost of ice class normally depends on vessel type.

As the oldest regulations serving the design of ice-going vessels, the Finnish-Swedish Ice Class Rules (FSICR) has been incorporated to the rules of many other international classification societies. In spite of Finnish-Swedish ice classes are referred to as Baltic ice classes, they are very often used when discussing vessels operating in other ice-covered waters of the world. Finnish-Swedish ice classed vessels are primarily merchant ships not intended for icebreaking operations. Finnish fairway dues, a system of fees charged for the use of sea lanes to cover the costs of management and icebreaker assistance, also depend on the vessels' ice class. Since ships of lower ice classes generally require more assistance during the winter months, their fairway dues are considerably higher than those of ships of the highest ice classes. For this reason the majority of ships regularly calling Finnish ports are built to the highest ice classes.

Many international classification societies (such as DNV) have incorporated the Finnish-Swedish ice class rules to their own rulebooks and offer ice class notations. Finnish-Swedish ice class is made for Baltic Sea operation so other ice infested area might offer different operational situation. Southern part of the Barents Sea is more or less ice free so there should not be much effect of using Finnish Swedish ice class for this particular area.

Icebreakers are normally assigned by polar classes. In 2006, the International Association of Classification Societies (IACS) standardized global ice classification specifications by releasing a document titled "Unified Requirements for Polar Ships". Seven Polar classes were established, where each of them represents requirements with respect to the certain operational capability and hull strengthening level.

As the existing ice classification rules are not all based on the same principles, the equivalency between ice classes is never completely correct. Technically, the equivalency ensures the same treatment of different ice classes by the maritime administration authorities. In 2003, HELCOM Ice Expert Working Group agreed on the equivalencies between ice classes (Table 8).

Table 8: Comparison Table[23]

Classification Society	Ice Class				
Finnish-Swedish Ice Class Rules	**IA Super**	**IA**	**IB**	**IC**	**Category II**
Russian Maritime Register of Shipping (Rules 1995)	UL	L1	L2	L3	L4
Russian Maritime Register of Shipping (Rules 1999)	LU5	LU4	LU3	LU2	LU1
American Bureau of Shipping	IAA	IA	IB	IC	D0
Bureau Veritas	IA SUPER	IA	IB	IC	ID
CASPPR, 1972	A	B	C	D	E
China Classification Society	Ice Class B1*	Ice Class B1	Ice Class B2	Ice Class B3	Ice Class B
Det Norske Veritas	ICE-1A*	ICE-1A	ICE-1B	ICE-1C	ICE-C
Germanischer Lloyd	E4	E3	E2	E1	E
Korean Register of Shipping	ISS	IS1	IS2	IS3	IS4
Lloyd's Register of Shipping	1AS	1A	1B	1C	1D
Nippon Kaiji Kyokai	*IA Super*	*IA*	*IB*	*IC*	*ID*
Registro Italiano Navale	IAS	IA	IB	IC	ID

In spite of having one of the Baltic classes, many ships have successfully operated in the Arctic waters. Following this, the two lowest Polar classes PC6 and PC7, attempted to be made somewhat equivalent to the two highest Baltic classes 1A Super and 1A, respectively. Combining all of these the following Table 9 has been made:

Table 9: Comparison Table for Case Study

Nominal Ice Thickness (h_{ice})	DNV Class Notations	FSICR Class Notations	RR Class Notations	Polar Class
Very light ice condition	ICE-C	Category II	LU 1	
0,4m	ICE-1C	1C	LU 2 (0,5 m)	
0,6m	ICE-1B	1B	LU 3 (0,65 m)	
0,8m	ICE-1A	1A	LU 5 (0,9 m)	PC 7
1 m	ICE-1A*	1A Super	LU 4 (1 m	PC 6

From Table 9, it is seen that vessel with ice notation of DNV's ICE 1A is equal to FSICR's 1A and polar code's PC7. They are able to operate up to 0,8 m thick ice when the channel is broken. Similarly ICE 1B or 1B vessel is capable of operating in 0,6 m thick ice. ICE C or Category II type vessel is capable of operating in very light ice condition. Based on the ice data and ice classification the following table is prepared

Table 10: Ice Class Decision Table

Location	**Ice Condition**	**Ice Condition (50 Year Period)**	**Ice Class (FSICR)**	**DNV Class Notations**	**Polar Class**
Area 1	Ice Free	Ice Free	Category II	ICE-C	
Area 2	Ice Free	0-10 cm	Category II or 1 C	ICE-C or ICE-1C	
Area 3	First Year Ice (30-200 cm)	First Year Ice (30-200 cm)	1 C or 1B or 1A or 1A S	ICE-1C or ICE-1B or ICE-1A or ICE-1A*	PC 7 or PC 6

In area 1 there is no ice but as it is part of Arctic sea so according to DNV rules ICE C is adequate. Area 2 is also ice free for current condition but if 50 year ice data is considered then there is up to 10 cm thick ice. For this area ICE C or ICE 1C should be enough. For area 3, higher ice class is required. Higher ice class will provide wide operational window such as lower ice assistance from ice breakers, possibility to operate more northern part of Barents Sea.

4.2.2.3. Wind and Waves

In chapter 3.1.5 Wind and Wave, the wind and wave condition of Barents Sea is described and analyzed. Now it is important to find out the specific condition for the selected 3 areas.

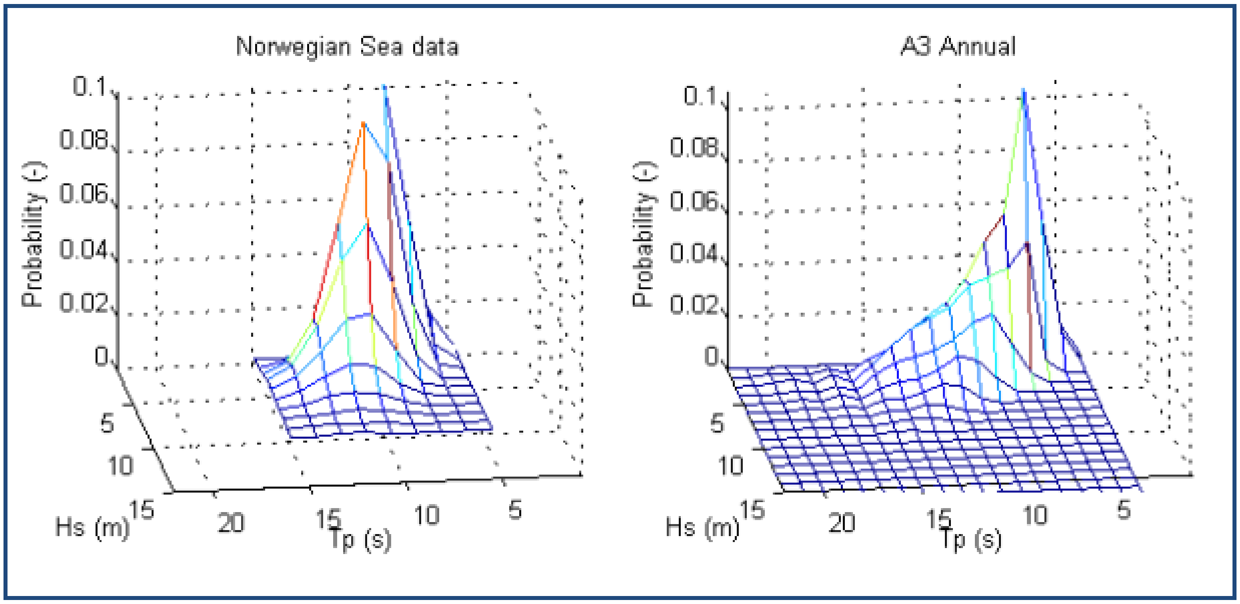


Figure 21: Wind and Wave Condition [24]

In Figure 21, a comparison of sea condition is shown between Norwegian Sea and Barents Sea (A3 Annual, at 72^{o} N). It is found that Barents Sea is rather calm compared to Norwegian Sea. In Barents Sea probability of having 5m significant wave height is lower than 2m wave height. Lower wave height has shorter wave period with high probability which may be near to vessel's natural frequency. It is very dangerous for vessel operation.

From area survey data of the selected areas scenario is presented in Table 11.

Table 11: Wave condition [15]

Hs	Frequencies			
Area	Area 1	Area 2	Area 3	
> 2 m	70	75	70	%
>3 m	40	45	40	%
>4 m	20	25	20	%

Table 11 shows that in all the three areas frequency of significant wave height (>2m) is quite high. Area 1 and 3 is similar in terms of frequencies. Area 2 has higher frequencies in all three significant wave heights. To operate in area 2 vessel will require higher freeboard. This will be the same case for area 3 also because the vessel has to go through area 2.

Significant Wave height is important in vessel design.

4.2.2.4. Icing

In chapter 3.1.3 Icing is discussed before. Both atmospheric and Sea spray icing create challenges for operation in the selected area. In the selected area significant wave height is quite high which easily lead to sea spray icing. Proper winterization is required to operate in these areas. Similarly temperature and wind speed is also important for icing problem. Considering wave, wind and temperature the following table is formed.

Table 12: Decision Table for Icing

Area	Winterization Notation (DNV)
Area 1	Basic
Area 2	Cold
Area 3	Arctic

In 2013, a joint project called “CIVARCTIC MAROFF” is completed. That project has the same operational area and it has also shown the icing related challenges.

They are:

- Forecasts and real time monitoring
- Ice thickness measurements
- Warning/alarm system
- Deicing system

Possible technologies:

- Sensors on construction
- Materials/coating
- Heating
- Deicing methods [24]

It can be said that icing has effect on different stages of ship design such as selecting material, heating system etc. but not on principal particular selection.

4.2.2.5. Icebergs

In chapter 3.1.4 Icebergs, detail discussion is made on icebergs. Although it is shown before that iceberg is rare after 72,5^{0} N for recent years. It was not very uncommon few years back so for safety purpose, data from previous years also have been taken into consideration. From the following figure (Figure 18), number of ice bergs in different years is shown. From this figure a probability table for the selected area is made which shows.

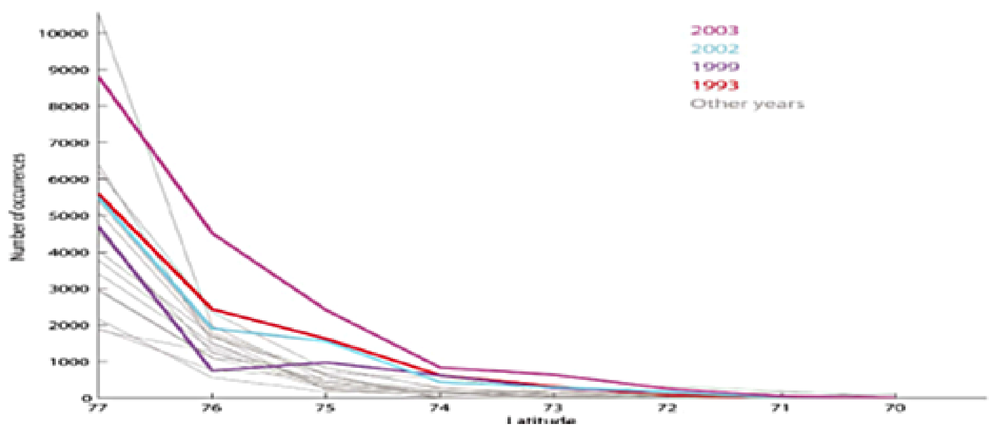


Figure 20: No of Icebergs in Barents Sea[25]

Table 13: Probability Table of Icebergs

Location	No of occurrences	Probability of having Iceberg
Area 1	Around 100	Very Low
Area 2	Less than 500	Medium
Area 3	More than 1000	High

From the Table 13 above, it can be said that Area 3 and Area 2 have higher probability of having icebergs. It is important to keep track of iceberg movements. Good communication equipment is necessary.

Challenge regarding to icebergs does not have any direct effect on principal dimension selection but it has effect on hull structure and communication.

4.2.2.6. Communication

In chapter 3.1.6 Communication, communication related challenges are described for the Arctic areas (especially whole Barents Sea). Now it is necessary to find out the challenges relevant to selected areas of Barents Sea. According to CIVARCTIC MAROFF project, navigation and communication related challenges are given below. The selected area is also similar to this project.

Communication and Navigation:

- Forecasts and real time monitoring of performance status
- GNSS (Global Navigation Satellite System) correction data
- Sufficient bandwidth capacity and quality of service

Possible technologies:

- Tools for assessment and prediction of system performance

Visibility is also a problem for operation in this area. Forecasts and real time monitoring is very essential.

Possible technologies:

- Sensors (ceilometer)
- Light
- Camera
- Radar [24]

4.2.2.7. Uncertainty

Uncertainty is also a challenge to design a ship for Arctic area. Weather condition is uncertain. Amount of ice is different in different years. Even there is uncertainty about ice related data. To deal with uncertainty it is necessary to find out the probability/prediction of different situation such as amount of ice in few years, number of ice berg occurrence in different areas etc.

Finally, after analyzing all seven Arctic challenges for the particular area the following table can be made.

Table 14: Effect on RBD

Arctic Challenges	**Effect on Risk Based Ship design**
Temperature	In stage 2 (Requirements and Constraints Stage) and Stage 4 (System Components and Hardware)
Ice	In stage 2
Icing	In stage 2 and Stage 4
Iceberg	In stage 2
Wind and Wave	In stage 2 and Stage 4
Uncertainty	In stage 2
Communication	In stage 2and Stage 4

4.2.3 Calculation and Result

Given data for the problem are

Criteria	**Expectation**
Operational area	300 nm
Operational days	360 days
Capacity	Up to 5000 DWT and 800 m^2 Deck Area

In this part first principal particulars will be calculated. Afterwards weight calculation and finally cost estimation will be done.

Principal Particulars Selection:

To select principal particulars different ratios such as L/B, B/T etc. are required. In this case study some supply vessel has been selected for base data. Offshore Supply Vessel transports and stores materials, equipment and/or personnel to offshore installations. According to ABS, it is also known as Platform Supply Vessel (PSV) [26]. The number of platform supply vessel is quite high but the number of ice classed platform supply vessel is low. Table 15 with vessel data is given below.

Table 15: Possible Case Vessels

OLYMPIC TRITON	**OLYMPIC INTERVENTION IV**	**BOURBON MISTRAL**	**FAR SOLITAIRE**	**FAR SERENADE**	**OSCV 03**	**PSV09**
Ice C	Ice C	Ice C	Ice C	Ice C	Ice C	Ice C
Loa =95m Lpp =82m B = 20.5 m D=9 m T = 7 m T(Design)= 6.5m Deck Area = 940 m^2 DWT: 4330 mt Speed 15.3 knot	Loa =95m Lpp =82m B = 20.5 m D=9 m T = 7 m T(Design)= 6.5m Deck Area = 940 m^2 DWT: 4195 mt Speed 15.4 knot	Loa =88.8m Lpp =82m B = 19 m D=8 m T = 6.6 m Deck Area = 985 m^2 DWT: 4779 mt Speed 15.4 knot	Loa =91.6m B = 22 m T = 7.2 m DWT = 5800 mt Deck Area = 1022,72m^2	Loa =93.9m B = 21 m T = 7.27 m DWT = 5944 mt Deck Area = 1002,14m^2	Loa =93.5m B = 22 m T = 7.8 m D=9.5 m DWT = 5800 mt Deck Area = 760 m^2	Loa =95m B = 24 m T = 7.8 m D=9.8 m DWT = 5800 mt Deck Area = 1022,72m^2
Delivered: 2007	Delivered: 2008	Delivered: 2006-07	Delivered: 2009	Delivered: 2012	Unknown	Unknown

From Table 15 several graphs have been drawn such as L/B, DWT vs. L, DWT/B etc. In Figure 22: DWT vs. Length, different deadweight is placed against length of the vessels. A linear trend line is also drawn from this graph which represents the average of the values.

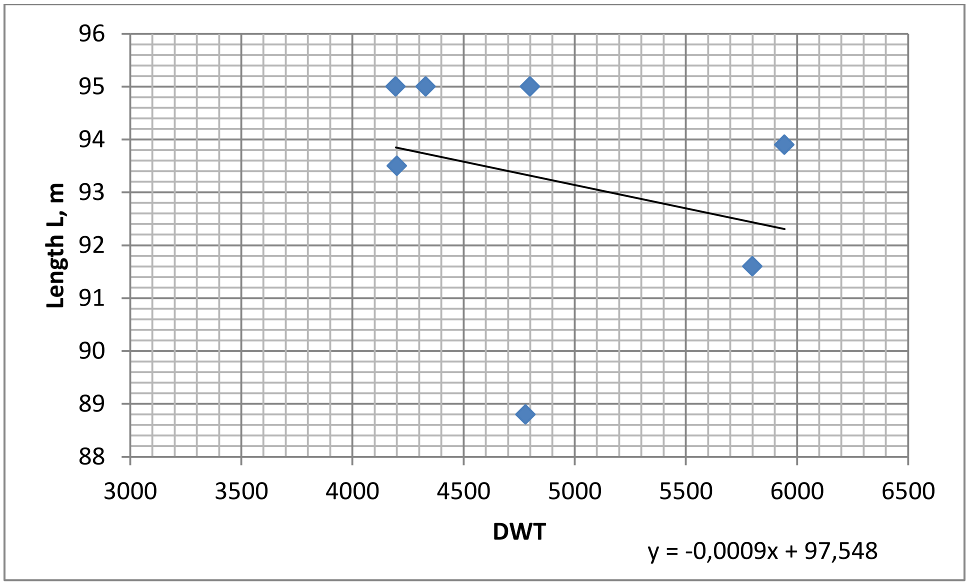


Figure 22: DWT vs. Length

According to the case study requirement the vessel's capacity should be 5000 DWT. From above figure for 5000 DWT the Length is 93 m.

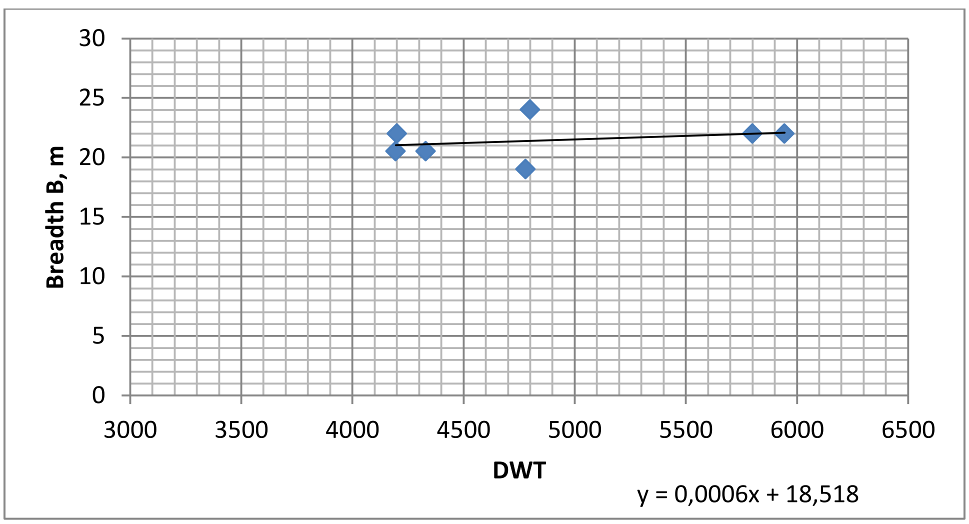


Figure 23: DWT vs. Breadth

In Figure 23 DWT vs. Breadth graph is drawn based on table 13 it is found that 5000 DWT gives 21.5m. The trend line equation is shown lower part of the figure 23 which will be used later.

Similarly from DWT vs. Breadth, DWT vs. Depth, DWT vs. Draft and DWT vs. Deck Area the other values are obtained. Results are shown in those graphs. They have been added in the appendix.

So the resultant values are shown in the following table.

Table 16: Principal Particulars

Principal Parameters		Validity Range (Finish Swedish Ice Class Rules) in meter	
	Dimension	Minimum	Maximum
Length Overall, Loa	93m	65	250
Breadth, B	21,5 m	11	40
Depth, D	9,2 m		
Draft, T (max)	7,2 m	4	15
Deck Area	925 m^2		

Here L/B ratio is 4,32. According to D.G.M Watson [27] vessels whose length lay in the range between 30 – 130 m should have L/B ratio within 4 and 6,5. The relationship graph is added in Appendix: A. This proves that the length and breadth are within the range.

T/D ratio is 0,78 which is also within the range. B/D ratio is 2,36. For small vessel B/D=1,8 provides good stability but here in this case vessel has higher B/D ratio. According to Taggart R (1980) this ratio is within the range[28]. Operational condition in North Sea and Barents Sea is harsh so vessel's operating in these areas has higher depth which gives higher B/D ratio. For this case study these types of vessels have been used for basic ship data.

Weight Calculation:

In the case study deadweight of the vessel is 5000 t. Now it is required to find out the light weight of the vessel for further design process. The components of lightweight in merchant ship practice consist of the structural weight, the outfit weight, the machinery weight and margin. In general, the structural group includes all steel or other structural material worked by the shipyards plus such items as deposited weld metal or rivet heads. Some outfit items are HVAC, sewage systems, watertight doors etc. It is not as obvious as it might appear at first sight as there are several items which could logically be placed in more than one group. It is therefore very desirable to have a demarcation that is standard at least within a design office.

According to Watson's weight based design formula[27]

$$Ws = Wsi\ [\ 1 + 0{,}05\ (Cb' - 0{,}7)]$$

$$Wsi = k\ .\ E^{1{,}36}$$

Here Ws = steel-weight for actual Cb' at 0,8D and

Wsi = steel-weight at Cb' = 0,7

Cb = 0,691 – 0,76 (according to SNAME[28] book 0,691- 0,722 and STX OSV 0,76)

E = Lloyd's equipment numeral= 800 – 1300 for offshore supply vessel

K = 0,045 ± 0,005 for offshore supply vessel

So

$$Wsi = (0{,}045\ \pm\ 0{,}005)\ .\ E^{1{,}36}$$

= 443,7 – 858,8 t

$$Ws = Wsi\ [\ 1 + 0{,}05\ (Cb' - 0{,}7)]$$

=446 – 863 t

Total displacement is

$$\Delta = DWT + Ws$$

= 5000 + Ws

= 5446 – 5863 t

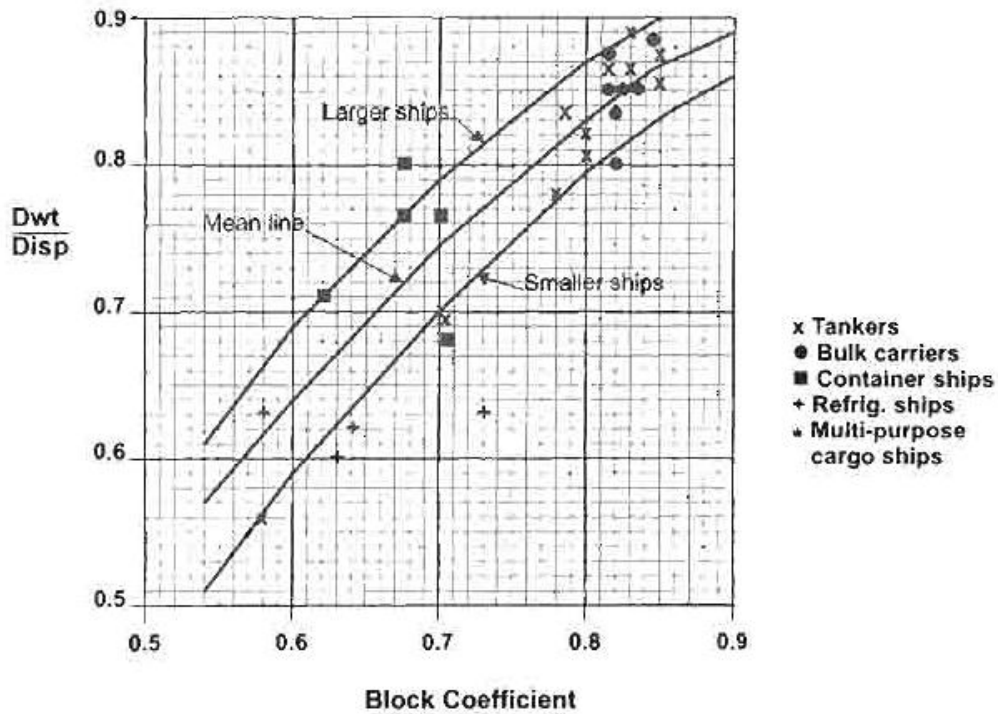


Figure 24: DWT /Displacement vs. Block coefficient[27]

From above Figure 24 it can be seen that for Cb =0,76 the resultant DWT/Δ = 0,76.

So, Δ = 5000/0,76 = 6578 t

This is 715 t higher than the previous one. This indicates that there are some weights which might not have taken into considerations such as ballast water or some machinery weight. Detailed weight calculation is necessary for finding appropriate displacement.

Plate Thickness

First it is required to find out the plate thickness for different ice classes.

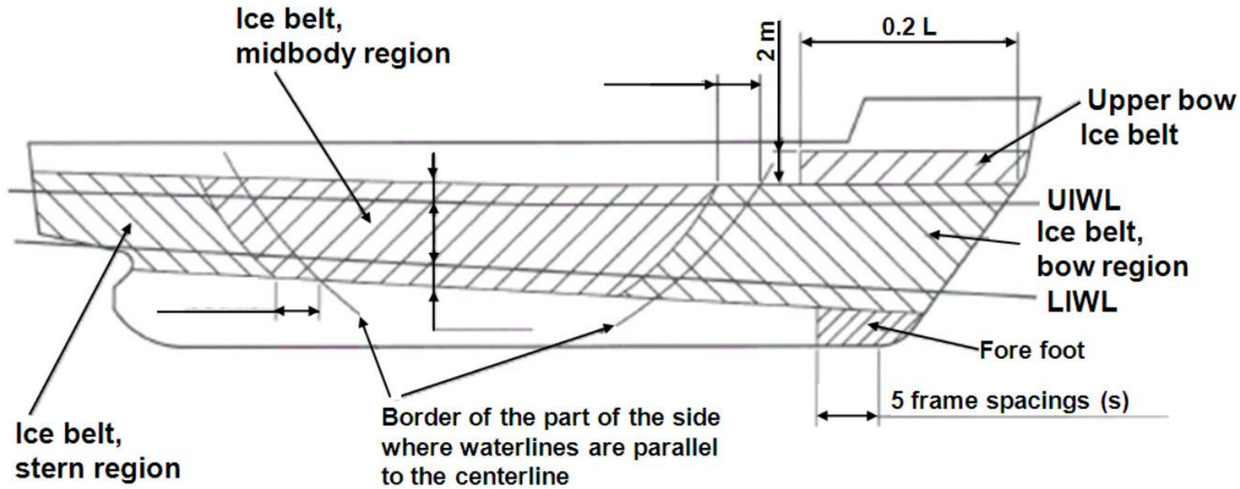


Figure 25: Ice Belt[29]

Figure 25 shows the ice belt for a vessel. For calculation purpose a plate from the bow region is selected.

Assumptions

Length = 5 m
Breadth = 2 m
Vessel Particulars
Length, L= 93m
Stiffener spacing, s= 0.4 m
Thickness =?

Calculations Following DNV Rules:

For plate thickness DNV Rules are used. These rules are similar to FSICR rules.

For ice class vessel plate thickness formula for longitudinal framing

$$t = 21.1 * s * \sqrt{\frac{p}{\sigma * f2}} + tc$$

Here
tc = corrosion allowance
p = design ice pressure
f2 = material factor
Design ice pressure formula is

$$p = 5600\ cd.ci.ca$$

c_d = a factor which takes account of the influence of the size and engine output of the ship.

c_i = a factor which takes account of the probability that the design ice pressure occurs in a certain region of the hull for the ice class equation.

c_a = a factor which takes account of the probability that the full length of the area under consideration will be under pressure at the same time.

For non-ice class plate thickness

$$t = \frac{\left[\frac{4{,}4 + 0{,}05\ L}{\sqrt{f1}}\right] s}{Ss} + 2$$

Stiffener spacing s = 1 m for non-ice class plate

Standard Frame Spacing, s_s = 0,48 +0,002 L = 0,66m

Material Factor, f1 = 1.28

Using the plate thickness and other plate dimensions the weight of the plate is calculated for non-ice class and ice class vessel. FSICR rules are also used for plate thickness calculation for ice class vessels only (Appendix: B).

Table 17: Plate Thickness and Weight

DNV Notation	**Design Ice Height, h(m)**	**Maximum Ice Height, ho (m)**	**Plate thickness, t (mm) for σ = 315 N/mm2**	**Weight, Ton**
ICE 1A	0.25	0.8	21	1,86
ICE 1B	0.22	0.6	20	1,78
ICE 1C	0.2	0.4	20	1,78
ICE C	0.18 (assumed)		19	1,7
Non Ice Class			15	1,3

The change in weight represents only a part of the vessel not the whole ship. According to Schneekluth and V (2007) book S S Sørstrand [30] estimated ice strengthening influence. For this case DNV ice class notations are added in the table. This influence has effect on cost calculation.

Table 18: Ice Strengthening Influence [28]

FSICR	Category 2	1C	1B	1A
DNV	ICE C	ICE 1 C	ICE 1 B	ICE 1A
Ice Thickness	Very Thin Ice	0,4	0,6	0,8
Percentage change in Steel Weight	2,00 %	4,00 %	8,00 %	13,00 %

Cost Calculation

For cost assessment simple PSV cost model is used. Then cost for different ice classes are estimated. The total scenario for different ice class vessel can be seen clearly by cost comparison estimation. For this calculation data for a basic PSV is used. The value of a basic PSV is considered 250Million NOK [31].

Table 19: PSV Cost[31]

Platform supply vessel (PSV)	STX Brattvaag, Ulstein Verft, STX Promar, others	150-250 MNOK

By using this basic price other calculations such as steel, cargo, machinery etc. have been made by using Main systems share model (Figure 26)

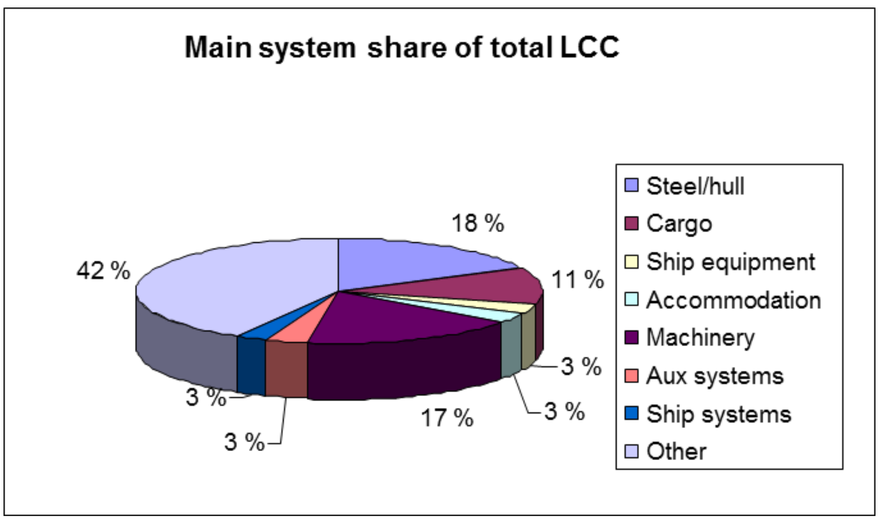


Figure 26: Main System Share[31]

From above Figure 26 and base cost of PSV (250 MNOK) the total building cost table is made (Appendix: C). After that using data of ice strengthening influence (Table 18) and cost of from system share model total cost is estimated. For this total cost share model is used.

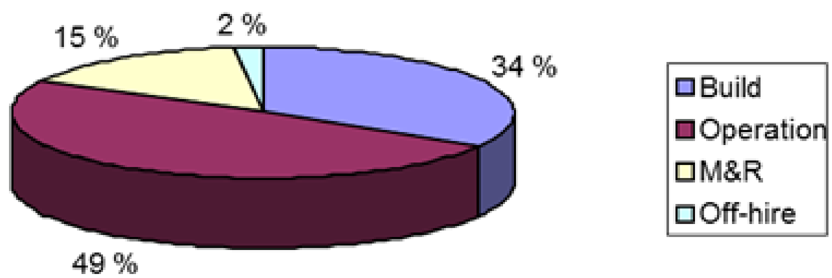


Figure 27: Total Cost Share Model[31]

Table 20: Total cost for different classes

Types of Cost , MNOK	**Percentage of cost**	**C**	**1 C**	**1 B**	**1A**
Building cost	34 %	252,1	254,2	258,4	263,65
Operating cost	49 %	363,32	366,35	372,40	379,97
Maintenance and Repair	15 %	111,22	112,15	114,00	116,32
Off hire	2 %	14,83	14,95	15,20	15,51
Total Cost (MNOK)		**741,47**	**747,65**	**760,00**	**775,44**

Ice Breaker: Ice class vessels have limitation for operating in ice. A vessel with ice class 1C means that it is capable of operating in the broken channel of ice up to 0,4m. Ice breaker assistance is important for ice operation in area 3. It has been found that in April and May (60 days) there is first year ice and from December to March (120) there is young ice. It is assumed that only one third of the operational day vessel will require ice breaker assistance. For example ICE 1C can operate in 20 days in first year ice and 40 days in young ice.

Table 21: Ice Operation and Ice Breaker Assistance

Ice Type		First Year Ice (30-200 cm)	Young Ice (10-30 cm)	
Time Period		Apr-May	Dec-Mar	Total
Operation in Ice (Days)		60	120	180
Ice Breaker Assistance (Days)	ICE 1C	20	40	60
	ICE 1B	20	13	33
	ICE 1A	7	No	7

Ice breaker charge is different for different types of ice breakers. Modern high capacity ice breaker charge is quite high. Old and lower capacity ice breakers' charge is less. Assumed ice breaker charges are 250, 000 NOK, 200, 000 NOK, 150, 000 NOK and 100, 000 NOK. Based on these charge and ice operation days sensitivity analysis of ice breaker use is done. For different ice breaker cost the sensitivity of Ice Breaker usage is calculated.

Table 22: Sensitivity Analysis of Ice Breaker Use

Sensitivity of ice breaker use	ICE 1C	ICE 1B	ICE 1A
Total Cost (when ice breaker charge 250,000 NOK per day), MNOK	763	768	777
Total Cost (when ice breaker charge 150,000 NOK per day), MNOK	757	765	776
Total Cost (when ice breaker charge 100,000 NOK per day), MNOK	754	763	776
Total Cost (when ice breaker charge 50,000 NOK per day), MNOK	751	762	776

If the maintenance cost is 4% higher for ICE 1C then total cost will increase 5 MNOK. If it increases 12% then the total cost will increase almost 15 MNOK.

For further investigation Ship Merit Factor (SMF) has been calculated[32] for only area 3. It is assumed that the vessel will operate within 300 nautical miles and total operational days in a year are 360 (240 days sailing and 120 days loading/unloading and waiting and standby time). The speed of the vessel is assumed to be 11kn, 10kn and 9kn for 1A, 1B 1C respectively. (Appendix: D)

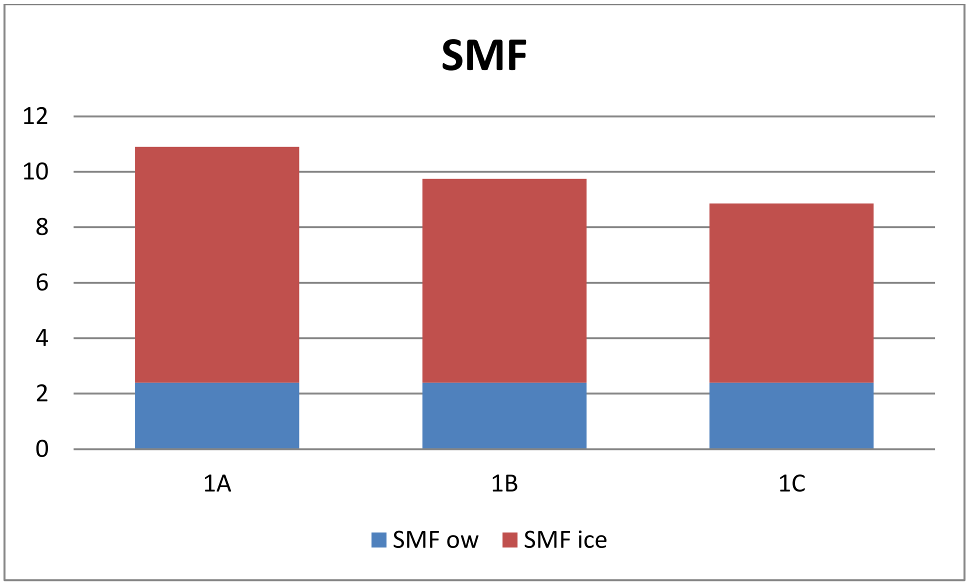


Figure 28: Ship Merit Factor

4.2.4 Program formation

A program is written for this case study using the methods and results those are described before. The program is written in a program language called Python 2.7.4 (Appendix: E)

The program is divided into the following parts.

1. Distance

2. Deadweight

3. Block Coefficient

4. Cost Evaluation

In the case study the selected location is divided into three areas. In this program first input is distance. It can calculate from 0 to 300 nm. From this input four points will be answered. Which area is it, then what is the wave condition there, what type of winterization is required and which ice class vessels are suitable for those area.

Next input is dead weight. The deadweight range is 2000-10000 DWT. From this data input the program can calculated L, B, D, T and Deck area. To calculate these values trend line equations from different ratios graphs (Figure 23) are used.

The last input is the Cb, block co-efficient. The value range is 0,69 to 0,76. From this input steel weight for different ice class vessels are calculated.

Cost evaluation is also shown in the last part of the program.

Program Input:

Distance in nautical miles: 200

Block Co- efficient: 0.7

Deadweight: 4000

Output:

Class is C/1C.

Lightship is 876 tons for C or 893 tons for 1C.

Area is 925 meters squared.

Length is 93 meters.

Breadth is 22 meters.

Draft is 7.3 meters.

Depth is 9.1 meters.

Merit factor is 9.5 for 1CPrices:

Building: 252 million NOK for C or 254 for 1C.

Maintenance: 111 million NOK for C or 112 for 1C.

Operating: 363 million NOK for C or 366 for 1C.

Off hire: 15 million NOK for C or 15 for 1C.

Total: 741 million NOK for C or 747 for 1C

4.2.5 Scenarios

The case study is done based on current condition of the Barents Sea. Now two other scenarios will be discussed here.

First scenario:

If the weather condition changes rapidly due to global warming, the amount of ice will be lower than now. It will give more access towards different remote Arctic location. In Barents Sea southern part is ice free now. If the amount of ice decreases that means others parts will have less amount of ice during the year. This will require lower ice class vessel in those areas. May be ICE C class vessel will operate in area 3 or further north.

Second Scenario:

If the weather condition changes rapidly due to cyclic order of long term climate change, the amount of ice might be higher than now. It will reduce access towards different locations of Arctic location. According to old ice data, it is possible to have ice in the southern part of the Barents Sea. Higher ice class vessel will be required to operate in this region. May be ICE 1A or PC 7 class vessel will operate in area 1.

5. Discussion

Three ship design methods have been analyzed to accommodate Arctic related challenges. For the Barents Sea related Arctic related challenges are temperature, ice, wind and wave, icing, icebergs, communication and uncertainty. These challenges have been discussed for the Barents Sea in chapter 3. Challenges in Arctic Seas) and afterwards, those have been tried to fit into different ship designs.

The selected Arctic related challenges can be dealt with through risk based design in the early stages of the design (Figure 15). It is possible to analyze the risks related to those constraints and uncertainties before decision making. This is one of the greatest advantages of risk based ship design. In other two ship design processes most of the selected artic related challenges can be dealt with except uncertainty (Figure 13 and Figure 14). For Arctic operation most of the platform supply vessels have different features according to the owner's specification. The number of successful vessel is low for Arctic supply vessel; therefore a database for system based ship design might be inadequate now. In the Arctic region competitive design is required from an operational and economic point of view. Conventional ship design takes time to complete and it is tough to accommodate an innovative idea in this process. This might be a disadvantage in the competitive ship design world. Based on these reflections, risk based design has been selected as optimal design solutions for the case study.

The case study is analyzed and solved in four steps, in which risk based design is used. First part of risk based design process is "Performance Expectation", which is defined according to the case study (Table 3). In step two "Requirements and Constraints" are defined and analyzed for the specific area. This is also the second part of risk based design. The relevant constraints are the area and route, weather conditions and infrastructure related to communication. In the third part, a program is written based on the result and in the final part different case scenarios are discussed.

From the research on the Barents Sea it is found that the southern part of the sea is mainly ice free. In the case study, the total area is divided into three areas which are denoted by area 1, area 2 and area 3 (Table 4). The first two areas are mainly ice free, and area 3 is covered with ice during the winter. These three areas have several other weather related threats such as ice bergs, icing, wind and high waves. They are limited in port capacity, infrastructure and have poor satellite coverage and other disadvantages. Therefore improvement in communication and infrastructure is necessary. As the weather is unpredictable, there is uncertainty in the weather data. However, the climate does have a great impact on the area, with the main influential factors related to design being ice thickness, wave height, wind speed and similar factors.

After ice data analysis (Table 7), it has been found that in the last 50 years, the maximum ice thickness that has been found nearby 75^{o}N (area 3) is first year ice with 200 cm thickness. In area 2, maximum ice thickness is 10 cm in last 50 years while area 1 is ice free. According to the case study the vessel has to operate throughout the whole year. To operate in area 1 vessel with ice notation ICE C should be fairly enough because there is no ice. In area 2 vessel with ice notation ICE C or ICE 1C should serve the purpose (Table 10). ICE 1C is also proposed for this area because it will provide wide operational range to the owner. In area 3, three options are proposed (ICE 1C, ICE 1B and ICE 1A). Higher ice class vessel will provide better operational range.

There is an uncertainty in weather condition and weather data. The selection of ice notation is based on ice data. If the ice condition changes (Chapter 4.2.5 Scenarios) then different ice class vessels will be required. In the first scenario it is seen that if the amount of ice decreases, then lower ice class vessel (ICE C) might be able to operate in area 3. In the second scenario it is shown that if the amount of ice increases rapidly, then higher ice class vessel will be required to operate area 1. For example: if first year ice with more than 200 cm thickness is found in area 1 then ICE 1A or PC 7 will be required here. In area 3, higher polar class vessel will be required. This type of change is very costly. Similarly, if the wave and wind conditions changes, then more analysis will be required before selecting vessel dimensions. In the case study both the

Norwegian Sea and the Barents Sea's wave conditions are analyzed which have provided better design decision support. Temperature, icing and icebergs also have effect in ship design process but not in preliminary dimension selection. The design process is sensitive to operational area's weather condition.

In plate thickness calculation, it is seen that there is a certain amount of change in plate thickness (see Table 17) from a non-ice class vessel's plate to that of an ice class vessel. For ice class vessels plate thickness change is very low form class to class. For ice class 1C and 1B the plate thickness is same. Result from FSICR shows almost similar values (See appendix). The plate is taken from the bow region, so the change in weight is very high from non-ice class to ice class plate. The change in weight represents only a part of the vessel not the whole ship, so an ice strengthening influence table (Table 18) is used.

Displacement calculated in this case study, is lower than what existing vessels are currently using. Existing ships are using more deadweight for different purposes. In the Arctic area ships are not allowed to discharge directly so larger storage tank is required. For fresh water and ballast purpose, large tanks are required.

The principal particulars of 5000 DWT vessel are calculated from the different ratio graphs (Table 16). Principal particulars are within the validity range of FSICR. It also has Deck Area of 925 m^2 which is 125 m^2 more than the required deck area.

In the cost assessment part, the total life cycle cost was calculated. From total cost table (Table 20) it is seen that ICE C has the lowest total cost, and ICE 1 A is very costly. The difference between ICE C and ICE 1A is 34 MNOK. A different scenario is found (Table 21) when the ice breaker charge is added in the whole life cycle assessment.

Table 23: Sensitivity Analysis of Ice Breaker Use

Sensitivity of ice breaker use	**ICE 1C**	**ICE 1B**	**ICE 1A**
Total Cost (when ice breaker charge 250,000 NOK per day), MNOK	763	768	777
Total Cost (when ice breaker charge 150,000 NOK per day), MNOK	757	765	776

Table 23 also shows that for higher ice breaker charge the difference in total cost is very close. Difference between ICE 1A and ICE 1C is only 14 MNOK. Difference is higher for lower ice breaker fee. Note that additional repair and maintenance cost are not added. When lower ice class vessel is operated for a long time in ice then it might require more repair and maintenance because of lower structural strength than a higher ice class vessel. Therefore, ICE 1C vessel should require more repair and maintenance than ICE 1A vessel. For more repair and maintenance tasks, operational days might be reduced which is very costly. The total life cycle costs will be same for ICE 1B and ICE 1C if the additional maintenance cost is 4% higher. If the additional cost is 12% more than ICE 1C and 1A will have same total cost. After ship merit factor calculation (Appendix: D), it has been found that higher ice class vessel gives better merit factor (See Figure 28). In conclusion, higher value gives better solution.

The suggested program is written on the basis of the case analysis (see chapter 4.2.4 Program formation). Most of the results are similar to the previous calculation. Draft value is 0,1 m higher than the manual calculation. This program gives a quick scenario for the whole case. It shows principal particulars, weight, total cost, ice breaker charge and ship merit factor value. This program is made for this case study. This means that it will require adjustment for different regions, although it might be easily adaptable to similar regions. After that two case scenarios are given based on weather condition changes.

Risk based design has more advantages than the other two ship design processes, therefore in the case study the risk based design method is applied. The solution of the case study satisfies all the defined requirements. The procedures of risk based design have been followed step by step, and this satisfies the hypothesis founded in the chapter 1. INTRODUCTION.

6. Conclusion

The Barents Sea offers a number of weather related challenges. There is lack of infrastructure and poor communication system in this area, therefore significant development is required. There is an uncertainty in the weather condition and weather related data, which have significant effects on the design. To cope with the uncertain factors that are found in the arctic area, three types of ship design processes are analyzed to find out their adaptability for arctic ship design. Both conventional ship design process and systems based ship design process can be applied to arctic ship design, but it appeared to be difficult to deal with uncertainty that go with these processes. However, in risk based ship design process it is possible to deal with uncertainty and arctic weather related risks at the very early stage of ship design, therefore this strategy is recommended and used in the case study of this research project.

To apply risk based design methods to the case study, seven arctic challenges were analyzed for the case study area. To reduce operational risk and uncertainty, long term ice, temperature and wave related data is used and checked with other data sources. It has been found that the amount of ice is decreasing in the Barents Sea, but still it has rough weather condition.

Principal particulars of the supply vessel are calculated based on the existing ice class vessels. In the case study, three areas have different ice conditions which lead to different ice class notations. A cost analysis is done for those ice class vessels and it is found that in ice free areas (area 1 and 2) lower ice class vessel (ICE C) is cost effective. In further north (area 3) during the winter season ice breaker assistance is required. After sensitivity analysis on ice breaker charge it has been found that with high ice breaker fee the difference between ICE 1A and ICE 1C is not large. With higher repair and maintenance cost the total cost could be equal. This analysis is sensitive to ice breaker fee. With low ice breaker fee lower ice class vessel is more cost effective. From Ship Merit Factor it has been seen that in area 3 higher ice class vessel provides better solution in ice operation. Higher ice class vessel provides wide operational range. The results from the case study show that use of ICE 1A or 1C has marginal cost difference but ICE 1A will provide safe and better operational range.

From the program it is possible to get a quick result of principal particulars, deck area, lightship and cost assessment. This result will provide designers an idea of preliminary design of a supply vessel design for the specific area of the Barents Sea.

This risk based design process provides robust methodology for the selected part of the Barents Sea. It makes it possible to deal with the selected Arctic challenges in the case study. This process is sensitive to area specific operation. For different areas it will require adjustments while analyzing the arctic related challenges because different Arctic areas offer different weather conditions.

Finally, after the evaluation of three ship design processes for Arctic challenges, it is found that the risk based design is the most suitable one, and it has been applied successfully in the case study.

7. Future Scope of Work

Risk based design is applied to a certain part of the Barents Sea. It is therefore suggested to apply this for other areas too. It is possible to implement the same methodology for different arctic seas. To get the most accurate data, area specific data is very important to analyze. More data sources should be utilized to find more detailed and updated information on weather conditions. It will be useful to use insights from different disciplines (e.g. climatic studies, geographical studies, arctic investigators etc.) in order to thoroughly investigate the area and therefore it is possible to better anticipate on the several risks concerning using the area.

Moreover, more detailed algorithm to find suitable design alternatives using optimization could be interesting with regards to finding more suitable designs. Thereby, the design could be better and quicker to be optimized with regards to an operational profile for an ice class supply vessel.

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Appendices

Appendix: A

L/B Relationship Graph[27]

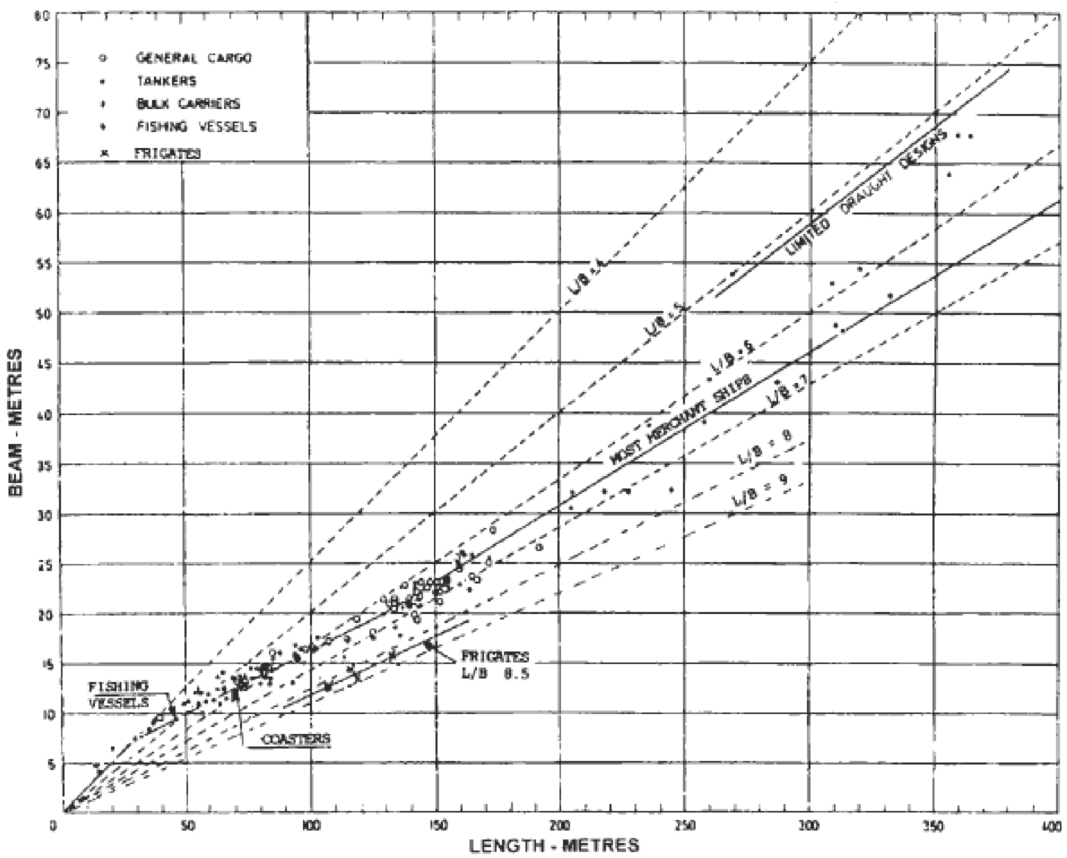

Fig. 3.7. Length–breadth relationship.

Appendix: B

Plate Thickness Calculation (FSICR)

Notation	Thickness of Brass Ice in mid channel, H_m	Plate thickness, t (mm) for σ = 235 N/mm2	Plate thickness, t (mm) for σ = 315 N/mm2	Plate thickness, t (mm) for σ = 390 N/mm2	Weight, Ton for σ = 235 N/mm2	Weight, Ton for σ = 235 N/mm2	Weight, Ton for σ = 235 N/mm2
ICE 1A	1	24	21	19	1.872	1.638	1.482
ICE 1B	0.8	22	20	18	1.716	1.56	1.404
ICE 1C	0.6	21	18	17	1.638	1.404	1.326

Appendix: C

Systems Cost Table

Share of different systems			
Steel/Hull	42%	105	MNOK
Cargo	11%	27.5	MNOK
Ship Equipment	3%	7.5	MNOK
Accommodation	3%	7.5	MNOK
Auxiliary Systems	3%	7.5	MNOK
Machinery	17%	42.5	MNOK
Ship Systems	18%	45	MNOK
Other	3%	7.5	MNOK
Total Building Cost		**250**	**MNOK**

Appendix: D

Ship Merit Factor

Ice Class	1A	1B	1C	Open Water
fv	0.73	0.67	0.60	0.87
fp	0.5			
Pb	4607.45	3186.72	2002.64	1800
V, kn	11	10	9	13
Rt	170	110	70	6
Rt, ton	17,17	11,11	7,07	6
AAC, NOK/year	41.4	39.6	37.8	34.2
k	2725.708	2477.916	2230.125	3221.291
SMFow (open water)				2.496
SMFice (Ice operation)		8.860	7.655	6.727
SMF t (Total)		**12.24**	**10.91**	**9.89**

Appendix: E

Program

```
distance = float(raw_input('Enter the distance: '))

if distance <= 100:
  i_class       = "C"
  i_wave        = 2
  i_winterization = "normal"
elif distance <= 200:
  i_class       = "C/1C"
  i_wave        = 2.5
  i_winterization = "moderate"
else:
  i_class       = "1C/1B/1A"
  i_wave        = 2.5
  i_winterization = "heavy"

block = float(raw_input('Enter the block coefficient: '))

if 0.68 <= block <= 0.76:
  i_wsi = 0.05 * (1300.0**1.36)
  i_ws  = i_wsi * ( 1 + 0.05*(block-0.7) )

  if i_class == "C":

    i_ws = "%.0f tons" % (i_ws * 1.25)

    i_bp = "252 million NOK"
    i_mp = "111 million NOK"
    i_op = "363 million NOK"
    i_hp = "15 million NOK"
    i_ip = "not allowed to go to this area"
    i_tc = "741 million NOK"
```

```
  elif i_class == "C/1C":

    i_ws = "%.0f tons for C or %.0f tons for 1C" % (i_ws * 1.02, i_ws * 1.06)

    i_bp = "252 million NOK for C or 254 for 1C"
    i_mp = "111 million NOK for C or 112 for 1C"
    i_op = "363 million NOK for C or 366 for 1C"
    i_hp = "15 million NOK for C or 15 for 1C"
    i_ip = "15 million NOK for 1C"
    i_tc = "741 million NOK for C or 747 for 1C"

  elif i_class == "1C/1B/1A":

    i_ws = "%.0f tons for 1C, %.0f tons for 1B or %.0f tons for 1A" % (i_ws * 1.04, i_ws * 1.08, i_ws * 1.13)

    i_bp = "254 million NOK for 1C, 258 for 1B or 263 for 1A"
    i_mp = "112 million NOK for 1C, 114 for 1B or 116 for 1A"
    i_op = "366 million NOK for 1C, 372 for 1B or 379 for 1A"
    i_hp = "15 million NOK for 1C, 15 for 1B or 16 for 1A"
    i_ip = "15 million NOK for 1C, 8 for 1B or 2 for 1A"
    i_tc = "747 million NOK for 1C, 760 for 1B or 775 for 1A"

else:
  print "The block coefficient must be in the range of [0.68..0.76]."
  raw_input('')
  exit()

dwt = float(raw_input('Enter the deadweight in tons: '))

if 2500 <= dwt <= 10000:
  i_length  = -0.0009*dwt + 97.548
  i_breadth =  0.0006*dwt + 18.518
  i_draft   =  -0.00003*dwt + 7.4518
  i_depth   =  0.0003*dwt + 7.5943
  i_area    =  0.0841*dwt + 504.87
```

```
else:
  print "The deadweight must be in the range of [2500..10000] tons."
  raw_input('')
  exit()

file = open("output.txt", "w+")

a = ""
a+= "Values for the distance of %.0f, the deadweight of %.0f and the block coefficient of %.2f are:\n" % (distance, dwt, block)
a+= "\n"
a+= "Class is %s.\n" % i_class
a+= "Wave is %.1f.\n" % i_wave
a+= "Winterization is %s.\n" % i_winterization
a+= "\n"
a+= "Lightship is %s.\n" % i_ws
a+= "\n"
a+= "Area is %.0f meters squared.\n" % i_area
a+= "Length is %.0f meters.\n" % i_length
a+= "Breadth is %.0f meters.\n" % i_breadth
a+= "Draft is %.1f meters.\n" % i_draft
a+= "Depth is %.1f meters.\n" % i_depth

if i_class == "C/1C":
  a+="Merit factor is 9.5 for 1C.\n"
elif i_class == "1C/1B/1A":
  a+="Merit factor is 9.5 for 1C, 10.4 for 1B, 11.7 for 1A.\n"

a+= "\n"
a+= "Prices:\n"
a+= "  Building: %s.\n" % i_bp
a+= "  Maintenance: %s.\n" % i_mp
a+= "  Operating: %s.\n" % i_op
a+= "  Offhire: %s.\n" % i_hp
```

```
a+= "  Total: %s.\n" % i_tc

file.write(a)
file.close()

print "\n------------------\n"
print a
print "------------------"

print "\nThe result is saved to \"output.txt\"."
print "Press any key to close."
raw_input('')
```