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Abstract

When the decision to study the development of an offshore field is taken, the concept phase of an offshore project development starts. The concept phase consists of the concept screening, conceptual engineering and concept selection stages. While concept screening and conceptual engineering stages represent a specific sequence of engineering calculations to determine technical feasibility and all aspects of each possible development concept for an offshore field, the concept selection stage represents a decision making process where a lot of factors should be considered in order to identify the optimal concept which satisfies all technical, economic and safety requirements along others.

According to recent tendency in oil and gas industry, the Arctic offshore area has a great potential for future field developments. However high ecological risks, challenging environment for operation and construction as well as requirements for huge money investments impose accessorial liability on decisions taken in the early phases of the project and especially in the selection of the optimal development concept.

The purpose of the thesis is concretization of the Concept selection process for Arctic offshore field development. Identification of the possible criteria influencing the definition of the optimal development concept is carried out. Prioritizing of each criterion according to its importance in the Concept selection process is then performed.

Attention is given to the main Arctic specifics and challenges that could affect the field development concept. On the basis of this analysis the concept screening and the conceptual engineering steps for Arctic projects are discussed. The main driving factors for qualifying the development concept are defined. Their effects on the development concept in the Arctic are then considered.

In the second part the Concept selection process for the Arctic offshore field development is considered. Criteria influencing the concept selection process were identified. Criteria identification is performed on the basis of wide literature survey which includes industry standards, scientific articles and English and Russian engineering books about offshore field development.

Evaluation of the criteria's importance is carried out by the help of experts' judgment method. A questionnaire for criteria evaluation was prepared and a group of relevant people from the industry, who deals with the Arctic offshore field development, weighted each criterion according to their importance in the Arctic offshore concept selection process.

As a result, a list of the most important criteria, representing the basis for selection of development concept for Arctic offshore fields, is prepared.

The results of the work are presented in the form of a methodological tool for the Arctic offshore concept selection. The model is dedicated to the Concept Phase of the Arctic offshore project. Each stage at that phase is considered in the model. Parameters important in the screening stage are listed. Their imposed limitations on the development concept are identified. A list of criteria for comparison of possible development concepts is included in the model. Thus, the model represents a step by step approach for the implementation of the Concept Phase of an Arctic offshore project.

The conclusion summarizes the acquired findings, provides reasonable recommendations for the concept selection of the Arctic offshore fields and gives the scope for the future work.

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1 Introduction

1.1 Background

The field development concept activity is the foundation stage for the whole offshore project implementation. The "right" choice of the concept for the offshore field development is the first and major step for achieving profitable and technically safe offshore field exploitation.

The offshore projects concept development phase consists of three steps: *concept screening*, *conceptual engineering* and *concept selection* [8].

The purpose of the *concept screening* step is to identify all possible offshore field development concepts.

The purpose of the *conceptual engineering* step is to confirm technical feasibility of considered development concepts.

The purpose of the *concept selection* step is to compare identified technically feasible concepts and choose the optimal one for an offshore field development which meets economical, technical, safety and risks requirements.

This Master Thesis is focused on the final step of the offshore projects concept phase – the concept selection process. The purpose of the Master Thesis is to assist in accurate decision making process for the concept selection.

1.2 Problem formulation

Selection of the "wrong" development concept at the early phase of the project could lead to immense loss of money at the later phases. Sometimes production can even not to start due to wrong decision. Example of such an accidental decision could be the Yme platform which was found inappropriate for operation on the Norwegian Continental Shelf. And now the Operator Company has to remove this platform without even starting a production. [55]

(Crager, 2011, [10]) shows an example of an offshore field in the West Africa. The field was developed with an FPSO with subsea tiebacks. However when production started it appeared that the hydrocarbon resources are higher than was expected at the beginning of the project and that installation of another semisubmersible platform would be more profitable than just increasing the tiebacks.

Thus the Operator Company installed a supplementary semisubmersible platform and had huge additional money investments.

Figure 1 shows the dependence between the easiness to make changes in a project and their expenses. It is seen that it is most expensive to make changes in the project at the last phases when the facility is already installed. And least of all expensive is to make changes at the early phases of the project. Simple numbers show how the importance of accurate and precise work on the decisions made at the beginning.

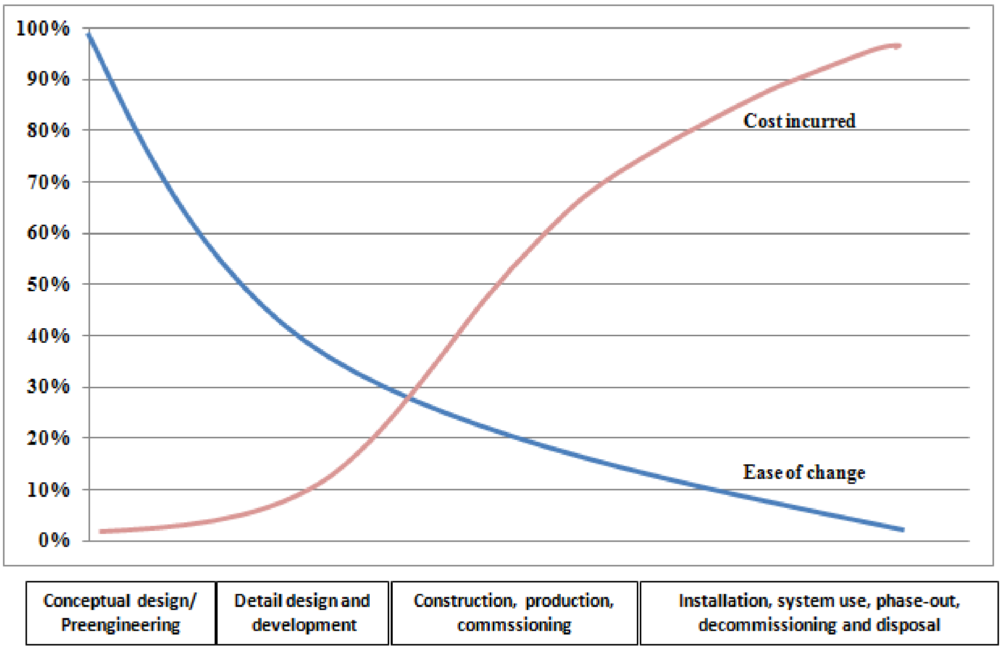


Figure 1 Dependence between changing of development concept and its cost during the project life [8]

Recent tendency in the oil and gas industry is characterized by high interest of the companies to the Arctic region. However such Arctic specifics as high ecological risks, challenging physical environment for operation and construction and requirements for huge money investments impose accessorial liability on decisions taken in the early phases of the project. The issue of the “right” concept selection for the Arctic development becomes even more critical under such circumstances.

But what is concept selection and what is the difference between concept development and concept selection? Let us consider definitions of these terms.

The Concept phase of the offshore project development consists of three steps: concept screening, conceptual engineering and concept selection [8].

The concept screening and concept engineering processes are relatively well described in the literature and represent a distinct chain of sequential considerations from the reservoir calculations till the market determination. The main purpose of these stages is to identify all possible and technically feasible development concepts according to all engineering parameters of the field as water depth, reservoir characteristics, ice conditions, wave and wind conditions etc. The more feasible concepts are found, the more accurate selection of the optimal one could be done.

The concept selection is a process of comparison of all technically feasible concepts from the economical, safety, regulations and such others points of view. And to determine the optimal development concept means to find a balance between technology, economics, safety and simplicity of the implemented concept.

The concept selection process should be based on a number of criteria that can distinguish between the feasible concepts. These criteria may vary from case to case but there is always a general list of important parameters for all of them.

Different papers attempts to identify these criteria that can highly contribute to the concept selection but most of them do not represent a comprehensive list of criteria (for more information see chapter 2, “Literature Survey”). Almost none of the criteria reflect the Arctic specifics.

1.3 Purpose and scope

The objective of this Master Thesis is to identify, analyze and evaluate all possible criteria that influence the Concept selection process; these criteria specifically reflected on the Arctic area situation and circumstances, which may bring dramatic challenges in concept selection process. The identification and determination of these criteria is based on a wide literature survey. Afterwards, each criterion analyzed and the impact of each one on the concept selection process is subjected to be assessed.

The main part of the criteria evaluation process is the expert judgment. People from the industry are asked to give weights to each criterion according to their importance in the concept selection process. As a result, a list of most important criteria is determined.

The result of the work is a holistic approach to selection of offshore field development concept for Arctic area.

1.4 Limitations

To respond properly to the purpose of this project, the above mentioned terms, i.e. concept phase of the offshore projects development, criteria influencing concept selection and Arctic offshore would delimit the study perspectives. In other words, the study is delimited to the concept selection process of the project's concept phase, while concept screening and conceptual engineering are not precisely studied in the thesis.

There are different methods for how to perform a concept selection (see Chapter on Methodology); however this thesis is concentrated on the "criteria based method" and considers criteria that could contribute to this method.

Prioritizing of criteria is performed by the method of experts' judgment with all limitations that provides this method. The level of data reliability increases with the number of answered experts. However the narrow area of subject and time available has imposed limitations on the number of interviewed people. Seven experts were found relevant for evaluation/ ranking of criteria according to their importance in the Arctic offshore concept selection.

Note that it is not an intention of this work to get to know the relevance of the development concepts according to the criteria. For example it will not be explained how to gain information about the concept's equipment reliability, or how to compare options according to technical safety.

1.5 Thesis organization

The Master Thesis is composed in the following way:

Chapter 2 (Literature survey) provides a description of the searching process for relevant literature related to the criteria identification. Reviewed literature includes standard documents, books and scientific articles.

Chapter 3 (Methodology) provides the description of the different methods for the concept selection process carrying out. The chapter includes the list of methods used in the thesis for research purposes.

Chapter 4 (Offshore project development process) provides an elaborated study of the offshore project's planning phase. The chapter includes a description of the whole chain of a project's development process and highlights the concept phase; consisting of concept screening, concept engineering and concept selection stages.

Chapter 5 (Arctic challenges) provides a study of the main challenges in the Arctic area, including environmental conditions, geotechnical conditions, underdeveloped infrastructure and main risks.

Chapter 6 (Arctic offshore field development) provides a definition of the Offshore Field Development Concept with respect to the Arctic area. It includes a description of the main parts of the development concept, including drilling systems for Arctic development, production system for Arctic development, process systems and transportation systems with comments about their relevance to the Arctic area.

Chapter 7 (Concept Screening and Conceptual Engineering) provides a description of the main stages of the concept phase of an offshore project development. The chapter includes identification of the main driving factors influencing these stages, including water depth, geological and reservoir data, ice conditions, icebergs, wave, current and wind conditions, seismic conditions, geotechnical data, distance to shore, period of maximal storm and limitations for structure draught, fabrication easiness, etc. The effect of these factors on the development concept is analyzed also.

Chapter 8 (*Concept selection process and criteria influencing it)* provides the list of identified criteria for the Concept Selection process. Explanation of each criteria and their influence on the concept selection process is provided in the chapter.

Chapter 9 (Evaluation of the Concept Selection criteria) provides the experts' judgments of the criteria list. People from the industry have shared their opinion about the criteria's importance and have givea weight to each criterion in the concept selection process. The results of the experts' judgment are discussed and presented in the chapter.

Chapter 10 (Results) provides a methodological tool for the concept phase of the project development. Limitations of this model are discussed.

Chapter 11 (Conclusion) provides a discussion of what was done in the Master Thesis and which results were obtained.

2. Literature survey

The objective of the Master Thesis is to identify the criteria that will be applied to the selection of the Arctic offshore field development concept. Identification of these criteria is based on a literature survey. Thus the bigger search is carried out, the better results are contributed.

It was decided to start the literature survey from the standard documents because they represent industries approved principles. However, standard documents do not cover the concept development phase comprehensively. NORSOK standards, however, consider the concept selection phase more than the others. The standards highlight that qualitative risk assessments should be performed in the concept selection phase. Most of the suggestions are given in general form and only the flexibility of the concept design for the further possible changes as an example of risk is mentioned. This will be considered in the further work. Importance of collision risk assessment is also highlighted in the standard.

NORSOK Standard S-003 [3] insists on the importance of environmental considerations and suggests ranking the screened concepts according to that criterion.

PSA standard [4] also gives some suggestions about what should be considered in the concept selection phase but in the author's opinion the given points are mixed and valid both for the concept screening and the concept selection stages.

After searching in industry standards it was decided to check most known offshore engineering books. This search gave good results in spite of the fact that only one book was found as relevant. In [1] the authors presented a method to select the optimal concrete platform for an Arctic field development. The method is based on expert judgments of platforms according to the list of criteria which was proposed by authors. Most of these criteria are applicable to any concept selection process that is considered in this Master Thesis.

But the main outcome was obtained from searching for the scientific papers. Onepetro, Scopus, WoodMackenzi and Google Scholar databases provided an opportunity to find several science articles relevant for the oil and gas industry. Most of the paper's authors insist on the expert's judgments method for the optimal concept selection. Some articles give approximate criteria for the concept selection. These criteria will be considered and studied in further chapters. General impression from reading the articles is that the problem of concept selection is very important nowadays.

The results of the literature survey are systemized according to key words and databases and are presented in Appendix Table A.1, A.2, A.3

2.1 Industry standards

Objective: Searching for Standardized Concept selection Procedures

NORSOK Standards

NORSOK Standard Z-013 [2]

The NORSOK standards are developed by the Norwegian petroleum industry and are presented in open access.

Searching for the relevant information in the NORSOK standard gave us the following.

The sixth clause of NORSOK Standard Z-013 is called «Additional requirements to quantitative risk analysis (QRA) in concept selection phase».

The clause provides the procedure of risk assessment performed in Concept selection Phase. It involves several subchapters:

6.1 General

Not applicable for concept selection

6.2 Establishing the Context

This Subchapter provides a procedure for QRA with listed specific objectives, which are:

a) Identify potential showstoppers for concepts and risk challenges for any of the concepts under evaluation i.e. evaluate if it is likely that the authority and acceptance criteria for any of the concepts cannot be met

b) Describe and characterize all risks that are significant for the facility, in order to assist the concept selection and optimization process

c) Identify possible significant risk reducing measures, so that safer, more environment friendly, more cost effective design and/or inherently safe options can be adopted

d) Provide a risk ranking of the proposed concepts. The risk may be expressed as risk to people, environment, assets and impairment of safety functions

e) Evaluate the robustness and uncertainties of the proposed concepts with respect to possible changes during design development

f) Identify need for any further risk assessments or detailed studies that should be performed

g) Identify need and scope for further risk assessments during the next phase,

h) Establish preliminary DSHAs (defined situations of hazard and accident)

i) Evaluate the layout of main areas

j) Establish preliminary dimensioning accidental loads and/or safety zones/separation requirements

6.3 Hazard identification (HAZID)

This Subchapter highlights that the HAZID in the concept selection phase shall focus on the construction and installation risks.

Also the following requirements for the concept selection phase are provided:

a) Hazards that represent a significant difference between concepts or represent a high risk shall be quantified. Normally limited information and time is available for a detailed analysis of initiating events. In a QRA in this phase it is therefore recommended to use data for comparable systems, or to use data from similar facilities;
b) Extra focus shall be on new unconventional concepts or concepts with limited operational experience;
c) Personnel transport risk, with respect to possible differences between the concepts or specific challenges, is an element that shall be considered in this phase;
d) When ship collision risk is deemed to be significant, a detailed collision analysis shall be performed in this phase. This is in particular the case when collision risk will be dimensioning for the facility structure or determining for the location of the facility;

e) Possible concept challenges and differences regarding effects from and impact on neighboring activities, environment and population (3rd party) shall be considered.

6.4 Analysis of initiating events

Not applicable for concept selection

6.5 Analysis of consequences

This subchapter provides the procedure for the consequence modeling performing.

6.6 Establishing the risk picture

Not applicable for concept selection6.7 Risk evaluation

Not applicable for concept selection

6.8 Communication and consultation

Not applicable for concept selection

6.9 Monitoring, review and updating the risk assessment

Not applicable for concept selection

Thus some useful information about main risks considered in Concept selection Phase is provided in this NORSOK Standard that we will use in the Thesis Later.

NORSOK Standard S-003 «Environmental care» [3] also includes information related to this Master Thesis. The Standard highlights that selection of project concept shall include environmental considerations. Also it gives examples of main conceptual decisions that will have different impacts on the air emissions and discharges to sea:

a) Stand-alone development or subsea tie-in to existing platform(s);
b) Platform or subsea-to-land solution;
c) Integration with existing platform(s) or infrastructure, e.g. wellhead platform, partial processing, full processing;
d) Power from land or from other platforms;
e) Transport solution for oil (pipeline transport or offshore loading);
f) Transport solution for gas (compression demand, processing requirements);
g) Reservoir drainage strategy (water and/or gas injection, increased oil recovery, definition of plateau rate);
h) Possibilities for well stream energy conservation or utilization;
i) Platform concepts, e.g. floating or fixed, with and without drilling facilities;
j) Possibilities for injection of produced water, either as a part of pressure maintenance strategy or as a disposal option;
k) Possibilities for injection of cuttings and excess mud;
l) Design for easy decommissioning and removal.

The standard suggests that for the Environmental Impact Assessment document evaluations and a choice be made in this phase and says that approval of the PDO/EIA will be an important confirmation of the decisions.

PSA standard

PSA (Regulations Relating to Design and Outfitting of Facilities etc. in the Petroleum Activities) [4] dictates that in choosing a development concept the following shall be taken into consideration:

a. major accident risk
b. form of operation
c. risk of pollution
d. geographic location
e. location conditions
f. reservoir properties
g. requirements to regularity
h. life time
i. subsequent removal, if any
j. need for development of new technology

Thus the PSA standard mentions in general words the requirements for Concept selection that we will take into account later.

DNV Standards

Searching for relevant information in DNV standards did not give any results. The search was made by key words as “DNV standard concept selection” in Google search service and no one relevant web site was found. Key words “DNV standard concept development” also did not give results.

API standards

This standard does not exist on open access.

However, NSSN (http://www.nssn.org/search/IntelSearch.aspx) – is the national resource for global standards that provides opportunity to search by key words in the majority of standards. Search by key words “Offshore Concept selection” in that database did not give any results. Key words “Concept selection” helped us to find 59 different standards but no one was relevant.

ISO Standards

Searching for the relevant ISO Standards on the official web site http://www.iso.org/iso/home.html by key words «Offshore concept selection», «Offshore Concept Development» and «Offshore Concept» did not give any result. The ISO 19906 Standard on Arctic Offshore Structures should, however, be useful.

2.2 Offshore Engineering books

For this search the majority of well-known books for offshore engineers were studied.

«Handbook of Offshore Engineering» Chakrabarti, S.K.

The book [5] has a single chapter dedicated to the Concept Development process. Chapter 6 of the book is called «Fixed Offshore Platform Design» and it has single subchapter 6.1.3.2 «Multi-criteria Concept selection». The chapter fully describes the whole process of the Concept Development Phase and mentions those most relevant for that thesis part - Concept selection. The 6.1.3.2 subchapter supports the idea of the thesis to select the optimal concept for offshore field by using a multi-criteria decision model. The author suggests to identify multitude selection criteria, to group them and then by experts judgments to order them in a hierarchical manner. Then he suggests identifying the optimal concept for the offshore field according to weighted criteria.

The described method for concept selection fits the idea of this Thesis but unfortunately the author did not give any example of application of the relevant criterion.

«Arrangements and development of the oil and gas offshore fields» Vyakhirev, R.I., Nikitin, B.A., Mirzoev, D.A.

Technical fundamentals, concepts of developing offshore oil and gas fields, taking into account the climatic conditions and equipment of the shore infrastructure are considered in this book [1]. The experience of creating surface, subsea, underground combination fields has been generalized.

The book has a Chapter that is called "Methodology of the optimal ice-resistant platform concept selection" that is quite relevant to our topic. In the chapter the authors suggest the methodology to choose the offshore field development concept by expert's opinions. Then they give a relevant criteria list for the optimal platform selection.

They advise the following:

1. Automatization level of technical processes
2. Convenience of technical equipment positioning
3. Level of operating personnel working conditions
4. Autonomy level of platform
5. Possibility to maximize autonomy level with minimal increasing of metal consumption
6. Complexity of construction, assembling and installation of the platform base structure
7. Complexity of construction, assembling and dismantlement of the whole platform
8. Possibility to use home country's plants for platform construction
9. Complexity of the equipment assembly
10. Volume of necessary construction operations performed offshore in comparison with onshore works
11. Possibility to execute the project by the help of several service companies
12. Duration of construction and installation works in open waters
13. Time to first production
14. Sensitivity to critical environmental conditions
15. Resistance to external loads
16. Reliability of base structure
17. Safety of assembling, transportation and installation
18. Safety during the operation
19. Maintenance complexity
20. Possibility to drill blow-out preventing wells on the platform
21. Possibility to use wells drilled previously
22. Possibility to use several drilling rigs
23. Influence of well number on the need to change the platform equipment
24. Influence of subsea risers on the platform construction
25. Influence of platform fundament type (piled, gravity, etc.) on the platform base
26. Possibility to use the platform on the other fields without big design changes
27. Need to extend the construction plant infrastructure
28. Need to extend the construction plant productivity
29. Need to reconstruct the construction plant for the platform base construction
30. Need for special construction works before platform installation
31. Need to construct special floating structures for platform installation
32. Flexibility for future expansion
33. Storage capacity

34. Material consumption of the platform
35. Complexity of the construction
36. Cost of the platform construction
37. Need in additional investments for construction of additional structures

In addition the authors suggest using these criteria not only for optimal platform selection but for other concepts also. Thus later we will analyze and choose some of these criteria relevant for our topic.

«Basics of Offshore Petroleum Engineering and Development of Marine Facilities» Gudmestad, O.T., Zolotukhin, A.B. et al.

The textbook [6] describes the main aspects of offshore engineering from geology till economics. It involves a chapter that is called «Chapter 7 Offshore facilities for field development». However there is no relevant information about concept selection process.

«Oil and gas resources» Gudmestad, O.T. et al.

The book [7] involves special chapter that called «Concept development procedure». In this chapter the procedure of Concept selection process organization is described, however, information about concept selection criteria is not found.

«Engineering aspects related to Arctic offshore developments» Gudmestad, O.T., Loset, S. et al.

The book [8] has a similar chapter that is called «Project development principles» and it has a subchapter «Approval point (AP 1), «Concept selection». This subchapter provides the purpose of the Concept selection process and mentions that it is necessary to have screening parameters and weightings for Concept selection but it does not give us any example of them.

2.3 Scientific articles/ papers

For searching for papers the main well-known databases were used: OnePetro, Scopus, WoodMackenzie, and Google Scholar. Articles were searched by key words: «Concept selection Criteria», «Concept Development criteria», «Offshore Concept selection Criteria», «Offshore Concept selection Criteria», and « Concept selection Criteria». Significant numbers of relevant papers were found (see Table 2).Not all of them are discussed in this Chapter but most of them are used in further work. Most relevant papers are studied below.

«Concept selection for Hydrocarbon Field Development Planning» Rodrigues-Sanchez, J.E., Godoy-Alcantar, J.M., Ramirez-Antonio I.

The paper [9] describes the following method for Concept selection:

1. Since oil and gas exploration and exploitation require a large amount of economic resources mainly in offshore environments thus, field development planning has the main objective of maximizing the revenue for a given investment, this is maximizing the utility index (UI) defined as $UI = \frac{NPV}{NPI}$ where NPV is the net present value and NPI is the net present investment value. Scenarios with the greatest median (P_{50}) NPV and lowest spread between P10 and P90 NPV will be selected.
2. The authors suggest that concept screening based only on economics do not take in account other aspects that can provide benefits additional to the economical ones during the service life.

The case study considered in the paper is an offshore gas field. Tie-back to shore concept is compared with an intermediate fixed platform with separation and compression facilities to send gas to shore and a semisubmersible platform also with compression facilities to send gas to shore.
For this case study a group of experts selected attributes considering those that make a difference between the three development concepts. The weighted valuation method considering all these attributes, which is defined as the «multiattribute decision model», is used as a second step for assisting on screening and concept selection.
The list of attributes and sub-attributes was prepared by the group of experts on the workshop and includes:

- Operability
  - Easy to start or shut-down
  - Production management
  - Gas quality at the delivery point
  - Operative flexibility
- Fabrication and installation
  - Easy to fabricate
  - Easy to install
  - Availability of drilling equipment
- Time to first production and cost
  - Total cost
  - Utility cost
  - Time to first production
- Reliability
  - Prevention or remediation of flow assurance events
  - Inspection, maintenance and repair
  - Redundancy

Attributes have to be pair wise rated according to its importance in the exploitation system thus, experts make a matrix according to AHP (Analysis Hierarchy Method) and weight are given according to the attributes relevance based on the understanding of the decision makers by assigning a weight between 1 (equal importance) and 9 (absolutely more important) to the more important attributes and the reciprocal of this value is then assigned to the other attribute in the pair.

3. To complete the MDM analysis a semi quantitative risk assessment is performed in this paper to compare the value to the risk involved with each development option.
In a similar manner as for the MDM analysis, risk events are identified by a group of experts of the technical fields involved.
The following risk events were considered in order to identify the most safety development option:
   - Change of reservoir information, well type and future growth
   - Damage to pipelines/umbilicals due to mooring lines or anchor failure
   - Equipment failure during commissioning and starting up
   - Infrastructure/pipelines failure during installation
   - Delay of infrastructure to start up
   - Problems during well construction
   - Control system failures during operation
   - Flow assurance problems/plug formation
   - Slug catcher flooding
   - Hurricanes

The impact of each event on such issues as Health & Safety, Environment, Asset value, Project schedule were estimated by the group of experts as well.

To carry out a risk assessment for each event, the product of the weight of the probability of occurrence times the weight of the risk event impact severity times the weight of the attribute is found.

As a result a risk weight appraisal for each concept was carried out and the concept with the smallest risks was obtained.

«Structured offshore field development concept selection adds real value» Crager, B.

In this paper [10] the author describes the method of field concept selection to an example of an offshore project where infield drilling and knowledge of reservoir performance over time indicated that there are more reserves and recovery to be had.

A good example of the situation when the selection of the right concept gave additional income is described in the paper.

A decision analysis method was used in the case. The goal of the project was to identify what alternatives exist for developing this currently untapped potential and compare these to select the one or two best concepts on the base of following key drivers:

- Reservoir performance
- Capital cost
- Operating cost
- Economic recovery
- Life of field

First of all they identified several options for the field that already had an FPSO with wellhead platforms and subsea tiebacks:

- More platforms (both wellhead and full production)
- Semisubmersibles with FSO
- Expansion of the existing FPSO
- Replacement FPSO
- Jack-up production facility
- More subsea tiebacks

These major concepts were then compared using comparison criteria. These criteria, developed by the project team and approved by the operator, included:

- Minimize risk
- Continuity of revenue stream
- Minimize estimated capital cost
- Minimize estimated operational cost
- Minimize schedule
- Maximize flexibility for future expansion
- Maximize reuse of existing facilities

The grading of these criteria was carried out by a group of knowledgeable engineers from various disciplines.

After the twenty options were identified for a given set of production profiles, pros and cons were developed for each major alternative. The twenty options were then reduced to six. At this point, a more rigorous cost and schedule effort was developed for each one, so that they could be more closely compared using the DA model.

In this project, it was initially felt that expansion or replacement of the existing FPSO was the logical solution. However, the option of a semisubmersible production system with an adjacent FSO, in place of an FPSO, was retained for the concept selection phase. While two floating units were expected to have a higher operating cost versus one FPSO, the semi could also have workover capability. This could be quite cost effective if subsea wells that needed regular workover were placed below it.

So, this paper seems quite relevant to the topic of the Master Thesis and supports the idea of doing proper Concept selection by the help of experts from various disciplines. Also it gives some specific criteria that could be considered also in Arctic field development concept selection.

«Feasibility Studies for Offshore Field Development» Williams, L.M.

In the paper [11] the authors divided the feasibility study for development of offshore fields into several steps:

- Selection of a project team
- Selection of criteria
- Description and evaluation of alternative concepts
- Preliminary design of the selected conceptual costing
- Economic evaluation

Each step is fully described in the paper. The Criteria selection part discusses mainly the part when we need to develop several options for the field development. The authors gave the following criteria requirements for these concepts' development:

- Reservoir data
- Production characteristics
- Geologic interpretations
- Water depth
- Distance from Shore Base and/or Terminal
- Environmental conditions
- Soil criteria
- Functional and operational requirements
- Governing Codes of Practice
- Special or unusual Design Codes

Thus authors have focused on the Concept Development. The Concept selection phase was not considered so properly. The authors mentioned that after determining all alternative concepts they should be ranked on the basis of:

- Technical merit
- Cost
- Schedule

From this ranking of the alternatives, one specific concept is selected for more in-depth studies.

So, the paper could be useful for this Master Thesis for better understanding of factors for Concept screening and conceptual engineering stages. Concept selection criteria are described very general.

«Selecting the Field Development Concept for Ormen Lange» Gustavsson, F. et al.

The paper [12] describes the Concept selection process for the Ormen Lange field.

The authors demonstrate how RAM analysis (Reliability Availability Maintainability) can be used in the decision making process.

Four different concepts were considered in this project: Subsea to Land, Tension leg platform, SPAR, Semisubmersible platform. The system's availability performance was estimated for each concept using the Monte Carlo simulation software package Extend ™. But not each historical data were available for the task, and in the project different sources of data were used:

- General industry data banks (WellMaster, OREDA, WOAD, E&P Forum)
- Vendor data
- Data from JIP projects
- Expert judgments
- Synthesized data [12]

Production availability was calculated as an average over the year, taking into account low summer demand and high winter demand. The major differentiator between the concepts was the possessing facilities, the onshore terminal was compared with an offshore installation, and the onshore terminal showed a higher availability than processing offshore. The main differentiator was local power generation with gas turbine driven compressor compared with onshore electrical compressors and power supply from the national grid.

In such way all concepts were evaluated and the optimal one was selected.

3. Methodology

A comprehensive literature survey shows that there are different methods for how to perform the offshore concept selection process.

Table 1 Different methods to perform the concept selection according to the literature survey

Title of the paper	Described method	Advantages/disadvantages
«Arrangements and development of the oil and gas offshore fields» Vyakhirev, R.I., Nikitin, B.A., Mirzoev, D.A.	The book describes a method for how to perform the platform selection for Arctic offshore field development. The authors suggest at first to find out all possible development concepts using gravity based platforms for the Arctic offshore fields' development and then compare them according to their list of criteria. The list involves thirty seven criteria that were suggested by authors. Then they advise by the help of experts' judgment how to evaluate alternative options on the basis of this criteria list	The method the authors have suggested seems very precise because it allows accurate consideration of the concept selection case from different points of view by the help of knowledgeable and experienced people. The mainy limitation with this method is that authors do not consider other development concepts except the GBS concept. Thus criteria they use are mainly relevant only for the GBS concept.
«Concept selection for Hydrocarbon Field Development Planning» Rodrigues-Sanchez, J.E., Godoy-Alcantar, J.M., Ramirez-Antonio I.	The paper describes a very precise method for the offshore concept selection as well. It consists of three stages: • Economic calculations • Criteria based evaluations • Risk assessment After all stages' completion the optimal concept is identified which represent a balance between economic, technology and risks point of view.	The method the authors have suggested is very good as well. They give an idea how to perform a concept selection which takes into account different issues for the field development concept. However, the list of criteria the authors have suggested is very specific and relevant for a given case. Especially it does not take into account the Arctic area which is considered in this thesis.
«Structured offshore field development concept selection adds real value» Crager, B.	The paper describes the concept selection process for an offshore field in the West Africa. The author showed how a precise concept selection process adds value to the project. The concept phase was divided into two steps. The first one included identification of as many as possible feasible development concepts. They found twenty of them. And the second stage is, on the basis of the	The method the author has described in the paper is proven to be sufficient, which is shown by the additional money value. The idea to find out all possible concept and then, on the basis of some criteria, to define the optimal one is very close to this master thesis's idea. The only limitation is that the list of criteria which were used in the paper is very few and refers to a specific case. The Arctic area is not mentioned.

	chosen criteria, to select the optimal development concept. Criteria were chosen by the help of experts' judgment.	
«Selecting the Field Development Concept for Ormen Lange» Gustavsson, F. et al.	The authors suggested using RAM analysis for the concept selection process. Development concepts were compared according to their reliability, availability and maintainability. To estimate these parameters the Extend TM software were used.	The qualitative method, which is based on statistical data and simulation model, appears to be very precise. However, this method does not consider such issues as safety to the environment, flexibility of the production system, schedule, constructability and such other. Arctic is not considered in the paper as well.

Table 1 describes methods for how to carry out concept selection. Most of them suggest performing the concept phase of the offshore project in two big steps. First to find out all technically feasible development concepts according to engineering data and all design calculations and then to compare different development concepts on the basis of some important criteria. The list of these criteria varies from paper to paper which seems logic, because they should depend on the each specific case.

Arctic area as being a main concern for operator companies nowadays is almost not mentioned in the literature.

As it is seen from the Table 1, the usual method is to identify relevant criteria in a workshop or by expert questioning. Comparison of different development concepts also is suggested to perform by experts' judgment.

Thus this master thesis is prepared on the basis of similar methods.

1. Review of literature related to the concept selection process. This entails a review of open source materials on criteria influencing the concept selection process, including standard documents, offshore engineering books in Russian and in English and scientific papers from different databases. Relevant literature is found by using the key words: “concept selection criteria”, “concept development criteria”, “offshore concept selection” and “offshore concept development”.

2. Interviews with a number of responsible persons has been arranged to seek for possible concept selection criteria.

3. Experts' judgment method. This method is used for the criteria evaluation according to their importance in the concept selection process. First, a questionnaire for people from the industry was prepared. It includes eleven groups of questions for criteria weighting and several questions about the respondent's experience.

   This method has its own advantages as well as disadvantages. The level of uncertainty should be taken into account when experts' judgment method is used.

4. Offshore project development process

According to [8] investment projects are divided into two periods: project planning and project execution. Decision to start project execution is a result of the planning period, and start-up of the completed facility is the result of an execution period. The two main periods are divided into several phases, where each has a defined purpose and defined result.

To control the project process and to ensure a structured decision process, a number of decision gates (DGs) and approval points (AP) are defined.

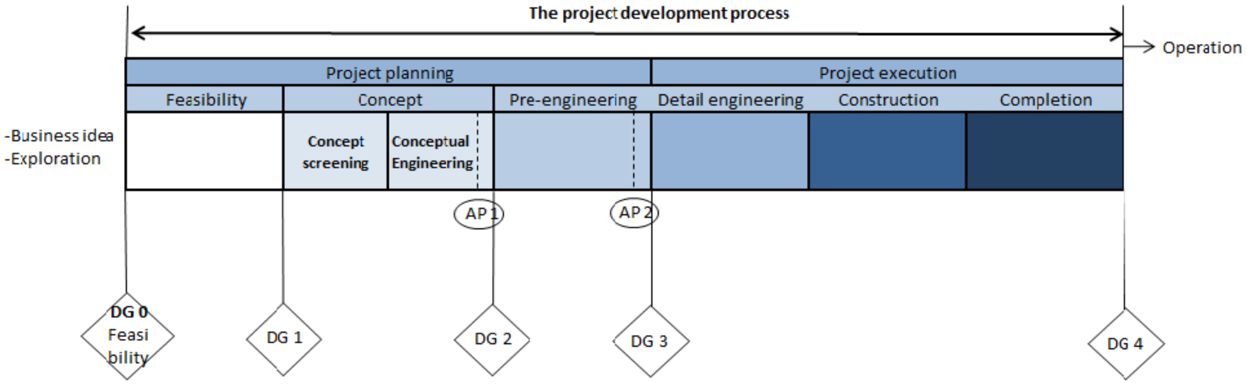


Figure 2 The project development model for investment projects with phases and decision gates [8]

The planning period

The planning period covers the *feasibility, concept and pre-engineering phases*.

Main objective of planning period is complex study of all possible development concepts, selection of optimal one and conceptual engineering for further detailed consideration of its technical feasibility, profitability, meeting the HSE requirements in given level of uncertainty. [8]

The feasibility phase

The main purpose of the *feasibility phase* is to establish and document whether a discovered hydrocarbon field is technically feasible to develop and has an economic potential in accordance with the corporate business plan to justify further development. The feasibility phase leads to a «Decision to start concept development»

The approval of the decision to start concept development (DG1) is an authorization by Company and the partners to continue developing the project through the concept phase towards decision to start provisional project sanction (DG2) in accordance with the approved project plans and budgets.

Decision gate 1 may be passed when the business concept has been developed to a level where it is likely that it is profitable, technically feasible and in accordance with the corporate business plan. [8]

The concept phase

The purpose of the *concept phase* is to identify all relevant and feasible technical and commercial concepts. Then to evaluate and define the optimal solution (preferably one) and confirm that profitability and feasibility of the business opportunity will be in accordance with the corporate requirements and business plans. The Field concept development phase consists of two sub phases: *concept screening* and *conceptual engineering*. The result of the concept phase is selection of the concept for further developing up to decision gate «Provisional project sanction». [8]

Concept selection - Approval point 1

The approval point «Concept selection» marks that one concept (or where necessary, a limited number of concepts) has been chosen for further detailing towards «Provisional project sanction».

Concept selection shall be the result of a screening process of all relevant and feasible alternative concepts for a further development.

The selection of the base concept shall be supported by documentation describing the concept screening process, focusing on:

1. Design basis
2. Concept alternatives and variants
3. Screening parameters and weighting
4. Description of and justification for both the selected concept and the rejected option
5. Technology qualification program.[8]

Provisional project sanction - Decision gate 2

Approval of the provisional project sanction is an authorization by company and the partners to continue developing the project through the pre-engineering phase towards decision to start project execution in accordance with the approved project plans and budgets.

The approval includes a decision to develop the necessary applications to the authorities.

The provisional project sanction documentation shall include an evaluation of the availability of qualified personnel resources and of the capacity in the relevant supplier industry. [8]

Pre-engineering phase

The objective of the pre-engineering phase is to further develop and document the business opportunity based on the selected concept to such a level that a final project sanction can be made, application to authorities can be sent and contracts can be entered into. The pre-engineering phase leads to approval point 2 «Application to the authorities», and to decision gate 3 (DG 3) «Project sanction». [8]

Application to the authorities - Approval point 2

The project shall compile and prepare for submittal of the necessary application for approval of the facility development in accordance with the relevant laws and regulations. [8]

Project sanction – decision gate 3

The DG 3 approval is an authorization by company and the partners to continue developing the project through the execution period in accordance with the approved project plans and budgets. [8]

Execution phase

The execution phase covers the *detail engineering*, *construction* and *completion phases*. The purpose of the execution phase is through a detailed design of the chosen concept and quality facility construction and installation come to the successful hydrocarbon production. [8]

Summary

The elaborate study of the Offshore Field Concept Development process shows that there are three stages relevant to this Master Thesis – Concept screening, Conceptual Engineering and Concept selection. All of them are parts of the concept phase of the project planning and the result of them is a defined field development concept for further design and construction of the field development system.

5. Arctic Challenges

The Arctic may be regarded as a single region, but it can be defined and delineated in many different ways. Figure 3 represents the wide variation in boundaries the Arctic can have as seen by different scholars and organizations. The various layers include environmental markers such as the tree line and 10° July Isotherm, as well as the definitions of the region as created by the Arctic Monitoring and Assessment Program (AMAP). This is an international organization established to implement the components of the Arctic Environmental Protection Strategy, which is under development. [29]

However, the main definition of the Arctic is the area inside the Polar Circle. Thus the Arctic Shelf includes the following sea basins: The Barents (including Pechora) Sea, Kara Sea, Laptev Sea, East-Siberian Sea, Chukchi Sea, Greenland Sea and the north part of the Norwegian Sea.

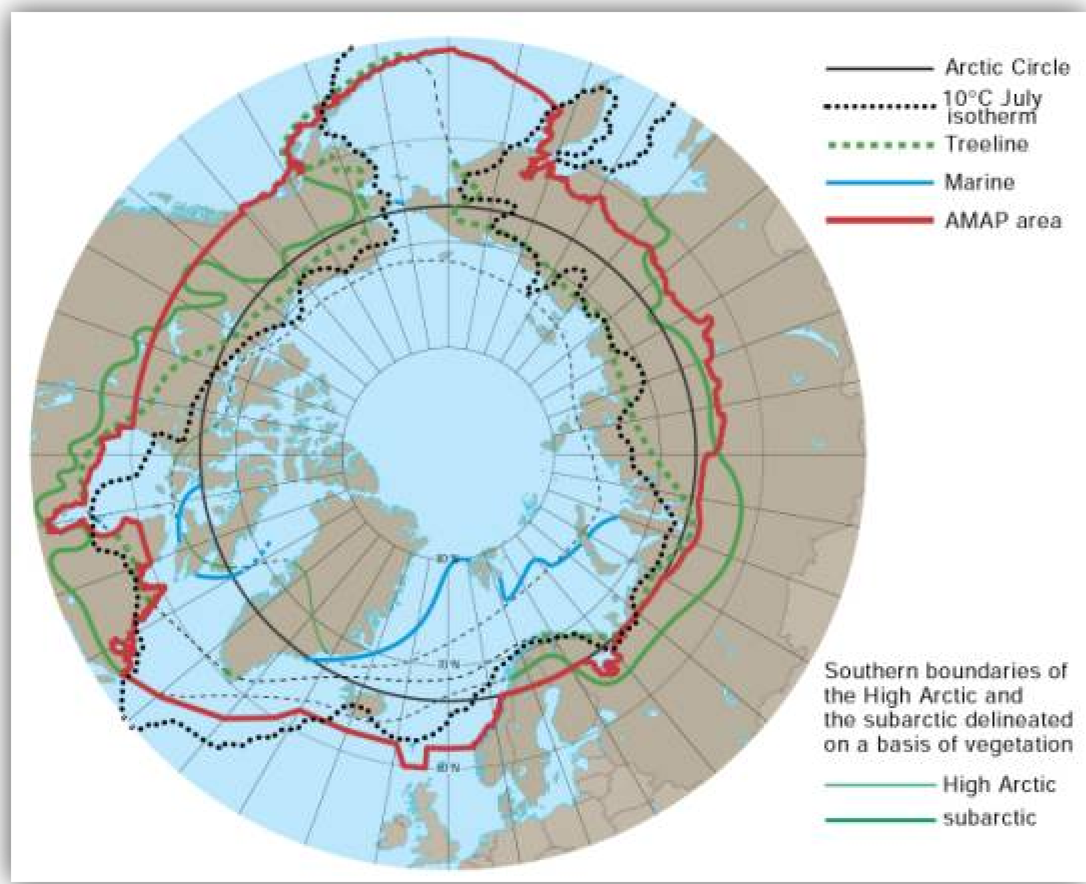


Figure 3 Arctic boundaries [30]

The most explored areas of the Arctic shelf are the southern area of the Barents Sea (both the Russian and Norwegian sectors), the Kara Sea and the Beaufort Sea (both the American and Canadian sectors). Thus these Arctic regions contain the majority of the discovered reserves of hydrocarbons. The Barents Sea contains more than 6 billion toe, the Kara Sea contains approximately 4.5 billion toe and the Beaufort Sea contains approximately 0.3 billion toe (see Figure 4[38]).

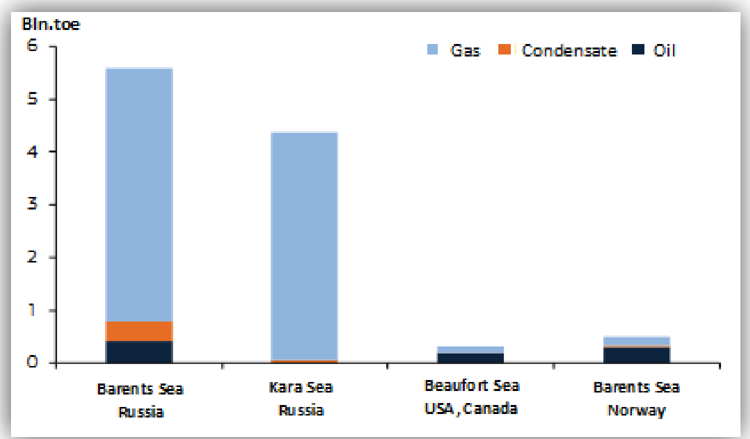


Figure 4 Hydrocarbon reserves in arctic shelf [38]

Up until now, exploratory drilling has not yet been performed in other Arctic seas. The potential resources of these areas have been estimated, however.

A U.S. Geological Survey offered an estimate of the potential oil and gas resources in the Arctic. Twenty five provinces were quantitatively assessed. Over 78 percent of the mean undiscovered hydrocarbon resources are estimated to exist in five provinces (see Table 2 [31]).

Table 2 Arctic resource appraisal [31]

Province Code	Province	Oil (MMBO)	Total Gas (BCFG)	NGL (MMBNGL)	BOE (MMBOE)
WSB	West Siberian Basin	3 659,88	651 498,56	20 328,69	132 571,66
AA	Arctic Alaska	29 960,94	221 397,60	5 904,97	72 765,52
EBB	East Siberian Basin	7 406,49	317 557,97	1 422,28	61 755,10
EGR	East Greenland Rift Basins	8 902,13	86 180,06	8 121,57	31 387,04
YK	Yenisey-Khatanga Basin	5 583,74	99 964,26	2 675,15	24 919,61

The undiscovered, though technically recoverable, conventional oil, natural gas and natural gas liquid resources north of the Arctic Circle are estimated to be the equivalent of 412 billion barrels of oil. Conventional oil is approximately 90 billion barrels, natural gas – 1.669 trillion cubic feet (47.3 bln m^3) and natural gas liquids – 44 billion barrels. 84 percent of these resources are expected to occur in the offshore area. According to the same geological agency these huge reserves make up 13 percent of the world's undiscovered conventional oil resources and 30 percent of its undiscovered conventional natural gas resources [31].

Arctic challenges

Along with huge hydrocarbon resources Arctic region brings a lot of difficulties for offshore activities. The principal Arctic challenges according to [34] are:

- Severe environmental conditions
- Difficult soil conditions
- Underdeveloped infrastructure

- High environmental risks
- Remoteness from the market

Each of these challenges shall be considered during the project execution.

5.1 Environmental conditions

To specific Arctic environmental conditions could be referred the following:

a. Ice and ice features
b. Icebergs
c. Ridges
d. Polar lows
e. Low temperatures
f. Darkness
g. Fog

Ice conditions

The main problem with offshore development in the Arctic is the difficult ice conditions which are specific to each Arctic sea basin. Most of the sea basins are characterized by a continuous layer of ice during the winter time (see Figure 5, [28]). In the central and eastern parts of the Barents Sea, drifting ice may occur. In the North Barents Sea the mean floe thickness was estimated at 0.9-1.2 m. North of the line connecting the Spitsbergen, Kvitoya, and Franz Josef Land, the average ice thickness exceeded 1.5-2 m. The Kara and Pechora Seas are covered by ice sheets every year and the ice stays for 3 or 4 or even up to 12 months depending on the location. Thermodynamical models of sea growth predict an ice thickness exceeding 3 m in this area. [33]

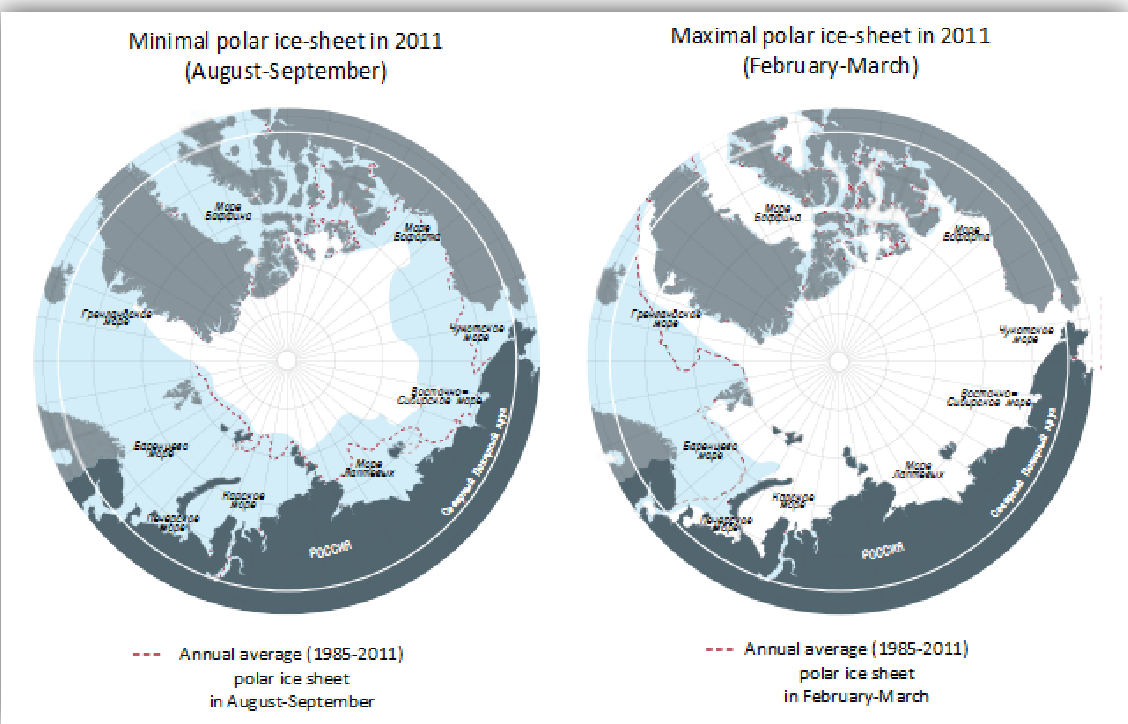


Figure 5 Arctic ice-sheet [28]

Icebergs

Another principal characteristic of Arctic is icebergs.

Icebergs are huge pieces of ice that have broken away from a glacier, they have an irregular shape that protrudes more than 5m above the water level, and they can either be afloat or grounded.

Ice mergers of arctic islands can produce icebergs with length up to 1-2 km and vertical sizes up to 60-100 m (however, large icebergs may break down on shallow water). Potential sources of icebergs are Archipelagos, Novaya Zemlya and Severnaya Zemlya.

The Icebergs propagation is shown on (Figure 6, [33]) for the periods from 1928 to 1991 and the frequency of their occurrence in some parts of the Barents and Kara Sea. The maximum concentration of icebergs is observed near the archipelagos and the islands. Further away from here, the concentration of icebergs decreases.

Most often icebergs occur at the Barents Sea but there is probability of icebergs existing in the Kara Sea as well (see Figure 6, [33]).

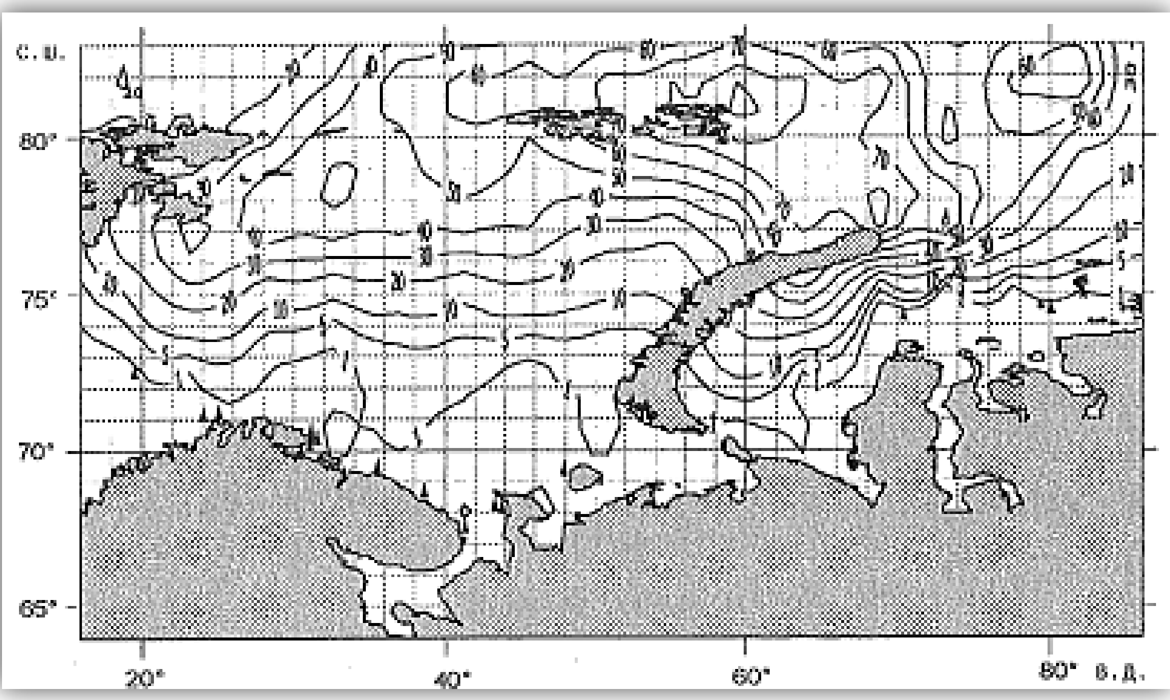


Figure 6 Lines of occurrence frequency of icebergs in the Kara and Barents Seas and location of icebergs recorded in 1% repeatability [33]

Ridges

Ridging of the ice is very common in the Arctic. It arises between ice sheets when compressive and shear forces in the contact area exceed some critical efforts resulting in the breaking of the ice and the broken ice gradually forms into ridges [32].

In 1980 an expedition vessel explored the north area of the Barents Sea. During this expedition ridges were investigated. The mean density of the ridges was recorded as low as 2.1 ridges sails per km was recorded with a mean sail height of 1.34m. Less than 1.2 percent of the ridges exceeded 3.0 m in sail height.

The ridge keel depth in the Pechora Sea is on the average up to 3-6m, but can sometimes reach 12m.

In the Kara Sea, the heights of the ridge sails in the fast ice zone are mainly in the range of 0.5 to 2.5m but can reach 3m. On average, the ridge sails are 1.2-1.8 m and the keel depth and width are up to 8-10 m and 20 m, respectively. Mostly the number of ridges per kilometer does not exceed 4.

Stamuchas

Stamuchas - hummocky ice formations sitting on the bottom of the sea are common in the shallower areas of the Arctic Seas in Russia, particularly in the Pechora and Kara Seas. They are located usually at a water depth of 5-15 m. They have a height of up to 3-7 m (rarely 10-15 m) and a length of 30-150 m. Very often the sail height is equal to the water depth.[35].

The main threat that ridges and stamuchas can bring is by causing damage to deepwater pipelines, cables or subsea production systems. Either located on the sea floor or buried in the seabed [34].

Low temperatures

Long cold winters and short cool summers are common for the Arctic region. However there are wide variations in climate across the whole Arctic area. Some parts of the Arctic are covered by ice all year round and some parts do not experience any form of ice on the sea surface.

The average January temperatures range from about -40 to 0 °C, and winter temperatures can drop below -50 °C, over large parts of the Arctic. Average July temperatures range from about -10 to +10 °C, with some land areas occasionally exceeding 30 °C in the summer. [40]

Low temperatures during offshore operations lead to marine icing problem. Winterization issues should be considered in Arctic project execution planning.

Long periods of darkness

The region inside the Arctic Circle experiences the other natural phenomenon that is called darkness or polar nights.

Polar nights represent the darkness which lasts for 24 hours.

Duration of the polar nights varies across the whole Arctic also.

For example, at the North Pole the sun never rises between September 24 and March 18. Approximately 6 months in total.

Additionally, in the Arctic Circle there are can be days when there is no Sun in the sky. However, from the beginning of December until the middle of January the Sun shines for less than 4 hours per day.

In the Mid Arctic between the Arctic Circle and the North Pole (approximately 78 degrees North latitude) the polar nights last from October 27 until February 15 (111 days). [41]

Thus the darkness issue could have a significant impact on the electricity demand for the manned offshore facility as well as on the fitness of the personnel [41]

Fog

Fog in the Arctic is caused by high air relative humidity. Arctic fog is a cloud over the sea which is formed when very cold air moves over warmer water. [73]

In winter, the frequency of fog is low because of the lower absolute humidity of water masses and a small number of condensation particles. In places where enough particles of condensation occur, frost fog can be observed.

In summer over the northern Arctic Sea, the air is very close to the point of saturation by water vapor, and a small decrease in temperature is enough for fog to form.

Visibility issues are the main problem for offshore activities in the Arctic that are caused by fog.

Polar lows

The next Arctic environmental issue is polar lows. Polar lows are mesoscale, typically 100-1000 km in diameter, maritime weather systems with a relatively short life time from 3 to 36 hours. [42]

Polar lows generally occur in the period from October to May and the monthly frequencies of polar lows in the Barents Sea are up to fifteen.

Polar lows are more prevalent in the Eurasian Arctic. However they can also occur in Greenland and the Canadian Arctic.

The main challenge that polar lows bring is the rapid change in wind. For example, gusts of 15 kts to 45 kts in 15 minutes with maximum wind speeds of 70 kts. Gale or storm force winds and seldom hurricanes are also possible.

The problem is that polar lows are difficult to predict and meteorologists cannot forecast them with reasonable accuracy for more than 9-12 hours. [43]

5.2 Geotechnical conditions

Permafrost, or perennially frozen ground, is defined as soil or rock having temperatures below 0 ℃ during at least two consecutive winters and the intervening summer.

Permafrost underlies most of the surfaces in the terrestrial Arctic. However under the Arctic Ocean which covers the North Pole, some of the sea floor is also frozen. Permanently frozen sea floor is called subsea permafrost.[38]

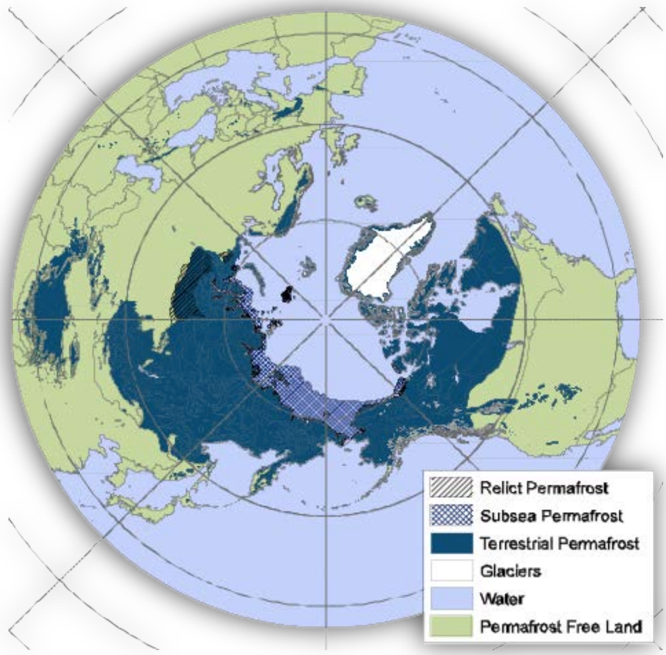


Figure 7 Permafrost distribution in Arctic area [13]

From the Figure 7 it is seen that Laptev Sea, Chukchi Sea and parts of the Kara Sea's bottom are covered with permafrost.

5.3 Underdeveloped infrastructure

Fig. 7 illustrates the population in the Arctic area. Each orange circle tells the relative strength of the local population, followed by its amount. For instance, in Alaska, there are "649 тыс. человек," meaning 649,000 people. From the map we can see that in the Kara Sea region there are approximately 153 thousand of people. Novaya Zemlya Island is populated by 3 thousand people. The area that belongs to the East Barents Sea consists of 842 thousand people. Close to the west Barents Sea there are approximately 462 thousand people. [74]

Thus the Arctic is a very sparsely populated area and therefore has extremely underdeveloped infrastructure. Underdeveloped infrastructure includes areas not covered by satellite and inaccurate maps of the area. Also there are a lack of a proper transport system, rail road system and electric power system.

Each of these problems needs to be solved before the execution of a project in the offshore Arctic. Consequently, enormous capital expenditures may be needed to be invested and this is one of the main challenges with Arctic offshore development.

Figure 8 Population in Arctic [39]

5.4 Environmental risks

The Arctic carries high environmental risks and dramatic consequences can occur in the case of hydrocarbon pollution.

Up to now there is no proven technology to remove spills from under the ice. Thus, the consequences will damage all aspects of the Arctic ecosystem.

Another factor that makes the consequences of a spill so dramatic is the sheer remoteness of the area from any suitable infrastructure. In the case of an emergency it takes a lot of time for the special emergency agencies just to reach the pollution center. In addition, some agencies simply cannot get to the area due to the remoteness and difficulty of the travel.

6. Arctic Offshore Field Development

6.1 Offshore Field Development Concepts

Once the hydrocarbon offshore field with a perspective value of resources is explored the next step is to decide on what is the best way to extract it. This decision requires studying of each possible development concept, performing engineering calculations to confirm their technical feasibility and then selecting the optimal concept on the basis of relevant criteria. This step is called Concept Phase of offshore project execution and begins from Concept Screening step (see 4. Offshore project development process).

The objective of the Concept Screening step is to identify all feasible offshore field development concepts for given conditions. Normally the offshore field development concept includes solutions regarding drilling system, production system, process system and transportation system of hydrocarbon field exploration. Therefore we can elaborate an offshore field development concept as a set of engineering solutions (see Figure 9).

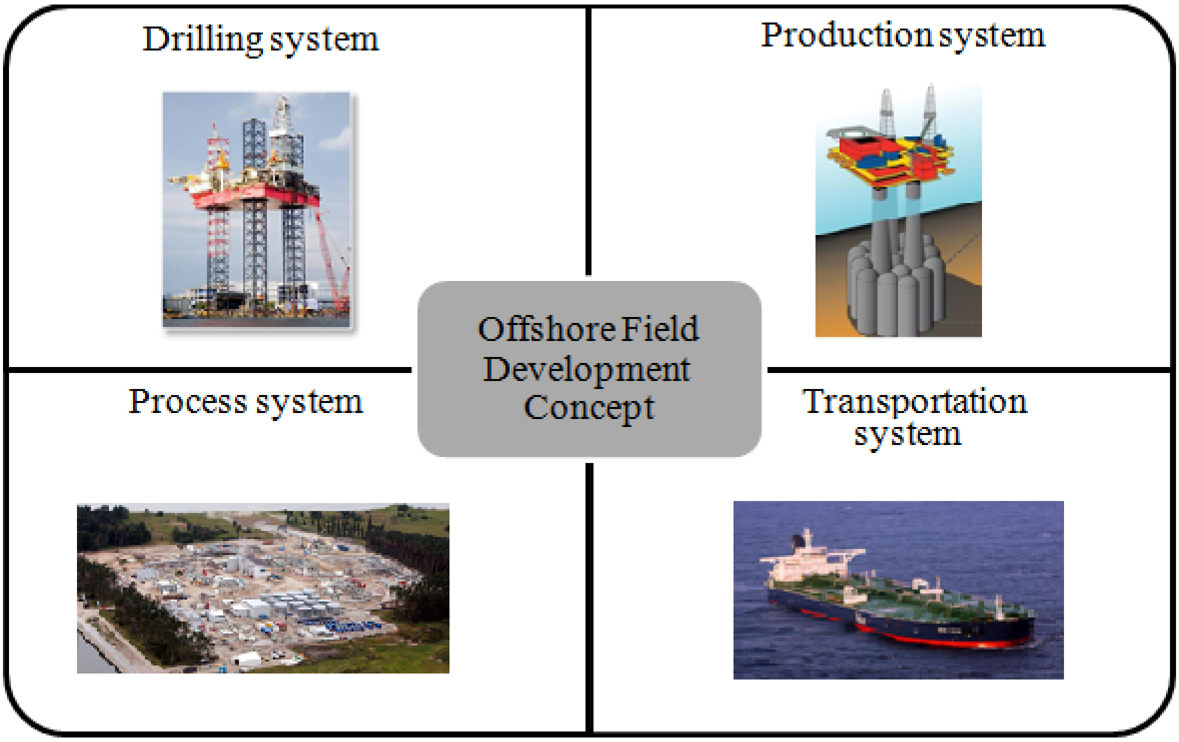


Figure 9 Block-scheme of offshore field development concept

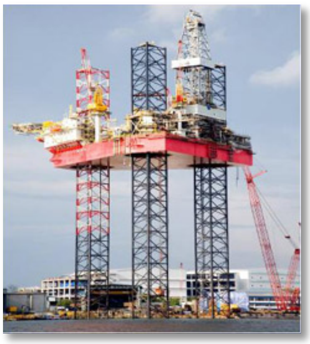
However an Arctic offshore field development has some specifics which distinguish it from development in other environmental conditions. Ice management, winterization and evacuation means in ice-covered waters are issues that should be considered for Arctic field development. While winterization and evacuation means should be considered in the design stage according to [52], ice management system as a support for production system could be considered during the concept phase.

6.2 Drilling system for Arctic conditions

The main problems for drilling in Arctic conditions would be a short ice-free period and ice loads on the drilling facility. Thus not every drilling facility is applicable for an Arctic Area. Let us compare them from this point of view.

Main traditional drilling solutions for offshore field development are described and their suitability for Arctic conditions is considered in Table 3

Table 3 Main offshore drilling systems and suitability for Arctic conditions

	**Drilling barges** Drilling barges are big floating structures grounded on the bottom that need to be tugged on the drilling point. They are ballasted to sink on the bottom before drilling. They are often used in shallow inner waters as bogs, lakes and other shallow waters. However they are inappropriate for the wave condition characteristics for the open waters in Arctic Area. [7]
	**Grounded submersible drilling platform** Grounded submersible drilling rigs are grounded on the bottom and suitable for the shallow waters. These drilling platforms consist of two blocks located one on another. Living quarters and drilling rig are located in the upper block. The lower block works as an outer casing of a submarine - when the platform moves from one place to another, the lower block is filled by air which makes the platform to float. When such drilling platform is installed on the location, the air is bleed and the platform is grounded on the bottom. The advantage of that platform is its mobility; however, its applicability is limited by shallow waters. [7] This solution is applicable for ice-covered waters but not for year-round operations, for several months more than other platforms for ice-free waters.
	**Jack-up drilling rig** A Jack-up drilling rig is a mobile drilling unit which can reach the drilling point independently or by the help of tugs. The jack-up drilling rig is equipped with long legs, which seek the bottom, lifting the drilling rig above the water. This type of drilling rig is suitable for operations in water depths up to150 m. [7] Jack-up drilling units are very popular solution for offshore drilling; however they are not appropriate permanent solutions for Arctic conditions because they can operate only in ice-free waters for about 45-90 days during the summer season.
	**Semisubmersible drilling rig** The semisubmersible drilling rig is the most popular type of marine drilling structure combining the advantages of submersible structures with ability to drill in deep waters. The operating principles are the same like for grounded submersible drilling rigs. The exception is that semisubmersible platforms are moored either by heavy anchors more than 10 tones in weight or kept in position by dynamic positioning system. Semisubmersible drilling rigs are applied for drilling in water depths from 600m to 2500m and more, depending on age, type and technical characteristics of the platform. They float away from the drilling point with the help of tugs or independently by thrusters. These

	platforms can withstand some ice loads and consequently extend drilling season in Arctic area. [7]
	**Drilling ships** Drilling ships are self-moving rigs, usually with high net load capacity. They can transport a lot of expendables and equipment for the drilling in remote locations. Drilling ships are also widely used for deep water drilling. These ships do not require towing on the drilling point and they are very popular for ice-free waters. However in Arctic Area they could be considered only for summer period. [7]
	**Drilling rig on the production platform** Drilling rig could be installed on the production platforms and used for drilling and workover operations. The total amount of wells that could be drilled from one platform varies depending on well and reservoir conditions, but is usually limited to 40-50 wells. Usually the drilling rig is installed stationary but it could be removed and replaced by a workover system when all the planned wells are drilled and completed. [7] For drilling in Pechora Sea (Arctic area) Gazprom constructed the Prirazlomnaya platform with drilling rig installed on the platform. It is announced that the platform is capable to perform year-round drilling in ice-covered waters of Pechora Sea. [47]
	**Artificial island** Artificial islands for offshore well drilling are used in water depths up to 20 m. They allow for year round drilling. Artificial islands are widely used in ice-covered shallow waters of the Beaufort Sea. Big experience gathered for many years of using them in Alaska region ensure safety and reliable solution for operation in Arctic waters.[1]
	**Grounded ice island** An ice sheet that is used as a base for drilling consists of natural and artificial ice with thickness up to 3 m. The drilling rig is installed on this base with a set of drilling and well control equipment, which in case of an accident (significant lateral moving or ice loosening) allows the operator to perform a quick disconnection of the conductor. Grounded ice islands provide relatively inexpensive and environmentally friendly technology. [8] It is possible to perform year-round drilling from ice islands.

Therefore analysis of drilling systems shows that in the Arctic area during the *ice-free period* it is possible to use the following solutions:

- Grounded submersible drilling platforms
- Grounded caisson drilling platforms

- Jack-up drilling rigs
- Semisubmersible drilling rigs
- Drilling ships
- Drilling rigs on production platforms
- Artificial islands

However for *ice-covered* waters only few solutions are relevant:

- Drilling rigs on gravity based production platforms
- Artificial islands
- Grounded ice islands
- Submersible gravity based drilling platforms (but not year-round, several months more than other platforms for ice-free waters

Therefore it is common practice for Arctic fields' development to plan drilling only during ice-free period from traditional drilling systems, such as jack-ups, semi submersibles and drilling ships.

6.3 Production System for Arctic conditions

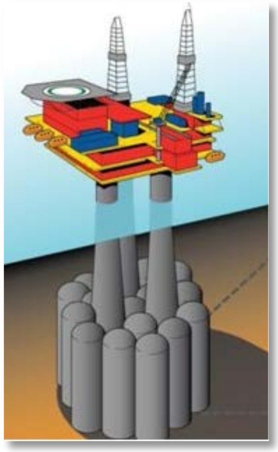
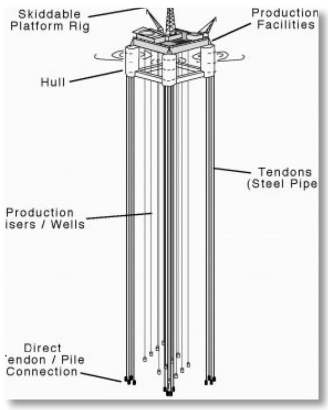
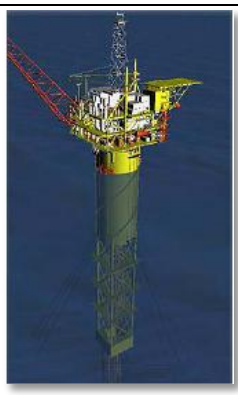
The production system or production facility is the main part of an offshore field development concept since it accommodates not only production equipment but often drilling and process systems also.

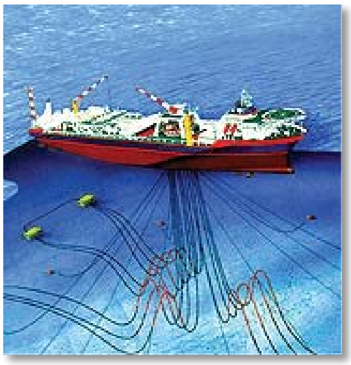
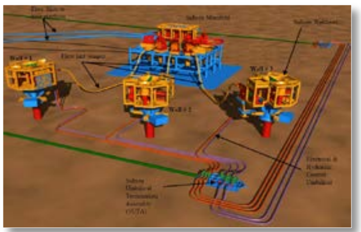
In the Arctic Area the production system is the guarantee for safe and successful operations and therefore it is even more important in the Arctic to choose the "right" production system.

In Table 4 the main production facilities that used for offshore fields are described with comments regarding their usage in Arctic areas.

Table 4 Main offshore production systems

	**Steel stationary platform (Jacket)** Typical fixed steel platforms consist of large legs and tubular steel cross bracing that form a «jacket». The jacket is supported by piles driven into the seafloor to transmit wave, wind, current or ice forces into the ground. They typically support a deck that contains a drilling rig, living quarters and production facilities. Jackets are usually used in shallow to medium water depths and are intended for long-term use. Steel jacket platforms can operate in up to 450m of water depth and withstand hurricanes and winter storms. They are typically not the best solution for severe arctic areas with large ice-ridges and multi-year ice. [7] However jacket oil platforms with legs equipped by cones are successfully used in shallow waters of Bohai Bay with first year ice conditions. [46] Traditional jackets could be used in year round ice-free waters of Arctic like in the West Barents Sea for example.

	**Jack-up platform** Self-elevating platforms (jack-up) can be used for hydrocarbon production as well as for drilling. Especially they are well suitable for shallow waters but have limitations in water depths. Main advantages of the jack-up platform are simple marine operations, possibility of onshore equipment assembly and possibility to install subsurface storage tanks. The mobility of the jack-up platform is also one of its characteristics. [7] However these structures cannot operate in multiyear ice waters in Arctic Area. There is possibility that reinforced structures can withstand light first year ice.
	**Gravity based structures (GBS)** These platforms take advantage of their large size and heavy mass to support large facilities. They can also be designed to resist severe arctic conditions, such as multi-year ice and icebergs. A GBS can be made of steel or concrete, and provide support for heavy drilling rigs and production equipment. This type of structure can have a storage tanks for oil or liquid gas. [7] These structures are known as the most suitable solution for ice-covered Arctic waters. But the depth of water in such conditions for gravity based structures is typically limited by 80m; in case of weak soils it is even limited by 60m. [48]
	**Tension leg platforms** These floating platforms can support a drilling rig and production facilities. The TLPs are similar to fixed platforms except they use a floating hull tethered to seafloor by a mooring system made of tension legs. These steel “tendors” limit vertical movements from wind and sea forces and keep the TLP in position. Many TLPs are built with a four-column design that supports the deck section. Below the water, a ring of pontoons connects the columns, much like a semisubmersible drilling vessel. TLPs can be used in up to 1800m of water. [7] According to [48] floating structures are not suitable solution for multiyear ice waters in the Arctic but for year round ice-free waters in Arctic they are considered to be technically feasible.
	**Platform with vertical cylindrical caisson (SPAR)** Much like the TLP, SPARs are moored to the seafloor, but with a more conventional lateral mooring anchoring system instead of tension legs. They are supported by a floating, hollow cylinder containing extra weight in the bottom, similar to a huge buoy. About 90 percent of the structure is underwater, so it has great stability in very deep waters – as much as 3000m. [7] As other floating structures this solution is not considered as technically feasible for ice-covered waters in Arctic. [48]

	**Semisubmersible platform** A semisubmersible production platform consists of a deck supported by four columns connected by four pontoons. Similar to TLPs, semisubmersibles can support living quarters and production equipment. Unlike TLPs, their floating hull uses a conventional lateral mooring system of steel cables or dynamic positioning system to keep the platform in position and is connected to subsea wells via flow lines. The subsea wells are drilled by mobile offshore drilling units since typically there is not a drill rig on a semisubmersible production platform. These platforms are widely used in water depths up to 2500m. [7] A floating semisubmersible platform is also not considered as a suitable solution for multiyear ice waters but could be a good decision for Arctic ice-free waters in the West Barents Sea or Bering Sea. [48]
	**Floating production vessels (FPSO, FPSDO, FSU)** Floating production storage and offloading units (FPSOs) can operate in water depths up to 3000m and are best suited for milder climates or where there are limited pipeline systems to transport oil to shore. These ship-like vessels can process all of the oil or gas produced from a reservoir, separating the oil and gas and storing the oil until it can be offloaded to tankers for transportation. The storage capacity of the FPSO allows oil to be stored and then periodically offloaded to a tanker so that the tanker does not need to be on standby for long periods while waiting to receive production. Subsea wells lift production to the FPSO through risers. Most vessels use mooring systems connected to a “turret”. The turret is mounted to the hull and allows the vessel to rotate freely. [7] Floating vessels as other floating structures are not suitable for multiyear ice waters but could be a good solution for ice-free Arctic waters with icebergs existing. The example of such FPSO application is Shtokman field in the Barents Sea where probability of icebergs existing is very high. In such case the disconnection capability of an FPSO is used to prevent collision with iceberg.
	**Subsea production systems** Subsea production systems are composed of wells, manifolds and flowlines lying directly on the seafloor. Wells for semisubmersible platforms and FPSOs are subsea wells drilled from the Mobile Offshore Drilling Unit. Additionally subsea wells can be connected to other systems, like SPARS, FPSOs or platforms to extend a reach to nearby reservoirs. Oil and gas from subsea wells flow in flowlines to processing platforms or to shore that may be in distance up to 160 km. The recent years’ tend is to extract the oil and gas by subsea equipment only. This technology is successfully applied on the Ormen Lange and Snohvit fields. [7] But there are some potential problems for subsea equipment that are specific for the Arctic. There is a possibility of ice keel scouring and it is necessary to heat subsea pipelines in shallow Arctic waters. [48]

	**Artificial Island** Man-made gravel islands may be used year-round in water depths of up to 20m and can support large drilling rigs and production equipment. Large amounts of gravel are placed on the seafloor to create the island. When production is completed the islands may be left to erode naturally or dredged to a depth that allows for vessel navigation. Gravel islands typically may be strengthened with concrete, rock or steel sheet piles to resist the impact of ice. [7] Artificial islands have been successfully used for oil production in ice-covered waters of Beaufort Sea for decades. The gathered experience has shown this production system as being suitable for Arctic shallow waters.[48]

Analysis of the existing types of production systems showed that there are only few technically feasible solutions for ice-covered waters in Arctic area:

- Gravity Based Structures
- Artificial island
- Subsea production system (with a lot of challenges)

For ice-free waters all of the solutions in Table 4 are suitable taking into account water depths limitations.

6.4 Process system for Arctic conditions

In most of the cases well flow from a reservoir is not a saleable product. Usually it is a mixture of oil, gas, water and several unwanted components. Thus offshore field development concept shall include a process system for extracted fluid.

Type and degree of product preparation depend on the composition and the properties of reservoir fluid and technical specifications of the sellable product.

There are also requirements for fluid injection into the reservoir, for transport and storage of product, for environment protection and for performance characteristics that should be met in the process system.

Traditional scheme of well product treatment includes: heating, separation, stabilization of oil and condensate, water cleaning, cooling and compression, acid gas treatment and drying.

Product preparation equipment is installed on the above water surface facility in the most cases.

However infrequently when the well product does not consist of too many impurities and it is possible to avoid any product preparation before transport by pipeline. Ormen Lange and Snohvit fields are great examples of full well stream flow transportation to shore.

In case of tanker transportation it is not possible to avoid oil stabilization and other processes. Thus a process system is required. [7]

Therefore it could be possible to differentiate offshore fields' process systems according to type of the well product.

For oil or condensate preparation we have two options. The process system could be deployed on the shore. In that case at first we have to transport our product to shore by full well stream flow pipelines because it is not possible to perform tanker transportation without any stabilization and treatment of product. Another option for oil or condensate product preparation is process system on the production facility. This scheme is most often recommended because it allows using tanker transportation from the platform which is known as more reliable solution in comparison with full well stream flow pipeline, especially in cold arctic waters (see Table 5).

For gas preparation we have similar options, either we have process system on the shore or on the production facility. In addition to usual gas separation and further transportation we have gas liquefaction. A Gas liquefaction plant we can install either on the production facility (this will result in a very large facility) or on the shore. The advantage of liquefied gas is possibility to transport it by tankers after liquefaction (see Table 6).

Table 5 Process solution for oil exploration

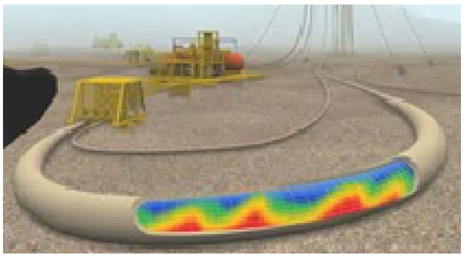
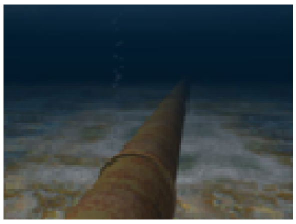
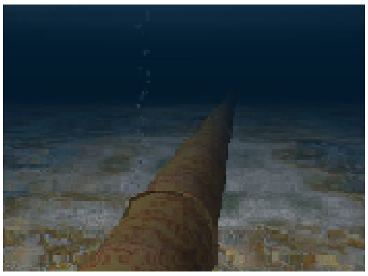
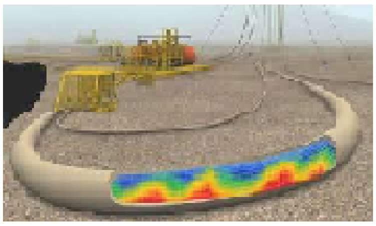
<table>
<tr><th colspan="3">Oil product</th></tr>
<tr><td>Process system on the shore
</td><td colspan="2">Process equipment on the surface facility
</td></tr>
<tr><td>Multiphase flow pipeline
</td><td>Tanker transportation
</td><td>Pipeline transportation
</td></tr>
</table>

Table 6 Process solutions for gas exploration

Gas product		
LNG plant on the surface facility	Process system on the surface facility	Process system or LNG plant on the shore
		
Tanker transportation	Pipeline transportation	Multiphase flow pipeline
		

6.5 Transport of hydrocarbon products in Arctic conditions

For the purpose of getting profit from hydrocarbon production it is necessary to deliver the hydrocarbon product from field to the consumer. As it was mentioned above there are two options for hydrocarbon transportation. Either we can transport them by tankers or by pipelines. Each method can be used for both oil and gas, depending on the product preparation process (see Table 5, Table 6).

However the product transportation process should be considered more carefully in a Concept Development study for Arctic offshore. There are some issues related to cold environment conditions.

Pipeline transport

More than 50% of all oil in the world is transported by tankers from field to refinery. However pipelines account for 90% of the total gas transport in the world. Gas and oil pipelines require high initial capital expenditures, but comparatively low operating expenditures. Their operating life is quite long – more than 50 years for well designed and constructed pipelines. However, pipelines are not flexible solutions, ones you install them you cannot change a route anymore. Pipeline capacity depends on its diameter and the power of compressor stations. In case of short distances and big product values pipeline transport is preferable solution in comparison with tanker transportation.

Figure 11 Icebreaking tanker offloading oil from the Varandey oil terminal [70]

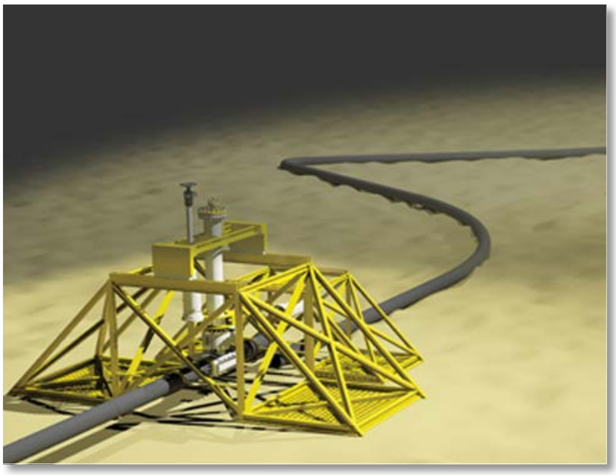


Figure 10 Pipeline transport [70]

However Arctic waters bring a lot of challenges for pipeline transportation.

First of all flow assurance issues should be considered very careful for cold waters. High risks of plug formations require preventing measures as for example chemical injection. Chemical injection requires additional pipeline installation as it was done on Ormen Lange and Snohvit fields.

Pipeline gouging by ridges and icebergs is another very serious issue that is relevant for Arctic region. Such gauging occurs especially in regards to shallow waters in the range from 20 – 40m where gouging is most severe [48].

Pipeline laying in Arctic waters could also be a challenge in ice-covered waters.

Tanker transport and offloading

Tanker transportation is a very flexible solution in comparison with pipeline transport: while pipeline connects the field with one or several potential consumers, a tanker can deliver oil to more than 500 existing refineries. Most of the oil tankers are constructed for the specific fields or point-of-sale, but they can freight and redeploy all around the world. The exceptions from that could be tankers with special equipment for marine loading.

As distinct from oil tankers, LNG transport vessels are usually designed for specialized trade, i.e. for round trips between two permanent harbors.

Gas transport by tankers requires liquefaction of gas by cooling it till -163°C. Liquid gas has 600 times less volume than usual gas that makes this type of transportation very viable. However the liquefaction process is quite costly since it requires special vessels and terminals on each end of the transport line. This is the reason why tanker transportation of natural gas is several times more expensive than for oil.

Tanker transportation is more profitable for long distances where the pipeline laying would be very expensive, that is why pipelines longer than 2000 km exist only in the areas without access to sea.

In ice-covered Arctic waters oil or liquid gas should be transported by special icebreaking tankers (see Figure 11, [70]).

Besides in case of tanker transportation the oil offloading issue should also be discussed in the Concept Development phase. For Arctic ice-covered waters there are two suitable solutions: offloading from a separate terminal as for example the Varandey oil terminal of Lukoil (Figure 11, [70]) or the offloading could be performed directly from the platform as it is planned on the Prirazlomnaya platform. [51]

6.6 Ice management

Ice management is a very important part of the Development Concept for ice-covered waters.

Ice management is a set of actions dedicated to decrease the global and local ice loads. Ice management is usually used for floating structures and can significantly influence on concept development. Besides, ice management can be used to control the interaction of the structure with different ice formations (icebergs, ridges, stamuchas etc.). In some cases ice management can be applied to decrease ice loads on stationary platforms as well. It could be used during offloading and evacuation operations. Ice management system includes detection, tracking and forecasting of the ice situation and physical ice management includes splitting-up of ice and ridges, towing of icebergs, icebreaking in front of a structure. Decisions to continue marine operations, to shut-down production, to disconnect and replace facility are made on the basis of the results of ice management actions.[52]

Floating structures and mooring systems should withstand all design loads from ice, ridges and interaction with icebergs without ice management. However ice management is required for decreasing the loads, accident situation prevention and for iceberg towing.

To provide sufficient ice management it is necessary to choose icebreakers with possibility to split ice sheet and ridges and to tow icebergs. Icebreakers' important parameters are velocity in given ice conditions and provision of towing capacity for icebergs towing. [52]

Summary

The main aspects of field development concepts for Arctic offshore, such as drilling system, production system, process system, transportation of hydrocarbons and ice management system are considered above. Challenges related to Arctic are highlighted and possible solutions for ice-covered waters identified.

Selecting one of the possible options of each main process and adding these give us a feasible concept for Arctic offshore field development concept.

For example if we have an Arctic offshore gas field we can select an ice resistant platform with drilling rig, decide that process equipment will be also on the platform and transportation will be implemented by pipeline to shore and then from shore to market by another pipeline. This preliminary version of a field development would be called as field development concept.

But of course such random choice is applicable only as an example for better understanding. In reality a lot of factors affect concept development. Some of them are more important, some – less, but each of them should be considered and taken into account.

Below main factors driving concept development process are reviewed and analyzed.

7. Concept Screening and Conceptual Engineering

As it was discussed in Chapter 4, the Concept phase of a project development consists of three main steps: concept screening, conceptual engineering and concept selection. This chapter is dedicated to first two of them.

The purpose of the concept screening and conceptual engineering stages is to provide a firm definition of the design basis and to identify all relevant and feasible technical and commercial concepts for offshore field development.

On the basis of the wide literature review (see chapter 2. Literature survey) key driving factors influencing the concept screening and then the conceptual engineering for Arctic offshore field development were defined as following:

1. Water depth
2. Geological and reservoir data (type of product, reservoir depth, number of resources, reservoir thickness, pressure, temperature, requirements for water and gas injection)
3. Ice conditions
4. Icebergs
5. Wave, current and wind conditions
6. Seismic conditions
7. Geotechnical data
8. Distance to shore
9. Period of maximal storm which does not allow offloading
10. Limitations for structure draught

7.1 Water depth

Bathymetrically the Arctic marine area is relatively shallow with broad continental shelves. Depths over the shelves average between 100 and 200 meters but are variable (see Figure 12, [72]), especially if continental landmasses and islands are approached.

Average depth of water at the drilling site and maximal theoretically possible water depth determine the size and the clearance of the production facility.

Besides most of the production facilities have their own limitations regarding the water depth, thus water depth determines also type of facility (see Table 4).

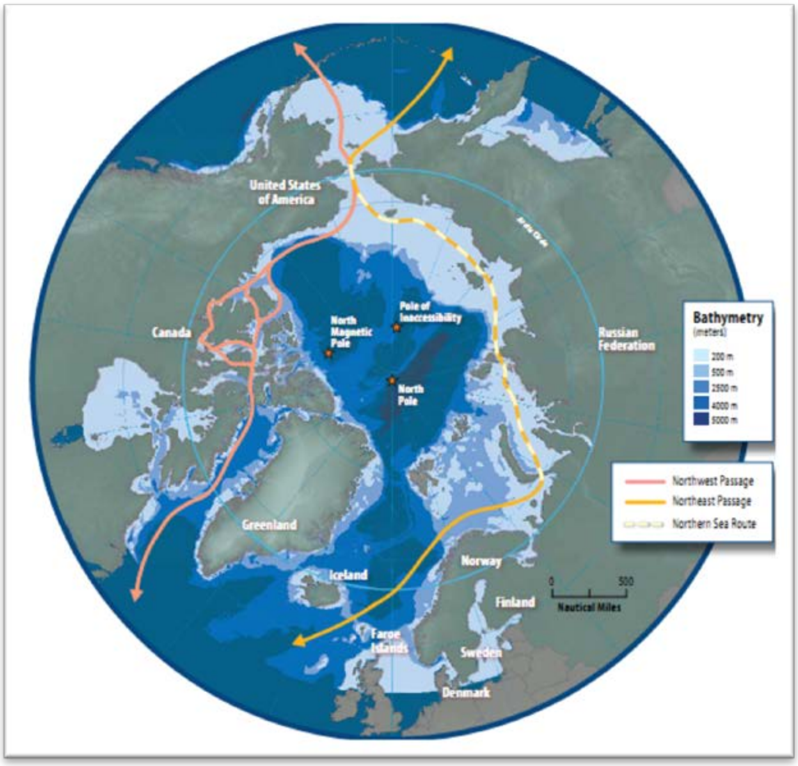


Figure 12 Arctic Marine bathymetry [72]

7.2 Geological and reservoir data

Reservoir data includes:

- Type of well product (oil, gas or condensate)
- Recoverable resources
- Reservoir and fluid parameters: pressure, temperature, permeability etc.
- Reservoir depth etc.

Type of well product has a major influence on well arrangement, surface equipment, process system (see Table 5, Table 6) and product transportation system.

Size of recoverable reserves determines number of necessary production wells and period of field exploitation besides it influences on storage capacity of the production facility. The area of the reservoir determines location and spreading of wells. Thus area of reservoir influences on number of platforms or subsea templates.

Reservoir and fluid parameters determine type of wells (horizontal or vertical), production profile, minimal well head pressure, period of production without needs for compressors etc.

Reservoir depth determines length of wells and consequently weight of derrick and size of structure.

There are other geological and reservoir data that more or less influence on the choice of production facility and development concept in general. Hence availability and accuracy of reservoir data have a major impact on the offshore field development concept and that is why exploration drilling for reservoir testing and fluid sampling is necessary to perform before developing a concept study.

7.3 Ice conditions

Ice occurs during winter time in most of the Arctic sea basin; in some areas thickness of ice reaches 1.2 m (see Figure 5).

The main impact of ice conditions on the development of feasible concept is the type of production facility: either it could be an ice-resistant structure or an ordinary structure. Types of facility that could be used in ice conditions are identified in Table 4.

Ice provides one of the main loads that act on the production facility and determines the structure's rigidity characteristics.

Besides, ice conditions influence on drilling period, transportation issue, installation and many other aspects, especially in case of severe ice conditions.

Thus it is necessary to know such data as maximal ice and ridges thicknesses during winter time, ice strength and ice-free periods in the field area.

7.4 Iceberg

In case of a collision with a structure icebergs provide extremely high loads that could easily collapse the structure. Thus in case of probability of icebergs like in the East Barents Sea or the West Kara Sea (see Figure 6) collision with icebergs should be considered during the Concept Engineering stage.

There are several mitigation means for iceberg collision. Either production facility is rigid enough to withstand such loads (e.g. Hibernia platform) or production facility can avoid collision by its disconnection capability (e.g. Shtokman FPSO) or there is another option when ice management is sufficient enough to prevent collision.

Hence possibility of icebergs and size of maximal possible iceberg is very important factors that should be known before field development concept identification.

7.5 Wave, current and wind conditions

Wave, current and wind provide large loads on a production facility; therefore they should be considered and accurately calculated during the Concept Screening stage. Especially this refers to ice-free waters when the ice loads do not provide the largest loads on a structure.

Thus such parameters as 100-year wave, 100-year current and 100-year wind should be known before field development concept identification.

7.6 Seismic conditions

Seismic conditions can have a major impact on the field concept development in case of high seismic activity. Sakhalin's offshore fields are good examples of such situation. Gravity based structures were chosen as the only ones that are suitable for the areas' seismic conditions.

Seismic activity at the site should be estimated in the Concept Engineering phase and seismic loads subjected on production facility should be calculated according to standards as for example SNIP II-7-81 "Construction in Seismic Areas" [60].

7.7 Geotechnical data

Geotechnical data that should be considered in the Concept Engineering stage includes:

- Geological structure
- Tectonic processes
- Mechanical-and-physical properties of soil

These geotechnical parameters mostly influence on type and size of production facilities foundation.

However the main geotechnical concern in the Arctic area as was discussed in Chapter 3 is permafrost.

Permafrost presents obvious problems for construction since permafrost thawing leads to consolidation settlement. In addition the strength of the soil is decreased because of the released water and methane gas from the thawed permafrost [7]. Thus the ability of the soil to support the production platform and its possible sinking should be considered during the Conceptual Engineering stage.

However, the permafrost issue mostly affects subsea equipment as subsea pipelines and production units because permafrost thawing can lead to quick equipment corrosion and sinking.

7.8 Distance to shore

Distance to shore has a biggest effect on transportation and consequently on the process systems.

Pipelines have limitation in length because of the need for compression. Either compressor stations should be installed under the sea which is not proven technology yet or the pipeline length is limited. Especially this refers to gas transportation because for oil transportation by tankers there are no such a strict limitations on distance.

7.9 Period of maximal storm which does not allow offloading

The Arctic area is characterized by difficult unpredictable weather conditions (see Chapter 5.1 Environmental conditions). Thus it is important to consider the maximal possible storm which does not allow oil offloading operations. Platform storage capacity should be calculated on the basis of this parameter.

7.10 Limitations for structure draught

Requirements for facility transportation (maximal water draught) that are dictated by shallow canals along the structure’s transportation route could also be a driving factor for Concept Development or the size of production facility. [6]

Therefore it is important to check, during the Concept Engineering stage, the approximate facility transportation route from the fabrication plant to the drilling site to be aware of too narrow or too shallow waters where the structure can get grounded during transportation.

8. Concept selection Process and Criteria influencing it

The Concept selection is an approval point of the Concept phase of the offshore project development (see Chapter 4. Offshore project development process). The result of the Concept selection process is an optimal offshore field development concept which comply to all technical, economical and HSE requirements.

The Concept selection is carried out after the Concept Screening and the Concept Engineering stages by the comparison of all feasible development concepts according to some important criteria for the operator company.

While it is quite clear what are the technical factors influencing the Concept Screening and the Concept Engineering stages (see Chapter 7), criteria for the Concept selection process are not fully identified (see Chapter 2).

The objective of this Chapter is to identify and elaborate all possible criteria that could influence the Concept selection for the Arctic offshore fields.

On the basis of wide literature survey that was described in the Chapter 4 the list of these criteria was prepared and then the criteria were grouped into the several categories.

I. Cost&Schedule Criteria

1) NPV or project's profitability
2) CAPEX
3) OPEX
4) Continuity of revenue stream
5) Schedule for the project execution

II. Safety Criteria

6) Risk of environmental contamination
7) Availability of the HSE barriers
8) Technical safety
9) Possibility to drill relief wells in case of blow-out
10) Risk of collision with vessels and structure rigidity characteristics
11) Stability characteristics
12) Proven technology
13) Sensitivity of facility to critical conditions (to environmental loads)
14) Ability to leave the site in case of accidence (disconnection capability)

III. Drilling characteristics

15) Risk of problems during well construction

16) Availability of existing drilling facility

17) Ability to install several derricks on the structure

18) Schedule for drilling (drilling season)

19) Workover capability

20) Heave motion characteristics

IV. Operability Criteria

21) Easy to start or shut-down

22) Power demand

23) Capability of well control

24) Level of autonomy

25) Level of production system automation

26) Oil or gas quality at the delivery point

V. Working environment criteria

27) Working environment for personnel

VI. Reliability and availability criteria

28) Reliability of equipment

29) Prevention of flow assurance problems

30) Complexity of maintenance

31) Number of back-up systems and redundancy

32) Reliable contractors

VII. Transportation, Assembly&Installation Criteria

33) Complexity of technical equipment layout (single staged or multi staged)

34) Requirements to perform marine operations and possibility to perform them in short period

35) Complexity of facility installation

36) Complexity of facility decommissioning

37) Safety of equipment during transportation, assembly & installation

VIII. Fabrication Characteristics

38) Possibility to construct on local construction facilities

39) Requirements to construction materials, tolerances of unions of component parts

40) The necessity to extend the construction plant infrastructure or plant reconstruction

41) The necessity to construct special floating structures for construction assembly

IX. Flexibility criteria

42) Flexibility of the concept for future field expansion

43) Possibility to use the facility on other fields without principal construction changes (sensitivity to different environments)

44) Weight flexibility

45) Possibility to maximize reuse of existing facilities

X. Government regulations Criteria

46) Industry standards compliance

47) Local State requirements compliance

Thus forty seven different criteria for the Arctic Offshore Field Concept selection were identified and grouped into ten categories.

Elaboration of each criterion and the way it could influence the Concept selection for the Arctic fields is presented below.

8.1 Cost & Schedule Criteria

The goal of each offshore field development projects is getting a profit. Each operator company before taking a decision to exploit an offshore field performs financial evaluations of the projects profitability.

Therefore economic parameters are one of the most important criteria in the Concept selection process.

1. The Net Present Value or Profitability

Profitability of alternative concepts could be estimated in the different ways:

- The Net Present Value
- The Internal Rate of Return
- Payback
- Accumulated expenditures compared with accumulated receipts. [6]

The operator company usually decides which method is suitable in each specific case. One of the most popular methods is comparing different projects according to their NPV.

The NPV is the difference between the present value of cash inflows and the present value of cash outflows [61].

Alternative concepts could vary according to their profitability in the following way:

- Project has comparatively high profit
- Project is unprofitable

The first case apparently is preferable.

2. CAPEX (Capital Expenditures)

Capital expenditures or capital investments are expenditures on capital equipment. They are usually one-off costs and incurred at the beginning of a project.

CAPEX typically include geological & geophysical costs, drilling costs, tankers, offshore platform construction and installation, process facilities, wellheads, flowlines and trunk lines to transport oil and gas, supply bases, camps and accommodation, storage tanks or vessels. [53]. Engineering costs are also considered CAPEX.

CAPEX does not characterize the projects profitability by itself. It could be very high in the very profitable project and it could be very low in unprofitable project. However CAPEX characterize project's affordability. Due to the fact that CAPEX are money that are invested mainly at the beginning of a project it is important to keep them at an affordable level for an operator company.

Especially some Arctic projects are characterized by extremely high Capital Expenditures which sometimes are not affordable for one operator company. This leads to sharing of one offshore project between several operator companies as it was on the Shtokman FEED project, for example. Companies might also set a limit to capital expenditure for one project to reduce the risk in the company's investment portfolio.

Different development concepts could vary according to the CAPEX in the following way:

- Project has a level of CAPEX that is affordable for the company
- Project has extremely high, unaffordable CAPEX

First case would be preferable in the Concept selection process.

3. OPEX (Operating Expenditures)

Operating expenditures are day-to-day operations' expenditures that usually occur periodically during a project. [53]

Typical examples of operating expenditures are personnel, materials, supplies, maintenance and overheads.

OPEX is the third main characteristic of the projects that is important to consider in the Concept selection process. Depending on each specific case it could be more preferable to invest more money at the beginning and not to spend them during the project or in opposite to save money at the beginning and spend them more during the project.

Thus there are could be the different situations with respect to OPEX:

- Project has comparatively low OPEX
- Project has comparatively high OPEX

In case all other economic criteria are satisfied the first case is preferable, however, for calculation of economic indicators as Net Present Value, the OPEX may be somewhat higher in case this reduces the CAPEX up front.

4. Continuity of revenue stream

Continuity of revenue stream could also be an important distinguishing factor for alternative development concepts. Long delays of project's income due to long platforms shut-downs, workover operations, reconstruction works etc. should be estimated at the Concept selection stage.

Some projects could be very profitable but with long delays of income and some in opposite less profitable but without any delays of income.

Thus development concepts could have different situations:

- Project with permanent income without long delays
- Project with long frequent delays of income

Th first case is preferable in the Concept selection process for offshore field development.

5. Schedule for project execution

For Concept selection it is important to estimate the whole time consumed from the design phase of the structure till its installation on site and the first production, including time on construction, assembling, transportation and installation for each possible concept. All possible changes in schedule also should be assessed.

Each stage of the project execution should be studied with respect to the schedule and time consuming.

Design phase *(following Concept selection comes the Front End Engineering (FEED) and the detailed design):*

- The best case is when the design time is accelerated as much as possible
- The worst case is when the design time is long and there is no possibility to accelerate it

Fabrication and pre-testing

- Minimal time of assembly works and material supply with maximal flexibility (possibility of equipment replacement if it is necessary)
- Prolonged period of assembly and lack of its flexibility. In order to ensure that the fabrication is done in the planned time, long lead items must be identified and procured to meet the schedule.

Transportation and installation

- Acceptable duration of transportation and installation in unfavorable weather conditions with capacity for flexible performing of operations. Contract for the work must be placed to ensure that the time is met.
- Prolonged duration of transportation and installation, lack of flexibility.

Pre-commissioning and start up

- Schedule is met in case the top side is functional and placement of additional ballast is planned properly.

- Requirements for the additional marine operations after facility installation and before drilling process could delay start up. Also non tested topside equipment may take long time to get started and necessary changes and updates could take long time.

Best development concept would have the shortest time to the first project's production.

8.2 Safety Criteria

6. Risk of environmental contamination

The high environmental risks in the Arctic were already discussed in Chapter 3.1. 5.4 Environmental risks therefore are even more important for Concept selection in the Arctic. The technology to be used should meet all safety and environmental requirements which comply with national and international standards. However, the operator company can choose even more safety technology to reduce the risk of environmental contamination.

Taking into account the uncertainty level that we have at the Concept Phase of the offshore project execution it should be possible to distinguish the different alternative concepts according to the risk of environmental contamination.

Hence two opposite situations could occur:

- The Development concept is characterized by comparatively low risk of environmental contamination

- The Development concept is characterized by comparatively high risk of environmental contamination

The first case apparently is more preferable for the selected concept.

7. Availability of HSE barriers

Safety barriers are physical or non-physical means that are intended to prevent, control or mitigate undesired accidents. [62] There are some challenges related to the Arctic HSE barriers.

The winterization issue should be considered at the Concept selection stage since low temperatures and wind require enclosed modules for the continuous operations of personnel.

Due to the fact that there are no proven technology for evacuation means in ice covered waters the technology for lifeboats should be considered at the Concept selection stage as well.

Since one of the main challenges for the Arctic operations is lack of standardized regulations for operations in ice-covered waters, the operator company should take the responsibility to provide all necessary HSE barriers for the selected development concept.

Thus it is very important during the Concept selection stage to assess the availability of all necessary Health Safety Environment barriers for operations in cold environment.

Hence two opposite situations could occur at the Concept selection:

- Availability at the production facility of all HSE barriers

- Solutions regarding HSE barriers are not found at the Concept selection stage

The first case is optimal apparently.

8. Technical safety

Technical safety on the facility is one of the most important issues and should be considered during the Concept selection stage. Even though all constructed facilities should meet all technical safety requirements of the industry, like for example NORSOK S-001standard [64] the operator company can always improve or increase the safety level.

Thus there could be two opposite situations for the Concept selection:

- The Development concept has comparatively low level of technical safety
- The Development concept has comparatively high level of technical safety

Apparently the first case is preferable in the Offshore Concept selection especially for the Arctic fields and in case the concept does not meet the safety standard, it cannot be approved.

9. Possibility to drill relief wells in case of blow-out

Relief wells are used to relief the excess hydrostatic pressure that causes a blow-out by intersecting a blowing well [44]. Such wells were used to mitigate the circumstances of Macondo field accidence. Relief wells are the last line of defense for blow-out. In some Arctic areas it is required by the government to install two drilling rigs for each well in case of necessity to drill a relief well. [64]

However there are a lot of countries in the Arctic that did not yet regulate this issue. Taking into account remote Arctic distances it takes several months only to transport an additional drilling rig for drilling a relief wells.

Therefore it is important to estimate the possibility for quick transport of an additional rig in case of blow-out.

For establishing alternative concepts there are could be the following situations:

- Field development concept has the possibility to quickly drill relief wells in case of blow-out
- Field development concept is characterized by the lack of possibility to quickly drill relief wells in case of blow-out

Taking into account high Arctic environmental risks the first case is significantly more preferable.

10. Risk of collision with vessels and structure rigidity characteristics

26 collisions between vessels and facilities have happened on the Norwegian Continental shelf for the last ten years [54]. Such a high risk of collision dictates the necessity to consider such incidents during the Concept selection stage of the offshore project. Either the probability of this event should be decreased or the structure should be designed to withstand collision loads.

Thus there are two opposite situations that can occur in evaluation of alternative concepts:

- Risk of collision with vessel is comparatively low
- Risk of collision with vessel is comparatively high

The first option is apparently preferable.

11. Stability characteristics

Strong Arctic winds and high waves with possibility for icing require very stable structure for safe offshore operations.

A demonstrative example of choosing an unstable facility is the Yme platform where the operation was stopped because of high risk of its collapse. [56] Thus it is very important during the Concept selection stage to estimate alternative facilities' stability characteristics. Structures fixed to the ground have the best stability characteristics and partly due to this fact they are more preferable solution for the Arctic.

Thus there are could be two opposite situations during the Concept selection:

- Production facility has comparatively high stability characteristics
- Production facility has comparatively low stability characteristics

The first case is preferable for the Selected Concept.

12. Proven technology

High environmental risks in the Arctic area dictate the necessity to use proven technology for the offshore field development. Considering different feasible concepts it is required to take into account previous experience of construction and exploitation in the potential area of hydrocarbon extraction. The Development Concept should be simple and technically feasible and technical decisions on each stage should be proven. All risks should be minimized.

Several different situations could occur during the Concept selection:

- There is solid experience with the considered structure for exploitation
- This type of structure was constructed but there is no data regarding its use for exploitation
- The concept was successfully used on another field in the Arctic but in softer ice conditions
- The concept is well studied but was not proven by relevant practice
- New type of structure – absolutely new concept [1]

The first case is apparently most preferable for application in Arctic.

Gravity based structures as stationary platforms and monopod structures are considered as proven technology in Arctic area (e.g. Prirazlomnaya platform and structures for Sakhalin I and II developments).

13. Sensitivity of facility to critical conditions

Different concepts may have different safety factors with respect to withstanding the physical loads even if the facility is designed to withstand maximal ice loads and icebergs loads. Estimation of facilities withstandability is of particular importance for the unpredictable Arctic weather conditions.

Therefore it is suggested to estimate the sensitivity of the facility to environmental loads as the nature of the soil, ice loads, ice drift, wave loads, currents, ridging, underwater erosion, pore pressure etc.

Therefore two opposite situations could occur after such estimation:

- Concept's facility has comparatively low exposure to environmental loads

- Concept's facility has comparatively high exposure to environmental loads

The first option is preferable.

14. Ability to leave the site in case of accidence (disconnection capability)

Disconnection capability of a facility provides an additional safety barrier because in case of emergency accidence (e.g. oil blow-out) the people on the facility could be saved by the help of facility's ability to disconnect from the site.

Thus there are two possible situations that could occur at the Concept selection:

- Facility has disconnection capability
- Facility does not have disconnection capability

In case all other safety requirements are satisfied a facility that have disconnection capability is more preferable.

8.3 Drilling characteristics

Drilling is one of the most risky operations in offshore field exploitation. Most of the disaster blow-outs have happened during drilling operations. Thus it is important to consider the drilling part of the field exploitation separately from others.

15. Risks of problems during well construction

Technical problems during well construction can lead to not only significant expenditures and long time delays but even to reservoir fluid blowout. Hence considerations of the reliability of the drilling technology should be carried out during the planning phase of the project development.

Main problems experienced during well construction are:

- Stuck drill string
- Parting of drill string
- Well control incidents or influx of formation fluid into the well
- Failures of downhole and surface equipment

One of the ways to analyze equipment reliability is to use industry databases, e.g. OREDA (Offshore Reliability Data) database [69].

Thus there are two different situations that could occur in the Concept selection process:

- Comparatively high risk of problems during well construction from the concept's drilling facility
- Comparatively low risk of problems during well construction from the concept's drilling facility

Apparently, the first case is significantly more preferable.

16. Availability of existing drilling facility

As was discussed in Chapter 6.2 Drilling Systems for Arctic conditions, not each type of drilling facility is suitable to be used in the Arctic ice-covered waters. Arctic conditions require special ice resistant structures. However it could be an advantage to check the current market for which existing facility that might be used on the specific field. An existing drilling facility can potentially be less expensive and can also bring on production more quickly.

Hence there are two opposite situations that could occur during the Concept selection:

- Suitable for this conditions' drilling facility is already constructed and available
- Drilling facility for the specific conditions should be designed and constructed

The first option is preferable.

17. Ability to install several derricks on the structure

This facility feature can be a very good advantage for well drilling during ice-free period because it allows reduction of the drilling period twofold. Thus it is suggested to estimate the possibility to install several derricks on the drilling facility at the Concept selection stage.

The significance of this criterion depends on number of planned wells and length of the ice-free period.

Two opposite situations could occur during the Concept selection:

- It is possible to install two or more derricks on the drilling facility
- Lack of possibility to install several derricks on the drilling facility

For ice-covered waters the first option is preferable.

18. Schedule for drilling

Drilling season for exploration and for subsea wells in the Arctic could be very short in ice-covered waters. Thus it is important to estimate during the Concept selection which concept has the shortest drilling schedule which influence on the CAPEX of the project and time to stable production.

There are two opposite situations that could occur in the Concept selection:

- The development concept has a comparatively short drilling schedule (because of several derricks or ice-resistant platform)
- The development concept has a comparatively long drilling schedule (ordinary drilling facility which allows drilling only in short summer season)

The first option is preferable in the Concept selection.

19. Workover capability

Workover operations are remedial operations for production wells with a purpose to increase production. They include sand cleanout, repairing of lines and casing, well recompletion etc. [56]. Requirements for the workover operations can appear any time during field exploitation but it could be very cost-consuming to perform workover operations at remote located Arctic fields. Thus capability of the production facility to provide workover operations could be a very good benefit for the development concept.

There are two opposite situations that could occur during the Concept selection:

- Production facility has workover capability (drilling rig is installed on the structure)

- Production facility require special drilling facility to provide workover operations

The first option is preferable for the Selected Concept.

20. Heave motion characteristics

Heave motion is a motion of the facility in vertical direction due to waves, wind and currents. The heave motion characteristic is one of the most important characteristics for the drilling facility especially in harsh environmental conditions. Therefore it is important to assess the drilling facilities of alternative concepts according to their heave motion characteristics.

There are two opposite situations that could occur at the Concept selection:

- Drilling facility has comparatively better heave motion characteristics
- Drilling facility has comparatively difficult heave motion characteristics

The first case is preferable for the Arctic offshore Concept selection.

8.4 Operability Criteria

21. Easy to start or shut-down

During the life span of an offshore field there are quite frequent situations when it is necessary to shut-down the production (e.g. heavy workover operations, emergency accidence etc.). Thus it is important to evaluate alternative concepts according to easiness of shutting down and starting up of the facility. Some offshore solutions have remote control of production facility (e.g. subsea solutions) and some of them have direct access to the wells (e.g. dry-tree solutions).

Thus the following situations could occur at the Concept selection stage:

- Development Concept is characterized by comparatively easy starting up and shutting down
- Development Concept is characterized by comparatively difficult starting up and shutting down

The first case is preferable for the Selected Concept.

22. Power supply

Power supply is one of the issues that usually are not considered during the Concept Development phase. However, operating expenditures vary for alternative development concepts. According to [68], depending on the process system and equipment on the facility, the required power may vary in the range of a few to hundreds of megawatts.

Thus at the Concept selection stage the following situations could occur:

- Development concept has comparatively high electricity demand
- Development concept has comparatively low electricity demand

The first case is preferable for the Selected Concept.

23. Capability of well control

Well fluid blow out is one of the most dangerous scenarios in offshore field development and that is why it is very important to evaluate different alternative concepts according to their capability of well control. Thus there are could the following situations at the Concept selection process:

- Development concept has comparatively high level of well control
- Development concept has comparatively low level of well control

The first case is preferable for the Concept selection.

24. Level of autonomy

Autonomy of the structure means the level of its dependency on shore infrastructure. Availability of storage tankers, material stocks, food reserves, life-saving equipment, fire fighting systems and periods of its resupply are included in the term autonomy. For remote Arctic offshore fields with difficult weather conditions this criterion could be very important. Unpredictable weather could bring challenges for supply vessels coming and remote locations make these supplies very expensive.

It is usually possible to increase the level of autonomy which influence on the required area of the deck. During the Concept selection it is, for example, advised to compare the expenses of ship supplying and expenses for structure expansion to install additional storage tanks. [1]

The following situations could occur in the Concept selection stage:

- Independent operation of the facility during the long period
- High dependency of the facility from shore infrastructure without possibility to decrease this dependency

For the Arctic offshore field Concept selection the first case is the preferable one.

25. Level of production process automation (number of people on the platform, possibility to reduce it)

Main Arctic specifics as low temperatures, darkness and storms have pernicious effect on state of personnel health. Thus, the high risk of personnel injury dictates one to consider the number of people on the production structure and the level of its automation.

During the Concept selection stage it is recommended to estimate the number of operating personnel on-deck for a long exploitation period, possibility to reduce it and the level of production process automation, availability of back-up and redundant systems, number of tending vessels and helicopters.

Thus, the different concepts could vary with respect to the number of operating personnel. The preferable concept for the Arctic area has the lowest number of people on the platform and consequently the highest level of automation in case of sufficient level of automation system reliability.

26. Oil or gas quality at the delivery point

Different concepts may process the petroleum products to different qualities at the delivery point. Some concepts allow installation of a full chain of process systems when others do not have sufficient space or it is not feasible at all to install process systems (e.g. full subsea production system). Thus the products from the platform depend on the selected field development concept.

Requirements from the consumer determine the significance of this criterion in the Concept selection process.

There could be the following opposite situations:

- Development concept provides comparatively high quality of the end product
- Development concept provides comparatively low quality of the end-product

Usually in the Concept selection phase the first option is preferable.

8.5 Working environment criteria

27. Working environment for personnel

Different concepts may vary according to the comfortability of work conditions for personnel. Difficult Arctic environmental conditions dictate one to consider the working environment conditions for personnel more closely.

Working conditions include enclosed modules for work, sufficient ventilation to avoid accumulation of explosive gases, additional heating systems, convenient location of living quarters with full hospital facility, availability of comfortable rooms for personnel rest etc.

There are could be the following situations:

- Comparatively high level of the working environment
- Comparatively low level of the working environment

The first case is apparently preferable in the Concept selection for the Arctic as well as other field developments.

8.6 Reliability and availability criteria

28. Reliability and availability of equipment

Reliability of equipment is a measure of how long it performs its intended functions.

Availability of equipment is a measure of the % of time the equipment is in an operable state. [65]

A RAM analysis (Reliability Availability Maintainability) at the Concept selection stage allows significant operating expenditures savings, focusing attention on the critical areas of the alternative concepts.

There are several methods how to implement RAM analysis [12]:

- Use of general industry data bases (WellMaster, OREDA, WOAD, E&P Forum)
- Vendor data
- Data from joint industry projects
- Expert judgments
- Synthesized data

All type of equipment of comparable concepts should be subjected to the reliability analysis, including:

- Support structure
- Pipelines
- Risers
- Well equipment
- Subsea production system (hydraulic and electrical umbilical, hydraulic and electrical termination units templates, manifolds, flow line jumpers, subsea trees etc.)

RAM analysis as presented in the paper [12] shows, for example, that a process unit placed offshore has lower availability than a process unit placed onshore. Or that the production availability of subsea tree is lower than the production availability of a dry tree. In such a manner alternative concepts were analyzed from a reliability point of view and the potential cost savings for each concept were calculated.

Thus there are could be the following situations during the Concept selection:

- Development concept has comparatively high reliability characteristics
- Development concept has comparatively poor reliability characteristics

The first case is apparently preferable.

Robustness or reliability of the support structure is a guarantee of safe facility operations and ability of personnel in case of emergency to take immediate actions. Poor level of structure robustness can lead to operational down time, loss of equipment, loss of life and environmental pollution.

In that case preferable constructions are solid structures placed on the seafloor.

Equipment for production system construction should be reliable as well; they should meet all requirements for the Arctic conditions and their application should not require development of new technology and special training of personnel.

Contractor for these materials should be well-known and reliable.

The optimal case according to this criterion is equipment that meet cold environment requirements from reliable, well-known supplier.

29. Prevention of flow assurance problems

The flow assurance issue is usually a key concern in the reliability analysis according to [12]. Special emphasis is placed on subsea development concepts with multiphase flow pipeline transport.

Main questions that require answers in RAM analysis of flow assurance are:

- What is the probability of plug formation in any of the lines
- Where will it occur
- How can we prevent it from occurring
- How can we remove a potential vax or hydrate plug [12]

All alternative concepts should be subjected to such analysis. The output of the analysis is the probability of plug formation at different locations of the flow line system and the evaluation of impact of plug formation on system availability both in terms of removal of plugs and replacing plug flowlines. The best concept after this analysis will have the lowest probability of plug formation with less impact on system availability in case of its occurrence.

30. Complexity of maintenance

The RAM analysis requires a maintainability analysis of the concept. The question that should be answered in maintainability analysis according to [12] is: "How much does it cost to maintain the facilities to ensure high level of production availability?" In the Ormen Lange RAM analysis [12], the subsea-to-land development concept had the highest maintenance cost as the main driving factors were mobilization of mobile offshore drilling units for workover operations while dry tree concepts allow intervention operations from the platform at a lower rig rate.

For the Arctic area the maintenance issue becomes of particular importance since remote locations and difficult weather conditions will increase these costs to extremely high levels.

The optimal development concept for the Arctic will have the lowest cost for maintenance works with acceptable level of equipment reliability.

31. Number of back-up systems and redundancy

Difficult Arctic environmental conditions, remote locations and high environmental risks require a high level of the operation's reliability and availability.

To increase the functional redundancy and number of back-up systems is one way to improve system availability. Thus it has a sense to compare alternative concepts according to this criterion.

Two opposite situations could occur during the Concept selection:

- Development concept has comparatively high level of redundancy and sufficient number of backup systems and consequently higher level of equipment availability
- Development concept has comparatively low level of redundancy and low number of backup systems and consequently comparatively low level of equipment availability

The first case is apparently preferable for the Arctic Concept selection.

32. Reliable contractors

Offshore field development projects entail huge investments and long-term commitment. They involve a lot of contracts and agreements with service and manufacturing companies that provide equipment, materials, personnel and other services. Selection of the "right" contractor is one of the key factors to reliable operation and high level of availability.

Thus it should be possible to compare alternative development concepts according to the reliability of their contractors. Two opposite situations could occur in the Concept selection stage:

- Materials and services suppliers of development concept are reliable and well-known
- Contractor is new on the market and does not have a sufficient work experience

The first option is preferable for the Selected Concept.

8.7 Transportation, Assembly & Installation Criteria

33. Complexity of technical equipment layout

The complexity of equipment's layout on the production facility should be estimated, i.e. whether the equipment is placed in a single or in several modules. It is also important to provide free access for equipment assembly, exploitation and maintenance. Technology of top side equipment assembly should be simple; the number of operations during the assembly should be minimized and the redundancy of the drilling system should be provided.

There could be the following situations:

- Single module when it does not cause large increase of material consumption
- Several modules with difficult drilling technology and well exploitation.

The first solution is preferable for the Concept selection.

34. Requirements to perform marine operations and possibility to perform them in short period

In the Concept selection for the offshore field development it is always important to consider the number of works which are necessary to be performed in open waters. The possibility to install production facility with all top side equipment at ones without requirements for additional marine operations could be a significant benefit for the development concept.

For the unpredictable Arctic environmental conditions it is very important to estimate the dependency of the structure's assembly and installation on the weather conditions. The ice-free period could be very short but even in this period there are difficult wave, wind and fogs conditions that can complicate the installation process. Therefore the duration of assembling and installation works in open waters for each Development Concept should be estimated.

Thus there could be the following opposite situations in the Concept selection process:

- The development concept requires comparatively low number of marine operations which is possible to complete during the summer period
- The development concept requires comparatively high number of marine operations that take longer period than one summer season

Apparently for Arctic conditions the first case is more preferable.

35. Complexity of facility installation

Remote locations and difficult weather conditions in the Arctic area require close consideration of facility transportation and installation issue.

It is reasonable to consider the top side connection with support structure, the number of blocks of equipment, weight-and-dimensional characteristics influencing on construction, assembly and installation technology.

The distance between the construction yard and the possibility to perform transportation in the summer period should be analyzed as well.

The best situation for the Development Concept is use of simple installation technology and easiness of its performance. The non-preferable case is use of difficult installation technology and huge number of equipment blocks.

In case of the use of a platform development concept the complexity of the top side installation and assembly should be estimated. Such items like principles of installation, existence of moving elements, need for tension leg assembling, ballasting, sand filling, plating of support structure and type of support structure (pile-supported, semisubmersible) should be analyzed.

The following situations in the Concept selection process could occur:

- Simple structural shape, direct sequence of installation, lack of use of moving elements
- Complicated structural shape, multistage sequence of installation, huge number of system elements

The first case is preferable one.

36. Complexity of facility decommissioning

The final phase of the project life cycle is decommissioning and abandonment. According to current regulations an initial Decommissioning and Abandonment Plan is required to be performed before being granted a permit for construction. This plan includes decommissioning of installations, abandonment of fields and abandonment of wells.

Therefore it is important to consider the removal issue at the beginning stage of the project execution.

Facility decommissioning is usually as complex as (or more complex than) critical installation. Risks involved in removal are even higher than in the initial installation: risks that an accident will occur during salvage or that the structure becomes unstable makes decommissioning operations nearly impossible. [66]

Thus alternative concepts could be distinguished according to the complexity of facility decommissioning:

- Development concept needs comparatively difficult decommissioning technology
- Development requires a comparatively easy decommissioning technology

For Arctic area apparently the first case is preferable.

37. Safety of equipment during transportation, assembly & installation

Important marine operations, such as facility transportation, assembly and installation are known as complicated and risky operations.

A lot of accidents related to pipeline failure or equipment drops usually occur during these operations. Due to this fact it is important to consider equipment safety during marine operations. Subsea production system installation should be given special emphasis due to high number of necessary marine operations.

Therefore in the Concept selection it is suggested to evaluate the number of equipment that needs to be transported, the number of operations in open waters, the required amount of supply ships and amount of service personnel that influence on the safety of the facility during transportation, assembly and installation operations.

Two opposite situations could occur in the Concept selection:

- The development concept is characterized by safety and simple operations during transportation, assembly and installation of the facility equipment

- The development concept is characterized by high risks for the equipment's safety during transportation, assembly and installation of the facility equipment

The first case is preferable.

8.9 Fabrication Characteristics

38. Possibility to construct at local construction facilities

In case the operator company intends to develop an offshore field in the home country it is important to consider the possibility to use the science and technology base and the industrial capacity of home country. Construction plant, suppliers and materials could be used from the home country. Usually this leads to saving of money and tax reliefs from the government. Also, all design calculations would be according to local state requirements and standards.

Thus at the Concept selection stage development concepts could be distinguished according to the possibility to use the home country industrial capacity. The following situations could occur:

- Development concept is possible to execute by the help of the home country's industrial capacity

- Development concept does not allow to use the home country industrial capacity

The first case usually is preferable if the quality of local industry meets the necessary requirements.

39. Requirements to construction materials, tolerances of connections of component parts

It is recommended in the Concept selection process to evaluate the complexity of the structure's assembling, i.e. the materials should be in extensive use, simple design with simple elements are recommended, one should set acceptable tolerance limits, use simple technology of component elements' connections, design easily-accessible and not overloaded work areas, require a minimal number of lifts and typical methods for system structure assembling. [1]

Thus there are could be the following opposite situations:

- Simple assembly of production systems which means simplicity of connections of large-size assembly elements

- Complicated assembly because of overloading and numerousness assembly elements, great many small parts, unproven assembly technology

The first case is preferable for the Concept selection.

40. The necessity to extend the construction plant infrastructure or plant reconstruction

At the Concept selection stage the possible contractor for facility fabrication should be considered. Estimation should involve:

- Necessary amount of constructor workers

- Amount of required buildings and assembly site

- Amount of required materials
- Access from the plant to the sea and capacity of the ground to load out heavy elements
- Size and area of dockyard
- Water depth at quay

After such estimation it can appear that the construction plant needs to be reconstructed or extended for massive structure fabrication. This influences on additional expenditures and complexity of project execution.

Two different situations could be in such case:

- The facility could be fabricated without principal changes of construction plant
- To fabricate the necessary facility it is required to extend construction plant

The first case is preferable in the Concept selection.

41. The necessity to construct special floating structures for construction assembly

The amount of required floating structures and their availability in contractors' shipyard (e.g. transport barges and tugs, anchor handler, vessel for bottom preparation, lift vessels, fire-fighting vessels, ice-breaking vessels for equipment supply, stand-by vessels, vessels for sand and rock soil supply etc.). [1]

The possibility to use these vessels in the Arctic is related to the ice-free period.

Thus in the Concept selection process the following situations could occur:

- The Development Concept needs a comparatively low number of special floating structures for supply
- The Development Concept needs comparatively high number of special floating structures for remote supply

The first case is preferable for the Selected Concept.

8.10 Flexibility of production system Criteria

42. Flexibility for future expansion

The Concept selection stage is an initial stage of offshore project execution which is characterized by high level of uncertainty. Sometimes the number of resources that was discovered during the exploratory work will be increased after the production has started. In that case, if the production facility is not designed for field extension it would be very expensive to make construction changes in the production stage as it is described in paper [10].

Thus it is very important in the Concept selection stage to consider the flexibility of the production facility for future expansions.

The following situations could occur in the Concept selection:

- The production facility has the possibility to increase the number of wells with increased well rates

- The production facility needs fundamental changes in case of field expansion

Apparently the first case is preferable for the Concept selection.

43. Possibility to use the structure on other fields without principal construction changes

It could be advised to estimate the sensitivity of the structure to be used at different environmental and geo-technical conditions.

For example if the structure was constructed for specific field conditions, would it be possible to use it on another field without principal changes? Such a possibility could save a lot of investments for future projects.

Thus there are two opposite situations that could occur in the Concept selection:

- The development Concept's facility is applicable for different environmental and geo-technical conditions
- The development Concept's facility has high sensitivity for different environmental and geo-technical conditions

The first case is preferable for the Arctic Concept selection.

44. Weight flexibility

Weight flexibility should be considered in the Concept selection process as well. During the offshore project life the field can be subjected to a lot of changes (e.g. number of recoverable resources could increase, the content of the product could change, methods of pressure maintaining could be required etc.). These changes usually require additional equipment installation and if the construction design does not allow these developments it could lead to big and costly challenges.

Thus it is important to consider the Development Concept's weight flexibility during the Concept selection stage. There could be the following situations:

- Development Concept has comparatively high weight flexibility
- Development Concept has comparatively low weight flexibility

The first case is preferable.

45. Possibility to maximize reuse of existing facilities

If there is a possibility for the Development Concept to use existing facility like for example already constructed pipelines, closely located platforms or onshore process systems it would be a great advantage for the project.

Sometimes also the Development Concept could have a higher CAPEX but provides some services for the surrounding fields. The example of such situation is Skrugard field. The floating structure will function not only for the Skrugard field exploitation but also as a hub for another close field, Havis, and future fields' developments. [75]

Thus it is important to take into account other surrounding fields and estimate the possibility to use their facilities or to function as a hub for other fields, bringing future cost savings.

Thus the optimal solution has maximal cost benefit for the given project as well as for other or future projects.

8.11 Government regulations Criteria

46. Industry standards compliance

At the Concept selection stage when all feasible development concepts are determined it is necessary to analyze the compliance of engineering solutions with technical regulations. The main technical regulation that addresses to Arctic is ISO19906 [52] but there are other standards in industry that could be applied for the developments in cold environment as well.

According to Russian regulations, mandatory compliance with technical regulations is provided by fulfillment of requirements of standards that the manufacturer chooses on the voluntary basis. These can be any feasible standards including regional standards, Russian national standards and international standards. [67]

Thus it is very important to ensure that the Development Concept is incompliance with industry standards. If the development concept does not fulfill standardized requirements it could not be considered for further studies.

47. Local Authority requirements

When feasibility of the Development Concept is approved, local authority requirements for each stage of project execution should be considered. For example to get access to the ice covered Russian ports the vessel should have an Ice Certificate or there are special rules of the Russian government when entering the Northern Sea Route as well. [67]

Another example is the USA which states by the Jones Act that crews on vessels must be citizens of the USA, the tankers must have at least 75% American ownership, and tankers for transporting hydrocarbons must be built in the USA. This state makes the FPSO concept for USA fields' exploitation significantly more expensive than in other regions. [23]

Thus it is important to consider the local authority requirements compliance for each feasible Development Concept. The optimal development concept meets all requirements from the local government without additional expenditures.

9. Evaluation of the Concept selection criteria

The objective of this chapter is to identify the most important criteria for the Arctic offshore concept selection and to evaluate all identified criteria according to their importance in the Concept selection process.

The evaluation of the identified criteria for the Arctic Concept selection was performed by the method of experts' judgment.

The experts' judgment method is used to gather information from an expert in response to a technical problem. It is applied when there is no available explicit information about the subject.

An expert is a person with background in the subject area and which is recognized by his peers or those conducting the study as relevant to answer the questions. [57]

Experts' judgment was performed in the following steps:

- First, the questionnaire for the experts was prepared
- Then, a group of experts in Arctic offshore concept development was chosen
- Finally, the questionnaire for expert judgment was sent to experts and feedback was gathered and analyzed

The questionnaire was prepared by the help of the on-line survey tool - http://www.surveytool.com/ (see Figure 1-12 Appendix 2). The link for the prepared on-line questionnaire is:

http://www.surveytool.com/survey/collect/id/73322#

First three questions in the questionnaire are dedicated to experts' competence. Table 6 represents this information.

Table 7 Information about experts

	Area of expertise	Years of experience in Oil&Gas industry	Nationality
Expert 1	Marine Technology	38	Norwegian
Expert 2	Offshore engineering	42	Russian
Expert 3	Maintenance engineering	32	Norwegian
Expert 4	Maintenance engineering	20	Norwegian
Expert 5	Asset management	10	Norwegian
Expert 6	Offshore Concept Development	15	Russian
Expert 7	Marine engineering	4	Russian

9.1 Experts' judgment

First, the experts were asked to evaluate the importance of the categories of criteria in the Arctic Concept selection Process by the following scale:

1 - Not important at all, 2 -Slightly Important, 3 - Moderately Important, 4 - Very important, 5 - Absolutely Critical.

Results of the experts' judgment of criteria categories are presented in Figure 13.

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Average
Cost&Schedule	5	5	5	5	5	5	5	5,00
Safety Criteria	5	5	5	5	5	5	5	5,00
Government regulations	5	4	4	5	5	4	4	4,43
Working environment	5	5	5	5	4	2	3	4,14
Reliability Criteria	5	4	4	4	4	3	4	4,00
Operability Criteria	5	4	4	4	4	3	3	3,86
Drilling characteristics	3	5	3	3	4	3	3	3,43
Transportation, Assembly&Installation	4	4	3	4	2	4	3	3,43
Fabrication characteristics	3	4	2	4	2	4	3	3,14
Flexibility characteristics of production system	4	4	2	3	2	2	3	2,86

Table 8 Experts judgment of categories of criteria

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Average
Cost&Schedule	5	5	5	5	5	5	5	5,00
Safety Criteria	5	5	5	5	5	5	5	5,00
Government regulations	5	4	4	5	5	4	4	4,43
Working environment	5	5	5	5	4	2	3	4,14
Reliability Criteria	5	4	4	4	4	3	4	4,00
Operability Criteria	5	4	4	4	4	3	3	3,86
Drilling characteristics	3	5	3	3	4	3	3	3,43
Transportation, Assembly&Installation	4	4	3	4	2	4	3	3,43

Fabrication characteristics	3	4	2	4	2	4	3	3,14
Flexibility characteristics of production system	4	4	2	3	2	2	3	2,86

After evaluation of the categories of criteria the experts were asked to evaluate each criterion separately according to their estimation of the importance in the Concept selection process for the Arctic area by the same scale where:

1 - Not important at all, 2 -Slightly Important, 3 - Moderately Important, 4 - Very important, 5 - Absolutely Critical

According to the experts' judgment, the importance of criteria is distributed in the following way (see Table 8):

Table 9 The results of experts judgment

		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Average
1.	Risk of environmental contamination	5	5	5	5	5	5	5	5,00
2.	Technical safety	5	5	4	5	5	5	5	4,86
3.	Local State requirements compliance	5	5	5	5	5	4	5	4,86
4.	Availability of the HSE barriers	5	5	5	5	5	3	5	4,71
5.	Risk of problems during well construction	5	5	4	5	4	5	5	4,71
6.	NPV	4	5	4	5	5	5	4	4,57
7.	Ability to leave the site in case of accidence (disconnection capability)	5	5	4	5	3	5	4	4,43
8.	Prevention of flow assurance problems	5	5	4	4	4	5	4	4,43
9.	CAPEX	5	4	5	5	4	3	5	4,43
10.	OPEX	5	4	4	5	5	3	5	4,43
11.	Schedule for project execution	5	4	4	5	5	4	3	4,29
12.	Sensitivity of structure to critical conditions (to environmental loads)	5	5	5	4	4	4	3	4,29
13.	Stability characteristics	5	5	4	4	4	4	4	4,29
14.	Capability of well control	5	4	4	4	3	5	5	4,29
15.	Industry standards compliance	4	5	4	4	4	4	5	4,29

16.	Continuity of revenue stream	5	3	3	5	5	5	3	4,14
17.	Safety of equipment during transportation, assembly & installation	4	5	4	4	4	5	3	4,14
18.	Working environment for personnel	5	5	5	4	4	2	4	4,14
19.	Reliability of equipment	4	5	4	4	4	4	4	4,14
20.	Risk of collision with vessels and structure rigidity	4	5	4	4	3	4	4	4,00
21.	Power supply	3	4	3	4	5	5	3	3,86
22.	Number of back-up systems and redundancy	4	4	4	4	4	4	3	3,86
23.	Possibility to drill relief wells in case of blow-out	5	5	4	4	4	1	4	3,86
24.	Complexity of maintenance in Arctic	3	4	4	4	5	3	4	3,86
25.	Proven technology	4	4	4	4	3	3	4	3,71
26.	Reliable contractors	4	5	3	4	3	3	3	3,57
27.	Requirements to perform marine operations and possibility to perform them in short period	4	4	5	4	3	2	3	3,57
28.	Easy to start or shut-down	3	3	4	4	4	3	4	3,57
29.	Weight flexibility	4	4	3	4	5	2	2	3,43
30.	Oil or gas quality at the delivery point	2	4	3	4	4	4	3	3,43
31.	Complexity of technical equipment layout (single staged or multi staged)	4	4	3	4	4	1	3	3,29
32.	Complexity of facility installation	3	4	3	4	3	3	3	3,29
33.	Schedule for drilling (drilling season)	4	4	4	2	3	2	4	3,29
34.	Level of autonomy	2	3	4	4	3	3	4	3,29
35.	Heave motion characteristics and possibility of lateral offset	4	4	4	3	4	1	2	3,14
36.	Level of automation	2	4	4	4	3	3	2	3,14

37.	Possibility to construct on local construction facilities	3	4	2	4	3	2	4	3,14
38.	Requirements to construction materials, tolerances of unions of component parts	2	3	2	4	4	5	2	3,14
39.	Availability of drilling facility	3	4	5	2	3	2	3	3,14
40.	Workover capability	3	4	4	2	5	1	3	3,14
41.	Complexity of facility decommissioning	3	4	2	4	2	3	3	3,00
42.	Flexibility for future expansion	4	3	3	3	3	2	3	3,00
43.	The necessity to extend the construction plant infrastructure or plant reconstruction	2	3	3	3	4	2	2	2,71
44.	The necessity to construct special floating structures for construction assembly	2	3	3	3	3	2	2	2,57
45.	Ability to install several derricks on the structure	2	4	3	2	3	1	3	2,57
46.	Possibility to use the structure on other fields without principal construction changes (sensitivity to different environments)	2	3	2	2	2	2	2	2,14
47.	Possibility to maximize reuse of existing facilities	2	3	2	2	2	2	2	2,14

9.2 Discussion of the results

First, experts were asked to evaluate the importance of the categories of criteria in the Arctic Concept selection Process (see Table 7) by the following scale:

1 - Not important at all, 2 -Slightly Important, 3 - Moderately Important, 4 - Very important, 5 - Absolutely Critical.

According to the experts' opinion, categories of criteria are distributed in the following way (see Figure 12):

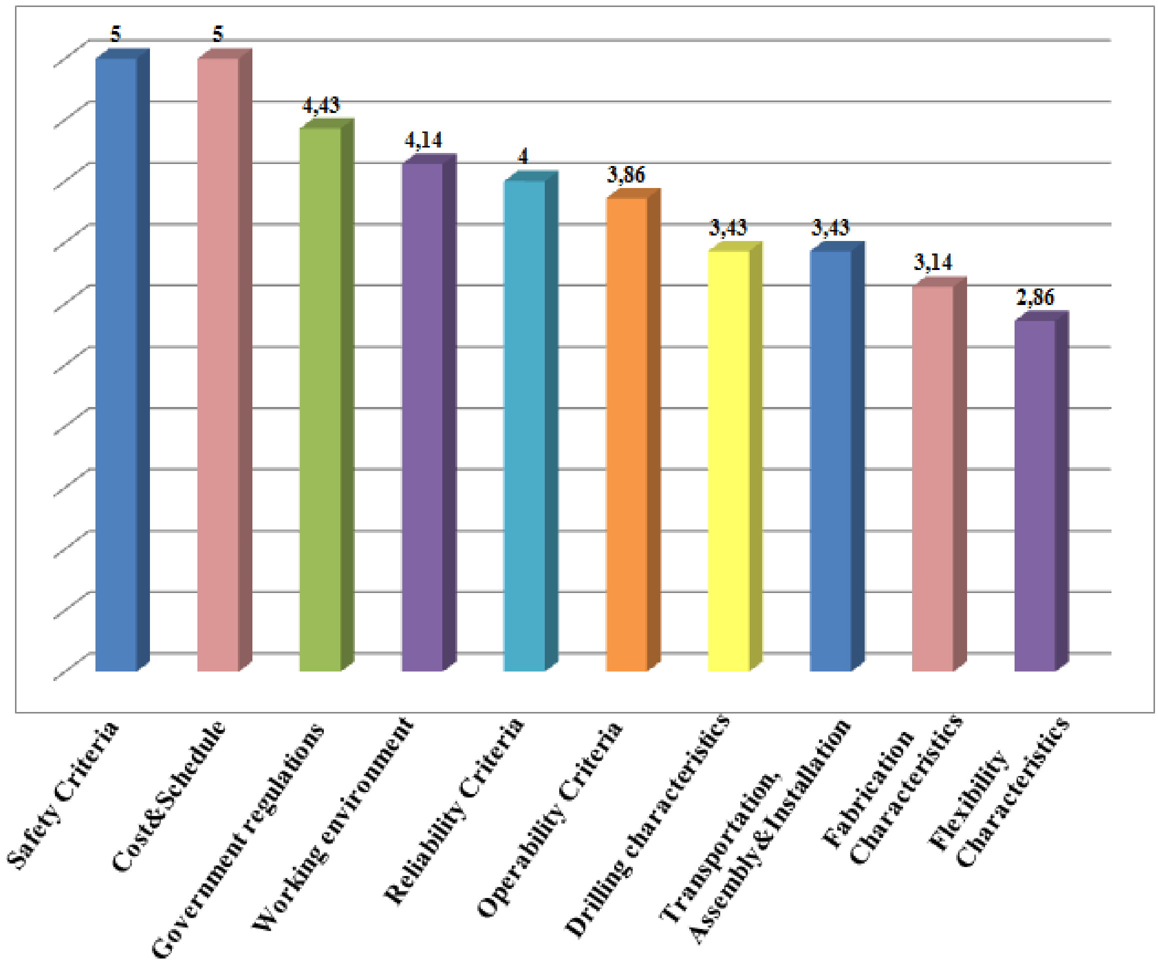


Figure 13 Distribution of criteria categories weights, where 1 - Not important at all, 2 -Slightly Important, 3 - Moderately Important, 4 - Very important, 5 - Absolutely Critical

If we assume that weights in the range of 4.4 – 5 ("more than very important" – "extremely important") reflect the highest importance of the criteria in the Concept selection process the most important categories could be identified.

From Figure 13, the three most important groups of criteria that influence the Concept selection process for the Arctic offshore:

- Safety Criteria
- Cost & Schedule
- Government regulations

These criteria would be also relevant for the Offshore Field Development Concept selection in all areas.

This is due to the fact that the main purpose of any offshore project is getting a profit. That is why economic criteria are one of the most important for any offshore project.

Reducing the risks for personnel and environmental safety on the hydrocarbon producing facility are highly important as well.

The Importance of governmental regulations also should not give rise to doubt since no one offshore project will be executed without compliance with government requirements.

However the list with each specifics criterion’s weight reflects Arctic specifics much more.

This list involves the ten criteria with weights in the range of 4.4 - 5:

1. Risk of environmental contamination (5.00)
2. Technical safety (4.86)
3. Local State requirements compliance (4.86)
4. Availability of the HSE barriers (4.71)
5. Risk of problems during well construction (4.71)
6. NPV (4.57)
7. Ability to leave the site in case of accidence (disconnection capability) (4.43)
8. Prevention of flow assurance problems (4.43)
9. CAPEX (4.43)
10. OPEX (4.43)

The distribution of these criteria’s’ weights is presented in Figure 13.

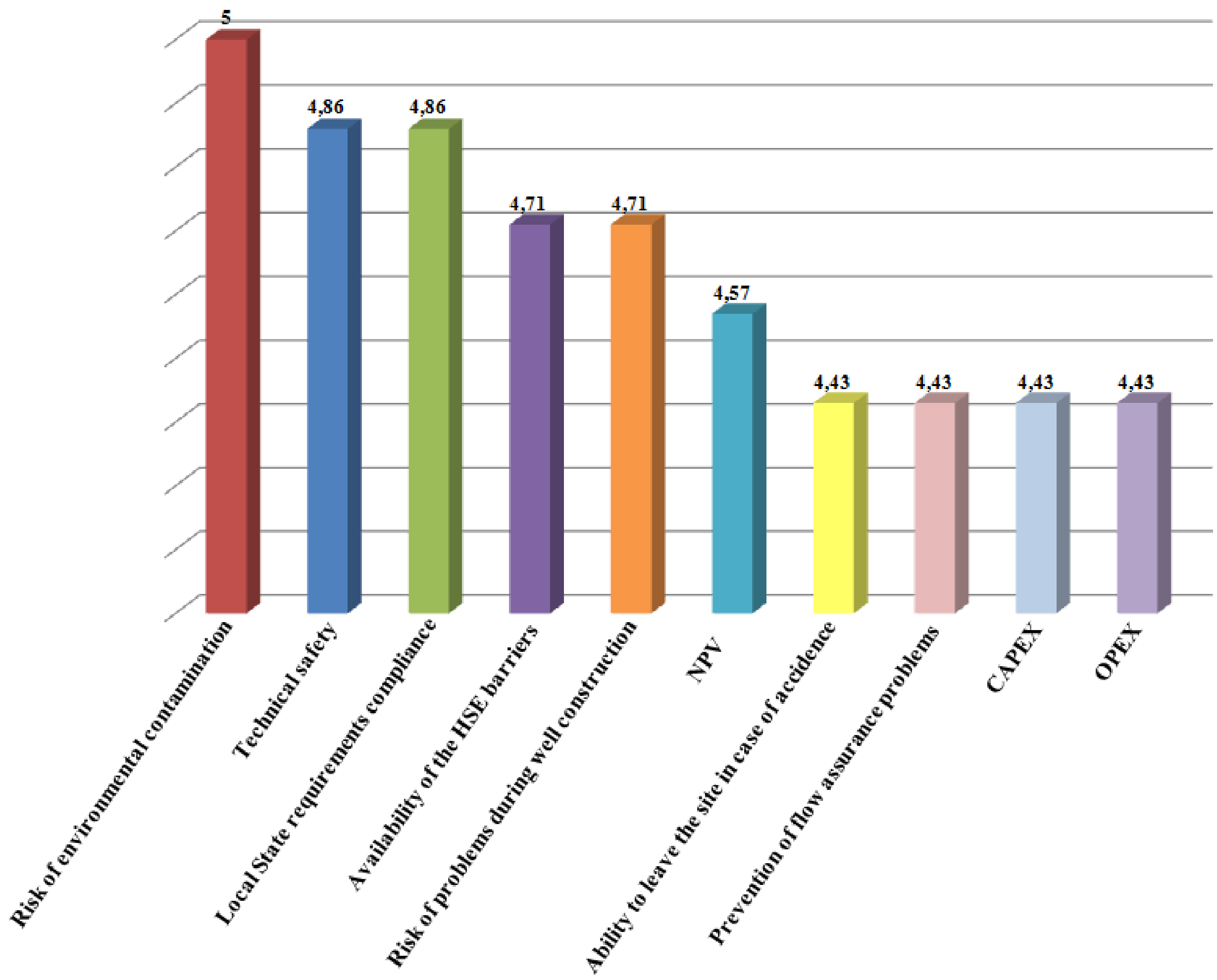


Figure 13 Weights of criteria for Arctic offshore concept selection, where 1 - Not important at all, 2 -Slightly Important, 3 - Moderately Important, 4 - Very important, 5 - Absolutely Critical.

Let us discuss them more closely.

Since the main concern about Arctic is high environmental risks (see Chapter 5.4 Environmental risks) the risk of environmental contamination and technical safety head the list of important criteria.

Local State requirements rank the third place of importance and this is due to the fact that these requirements are mandatory for the project execution.

NPV or development concepts profit ranks number four in the criteria list. This is from the first view not a logical result but it becomes more reasonable with address to the high Arctic environmental risks. Since loss of money and reputation will be irreparably harmful for any operator company, we could take the case of the Macondo field accident recurring in Arctic.

Other economic criteria as CAPEX and OPEX only complete this list.

Availability of HSE barriers in the Arctic is at the top of the list as well. This fact also relates to the biggest concern about Arctic – increasing the safety level of the operation due to the high risks.

Risk of problems during well construction rank the same place as the projects profit. This could be due to the fact that one of the problems during well construction is loss of well control and blowout, consequences of which are too high in Arctic conditions.

Schedule for the project execution would be of high importance since all offshore operator companies pursue a purpose to get back investments and gain a profit as soon as possible.

Prevention of flow assurance problems being of main concern regarding the operation reliability is one of the most important criteria in the Concept selection process for the Arctic offshore.

Thus analysis of the experts' judgment showed unanimous opinion that safety issues are the most important for the Concept selection in the Arctic. Besides, it also resulted in that considerations of the local state requirements are even more important than high projects profitability.

The list of the most important criteria for the offshore field development Concept selection in the Arctic area is prepared by the help of experts' judgment.

10. Results

The main result of the work is the list of criteria that should be considered during the concept selection process for the Arctic offshore. However this list consists of forty seven criteria which make the multi-objective problem of the development concept selection even more difficult.

The first intention of this work was to identify criteria on the basis of which it should be possible to compare different technically feasible concepts.

It was suggested to achieve technical feasibility of the development concepts on the basis of field engineering parameters as water depth, ice conditions, wave and winds etc. And selection was suggested to be performed on the basis of comparison criteria that could distinguish different possible concepts from each other.

However, during the work process there were found different issues that should be considered at the concept phase of the project as well. To such issues we can refer:

- Industry standards compliance
- And local authority requirements

It is better to say that these criteria place limitations on the development concepts. Either development concept satisfies to these requirements or it is not considered as possible solution at all.

Such limitations could be set by almost each criterion. For example, either development concept satisfies to the required level of technical safety or it is not considered as possible solution. Or if the development concept has a NPV which is less than the required level then it is not considered as an alternative option.

Another way to simplify the selection process is to express them in money equivalent. For example the following criteria should be possible to turn into money equivalent:

- All cost & schedule criteria
- Risks of problems during well construction
- Availability of existing drilling facility
- Workover capability
- Power supply
- Level of autonomy
- Reliability and availability of equipment
- Prevention of flow assurance problems
- Complexity of maintenance
- Requirements to perform marine operations and possibility to perform them in short period
- Complexity of facility installation
- Complexity of facility decommissioning

- The necessity to extend the construction plant infrastructure or plant reconstruction
- The necessity to construct special floating structures
- Possibility to use the structure on other fields
- Possibility to maximize reuse of existing facility

Some of the criteria are possible to express in time equivalent also:

- Schedule for project execution
- Continuity of revenue stream
- Availability of existing drilling facility
- Ability to install several derricks on the structure
- Schedule for drilling
- Workover capability
- Complexity of facility installation
- Complexity of facility decommissioning
- The necessity to extend the construction plant infrastructure or plant reconstruction
- The necessity to construct special floating structures for construction assembly
- Possibility to maximize reuse of existing facility

Thus the more such connections will be established, the easier become the multi-objective problem. However, this list of important criteria could be a useful indication of what aspects should be considered during the concept selection stage for the Arctic development.

But due to complexity of this task – expression of all criteria in money and time equivalent, the proposed method is the experts' judgment method. The group of experts should not only give the weights to each criterion but distinguish alternative concepts according to the criteria or estimate how much the concept satisfies each criterion.

Then in order to choose the optimal development concept different decision making tools could be used. For example it could be the Analytical Hierarchy Process (AHP) as was used in paper [9].

For this purpose the master thesis's work could significantly contribute. Criteria ranking that were obtained from the experts judgment can be a useful indication of people from the industry's opinion. And it could be used either in addition to another experts' questioning or alone during the process of concept selection for the Arctic offshore field development.

10.1 Model development

Other results of the master thesis's work can be presented as a methodological tool for the selection of the development concept for the Arctic offshore field. This tool in the form of a model is shown on Figure 14.

The model represents the whole chain of the offshore project development which consists of two main parts as planning phase and execution phase.

The work of the thesis is concentrated on the planning phase, particularly on the concept phase of the project. Concept phase consists of two steps as concept screening and conceptual engineering and one approval point as concept selection.

This model represents a step by step approach for the implementation of the concept phase of the Arctic offshore project.

The first activity of the model consists of necessary input factors for the concept screening stage with comments about the parameters which should be known. These factors impose limiting conditions on the development concept. For example water depth sets bounds to production systems size, ice conditions sets bounds to the structure rigidity characteristics etc. Such limitations or effect on the development concept of each specific input factor are elaborated in the second activity of the model.

The third activity consists of identified criteria influencing the concept selection process i.e. criteria on the basis of which it is possible to compare technically feasible development concepts and choose the optimal one for the Arctic offshore field development.

Thus model includes each stage of an offshore projects concept development phase and represents factors influencing each of these stages as well as their effect on them.

It is supposed that this model could contribute for the Arctic offshore field development process.

10.2 Model limitations

The model represents a tool for identification and selection of the best development concept for an oil and gas offshore project in the Arctic. The model was developed on the basis of wide literature survey with all limitations that provide this quantitative method.

Concept selection criteria prioritizing were performed by the method of experts' judgment which also sets bounds on the gained data reliability level. We should be aware that few responses have been received from the experts' judgment so concluding strongly regarding the ranking of the different criteria should be avoided. The ranking discussed above could, however, be taken as a relevant indication for how the industry specialists judge the different criteria for concept selection.

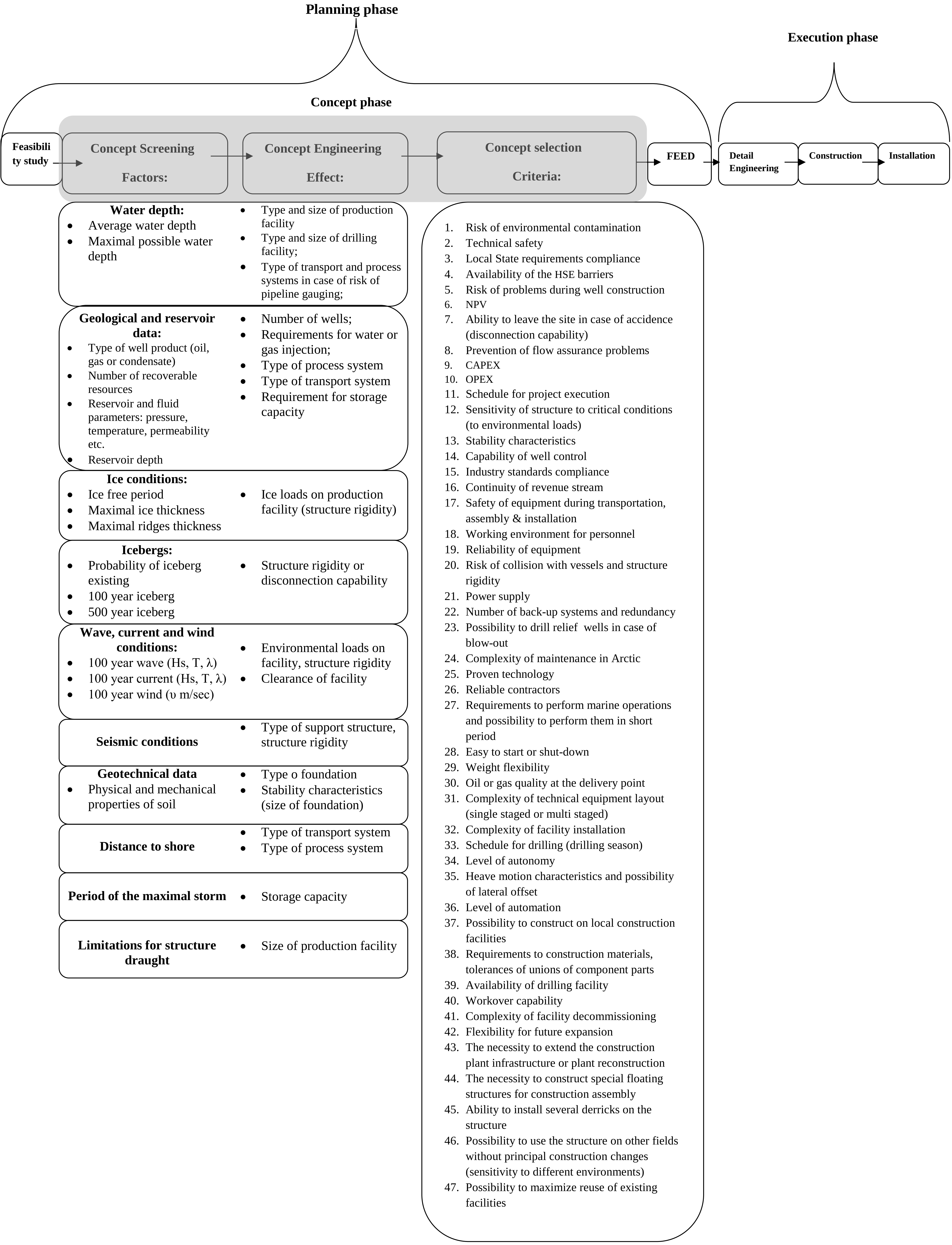


Figure 14. Methodological tool for the concept phase implementation of an offshore project development

11. Conclusions and further work

The present research appears to be one of a few theoretical studies of the Arctic offshore concept selection. It accounts for the specificity of a field located in the Arctic, whether it is located in ice-covered waters or in ice-free waters.

The research provides a comprehensive analysis of each stage of an offshore project's concept phase with respect to the Arctic continental shelf. It gives a list of factors that should drive the concept screening stage and conceptual engineering stage. Effect of each factor is considered and shown in the research.

Thereafter, an elaborating study of the concept selection stage of an Arctic offshore project is performed. The list of comparison criteria that should contribute to the concept selection stage is prepared on the basis of a wide literature survey. This list consists of the main issues that should be considered during the concept selection.

The conclusion that is made after the analysis of the criteria is that it is possible to distinguish them into several groups: comparison criteria, established limitations and necessary requirements.

The comparison criterion evaluates the characteristic of the project (e.g. is it easy to start and shut-down or not, is there capability of well control or not, what is the quality of the end product etc.)

The established limitations for the use of the criteria are supposed to exclude improper development concepts that do not meet requirements established by the Operator Company (e.g. NPV, CAPEX, technical safety, schedule, etc.).

The necessary requirements also should exclude inappropriate development concepts set by government (e.g. industry standard compliance, local authority requirements, etc.).

Thus establishing criteria where it is possible to exclude inappropriate development concepts could significantly simplify the multi-criteria problem of the optimal concept selection.

The experts' judgment method for ranking of criteria according to their importance in the concept selection process has been used. On-line questionnaire for criteria evaluation was prepared and sent to the experts. Unanimous opinion of people from the industry is that safety issues go before high profit. NPV or projects profit comes sixth after safety and regulations criteria. Of course it does not mean that unprofitable project would be more preferable than safe one, but it means that if a project has an average profit and high level of safety it would be more preferable for Arctic development than project with high profit and not sufficient level of safety. That is what experts' opinion expresses in the project. And this result very much reflects the main Arctic challenge as being the high environmental risk.

We should, however, be aware to use the experts' opinion in the thesis as the final authority of the truth due to the fact that few responses are obtained. The limited number of experts in the Arctic area and the short time available for the research did not allow making a wider observation of industry people's opinion. But the results from the experts' judgment about which criteria are the most important in the concept selection process could be a useful identification of what should be considered first and what aspects are obligated to be taken into account in the concept selection process of an Arctic offshore project.

The result of the master thesis is a methodological tool for the concept selection in the Arctic area. It includes all stages of the project's concept phase with necessary to know parameters, their effect on the concept selection and a ranked list of the criteria influencing the concept selection.

Based on the conclusions of the work some points for future work can be suggested:

- Simplification of the multi-criteria problem of the concept selection by differentiating them into several groups, as for example: necessary requirements, established limitations and comparison criteria, would contribute a lot to the concept selection process
- To increase the reliability of the data gained from the experts' judgments by asking more experts on Arctic field development
- Testing of the proposed model for the concept selection process on real Arctic offshore field developments would prove the method's efficiency and contribution
- The way to obtain the information about concepts' characteristics, according to the criteria, could be considered and analyzed more precisely in order to complete the methodology of the concept selection

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Appendix A Literature survey results

Table A.1. Standards survey

Date	Standard organization	Key words	Found relevant standards
19.03	NORSOK	Concept selection	NORSOK Standard Z-013
			NORSO Standard S-003
19.03	DNV standards		No relevant standards
19.03	API standards		No relevant standards
19.03	PSA standards		Regulations relating to Design and Outfitting of facilities etc. in the Petroleum Activities (the Facilities Regulations), Stavanger, Norway, 2005.
19.03	ISO standards		No relevant standards, however, ISO 19906, Arctic Offshore Structures should be consulted

Table A.2. Offshore Engineering Books Survey results

Name of book	Authors	Searching information	Found information
Engineering Aspects Related to Arctic Offshore Developments	Gudmestad, O.T. ,Loset, S., Alhimenko, A.I., Shkhinek, K.N. and Torum, A., Jensen A.	Concept selection Process	Reference to PSA standard Procedure of the Concept Development Phase
Arrangement and development of the oil and gas offshore fields	Vyakhirev, R.I., Nikitin, B.A. and Mirzoev, D.A.	Concept selection Process	Factors affecting the selection of hydrotechnical constructions; Methodology of selection of optimal ice-resistant platform
Oil and gas resources	Gudmestad, O.T., Zolotukhin, A.B. Jarlsby, E.T.	Concept selection process	Describing the whole procedure of Concept Development
Basics of Offshore Petroleum Engineering and Development of Marine Facilities	Gudmestad, O.T., Zolotukhin, A.B., Ermakov, A.I., Jakobsen, R.A., Mitchenko, I.T. Vovk, V.S., Loset, S. Shkhinek, K.N.	Concept selection Process	Factors For Platform Concept Development
Handbook of Offshore Engineering	Chakrabarti, S.K.	Concept selection Process	Multicriteria decision model for Offshore field concept selection

Table A.3. Databases survey results

Date	Database	Keywords	Found relevant papers
18.03	Onepetro	Concept selection Criteria	1. Feasibility Studies for Offshore Field development, Williams, L.M., Watt, B. [11]
			2. Best Practice in Arctic Development Concept selection - How to Avoid the Traps , Mol, C. Paulin, M., Sturge, A. [13]
			3. Platform Design For Arctic Shallow Waters, Livshyts, R.B., Lenskiy, V.F., Nesin, D.Y. [14]
			4. Concept selection and Global Sizing of the Mars TLP, Larrabee, R. D., Hodges, S. B., Cox, B. E., Gonzalez, R. [15]
			5. Selection of Environmental Criteria for Offshore Platform Design, Bea, R.G.[16]
			6. Agbami Field Development Concept selection: Evaluating Facility and Field Development Alternatives in an Environment of Significant Subsurface Uncertainty, Reynolds, K.C et al. [17]
18.03	Onepetro	Concept Development criteria	1. Identification And Evaluation of RAMS+I Factors Affecting the Value-Added By Different Offshore Wind Turbine Concepts In Nordic Context, Tiusanen R., Jännes J. and Liyanage, J. P.,, University of Stavanger [18]
			2. Use of Economic Measures as the Criteria for Optimizing Functional Blocks and the Selection of Development Concepts, Holsen, M. et al. [19]
			3. The Heidrun TLP And Concept Development For Deep Water, Munkejord, T. [20]
			4. The Development and Use of Risk Acceptance Criteria for the Construction Phases of the Karsto Development Project in Norway, Berg, F.R. [21]
			5. The Fundamental Issues in Future Field Development Concepts, Wray, C.R. [22]
18.03	Scopus	Offshore Concept selection Criteria	1. Mapping factors influencing the selection of subsea petroleum production systems: A case study, Moreno-Trejo, J., Kumar, R., Markeset, T. [23]
			2. A review on offshore concepts and feasibility study considerations, Maddahi, M., Mortazavi, S.J. [24]
			3. Factors influencing the design of shallow water minimal offshore structures, Datta, B., Cortez, A.J., Zwiebel, K. [25]
			4. Design considerations for concrete offshore platforms subjected to iceberg impact loads, Zaleski-Zamenhof, L.C., Rojansky, M.[26]
19.03	Google Scholar	Offshore Concept selection Criteria	1. Optimizing Field Development Concepts for Complex Offshore Production Systems, Cullick, A.S. et al. [27]
19.03	WoodMackenzie	Concept selection Criteria	No relevant papers

Appendix B Questionnaire

Criteria for Arctic Offshore Concept Selection

Dear Sir or Madam!

This questionnaire is prepared as a part of a Master Thesis with the topic "Criteria Influencing Arctic Offshore Concept Selection".

The objective is to identify all criteria influencing the concept selection process for Arctic conditions and rank them according to their importance. These criteria were sorted on the basis of literature survey and input from supervisors.

The identified criteria are supposed to be used after completion of feasibility stage of Offshore Field Development Project, i.e. after consideration of the factors such as: water depth, type of product, reservoir conditions, distance to shore, ice and wave loads, icebergs, geotechnical conditions, water and gas injection requirements etc.

For example, we have to compare three different technically feasible concepts, all of them are possible to execute for the specific field from the technical point of view; But there are other factors/criteria, which affect decision-making.
In such case we should compare these concepts according to other criteria that were identified in the Master Thesis, and listed in this questionnaire to be prioritized.

Please evaluate the criteria according to your knowledge area and work experience by the following scale: 1 - Not Important at All, 2 -Slightly Important, 3 - Moderately Important, 4 - Very important, 5 - Absolutely Critical.

If you think that some of the questions are out of your area of expertise, you can skip them.

Faculty Supervisor at University of Stavanger - Professor O.T.Gudmestad.
Faculty Supervisor at Russian State University of oil and gas - A.B.Zolotukhin.
External Supervisor at AkerSolutions - Ali Mcniri.

Thank you for taking time to fill out this questionnaire. The survey results will be applied for research purposes.

Kind regards,
Tatiana Gordeeva
Master Student at the University of Stavanger and Gubkin Russian State University of Oil and Gas

Figure B. 1 Questionnaire

INFORMATION ABOUT RESPONDENT

Please mention your position / area of expertise

Please mention how many years of work experience in Oil & Gas industry do you have?

Please mention you nationality

Figure B. 2 Questionnaire

0. GENERAL OVERVIEW OF CRITERIA CATEGORIES FOR ARCTIC OFFSHORE CONCEPT SELECTION

(1 - Not Important at All, 2 -Slightly Important, 3 - Moderately Important, 4 - Very important, 5 - Absolutely Critical)

	1	2	3	4	5
1. Cost & Schedule Criteria (CAPEX, OPEX, Schedule for execution etc.)	○	○	○	○	○
2. Safety Criteria (safety for personnel and environment)	○	○	○	○	○
3. Working Environment Criteria	○	○	○	○	○
4. Drilling Criteria (reliability of drilling, schedule, number of rigs on platform etc.)	○	○	○	○	○
5. Operability Criteria (easy to control wells, autonomy level etc.)	○	○	○	○	○
6. Reliability Criteria (easy to maintain, number of back-ups, flow assurance problems etc.)	○	○	○	○	○
7. Transportation, Assembly & Installation Criteria (difficulties in these processes)	○	○	○	○	○
8. Fabrication Criteria (difficulties in construction of facility, special floatings etc.)	○	○	○	○	○
9. Flexibility of Production System Criteria (in case of future expansion of field or facility)	○	○	○	○	○
10. Government Regulations Criteria (local state requirements, standards)	○	○	○	○	○

Please add any comments if appropriate

Figure B. 3 Questionnaire

1. COST & SCHEDULE CRITERIA FOR ARCTIC OFFSHORE CONCEPT SELECTION

(1 - Not Important at All, 2 -Slightly Important, 3 - Moderately Important, 4 - Very important, 5 - Absolutely Critical)

	1	2	3	4	5
1.1 CAPEX (Capital Expenditures)	○	○	○	○	○
1.2 OPEX (Operating Expenditures)	○	○	○	○	○
1.3 NPV (Net Present Value)	○	○	○	○	○
1.4 Continuity of revenue stream (without any longtime delays of cash flow)	○	○	○	○	○
1.5 Schedule for project execution	○	○	○	○	○

Please add any comments if appropriate

Figure B. 4 Questionnaire

2. SAFETY CRITERIA FOR ARCTIC OFFSHORE CONCEPT SELECTION

(1 - Not Important at All, 2 -Slightly Important, 3 - Moderately Important, 4 - Very important, 5 - Absolutely Critical)

	1	2	3	4	5
2.1 Risk of environmental contamination	○	○	○	○	○
2.2 Possibility to drill relief wells in case of blow-out	○	○	○	○	○
2.3 Risk of collision with vessels and structure rigidity characteristics	○	○	○	○	○
2.4 Stability characteristics (for platforms or floating structures)	○	○	○	○	○
2.5 Proven technology (reference case)	○	○	○	○	○
2.6 Sensitivity of structure to critical environmental loads (ice, waves, wind etc.)	○	○	○	○	○
2.7 Ability to leave the site in case of accidence (disconnection capability)	○	○	○	○	○
2.8 Availability of HSE barriers (e.g. safety boats)	○	○	○	○	○
2.9 Technical safety	○	○	○	○	○

Please add any comments if appropriate

Figure B. 5 Questionnaire

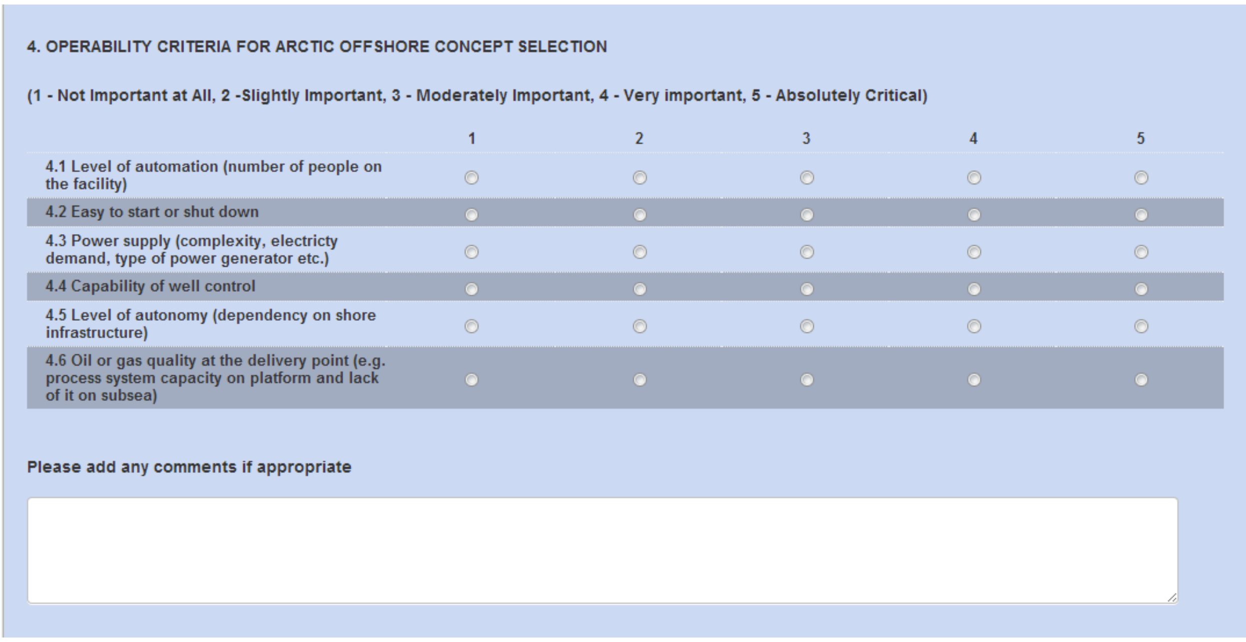
3. DRILLING CHARACTERISTICS FOR ARCTIC OFFSHORE CONCEPT SELECTION

(1 - Not Important at All, 2 -Slightly Important, 3 - Moderately Important, 4 - Very important, 5 - Absolutely Critical)

	1	2	3	4	5
3.1 Risks during well construction	○	○	○	○	○
3.2 Availability of drilling facility (e.g. drilling platform for that conditions is already constructed and available)	○	○	○	○	○
3.3 Ability to install several derricks on the structure	○	○	○	○	○
3.4 Schedule for drilling (ice-free period is short)	○	○	○	○	○
3.5 Workover capability (e.g. rig is installed on the production platform)	○	○	○	○	○
3.6 Heave motion characteristics and possibility of lateral offset for drilling facility	○	○	○	○	○

Please add any comments if appropriate

Figure B. 6 Questionnaire



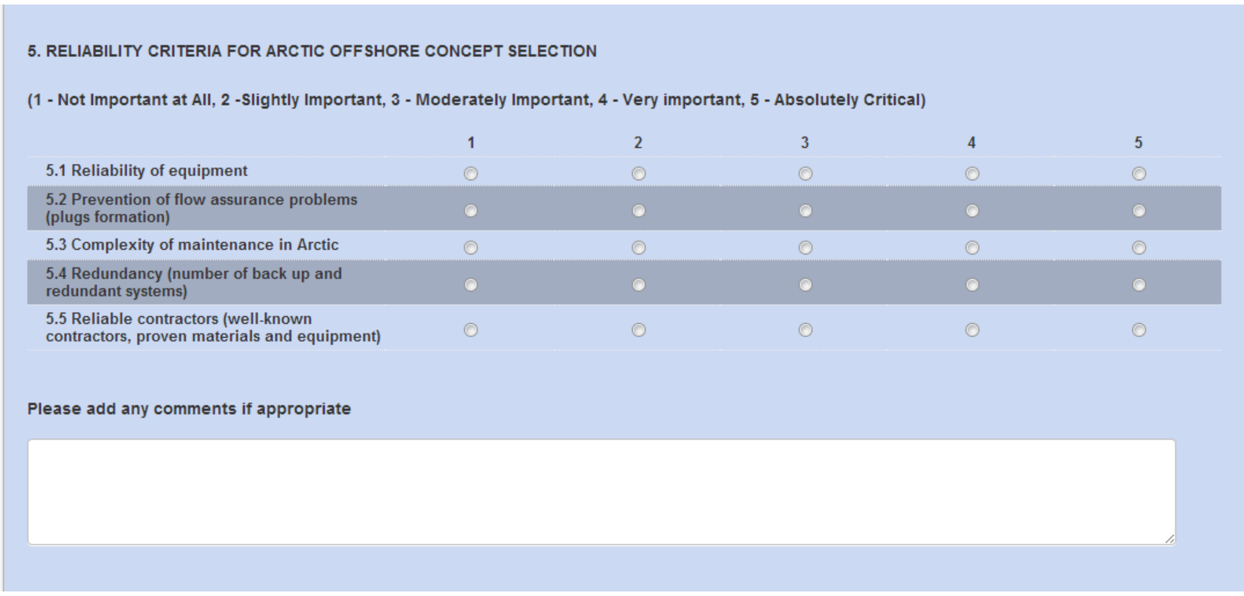
4. OPERABILITY CRITERIA FOR ARCTIC OFFSHORE CONCEPT SELECTION

(1 - Not Important at All, 2 -Slightly Important, 3 - Moderately Important, 4 - Very important, 5 - Absolutely Critical)

	1	2	3	4	5
4.1 Level of automation (number of people on the facility)					
4.2 Easy to start or shut down					
4.3 Power supply (complexity, electricty demand, type of power generator etc.)					
4.4 Capability of well control					
4.5 Level of autonomy (dependency on shore infrastructure)					
4.6 Oil or gas quality at the delivery point (e.g. process system capacity on platform and lack of it on subsea)					

Please add any comments if appropriate

Figure B. 7 Questionnaire



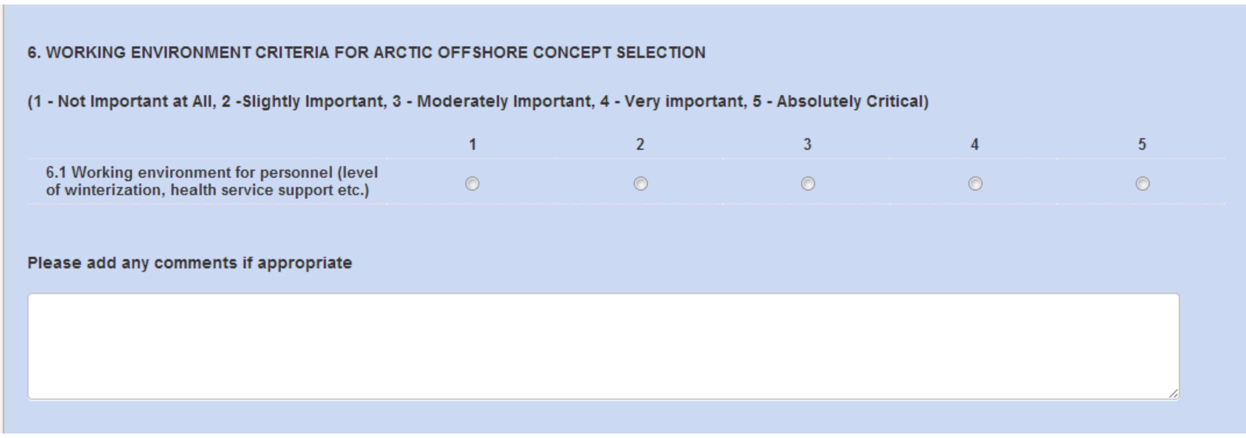
5. RELIABILITY CRITERIA FOR ARCTIC OFFSHORE CONCEPT SELECTION

(1 - Not Important at All, 2 -Slightly Important, 3 - Moderately Important, 4 - Very important, 5 - Absolutely Critical)

	1	2	3	4	5
5.1 Reliability of equipment					
5.2 Prevention of flow assurance problems (plugs formation)					
5.3 Complexity of maintenance in Arctic					
5.4 Redundancy (number of back up and redundant systems)					
5.5 Reliable contractors (well-known contractors, proven materials and equipment)					

Please add any comments if appropriate

Figure B. 8 Questionnaire



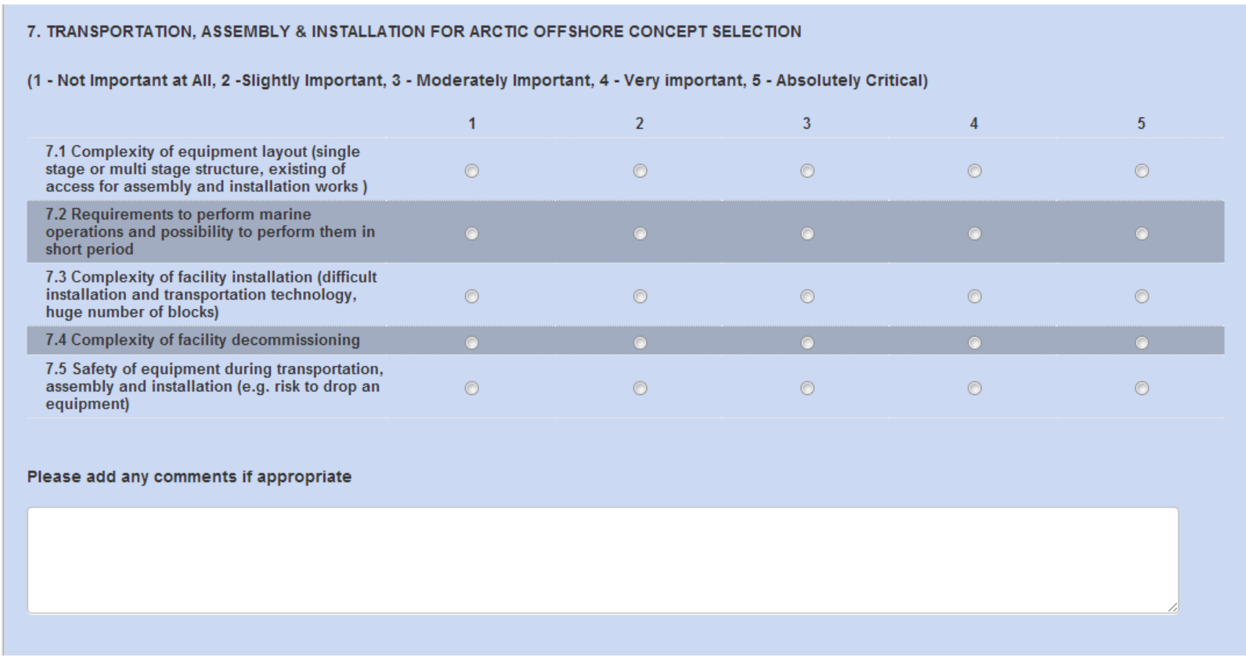
6. WORKING ENVIRONMENT CRITERIA FOR ARCTIC OFFSHORE CONCEPT SELECTION

(1 - Not Important at All, 2 -Slightly Important, 3 - Moderately Important, 4 - Very important, 5 - Absolutely Critical)

	1	2	3	4	5
6.1 Working environment for personnel (level of winterization, health service support etc.)					

Please add any comments if appropriate

Figure B. 9 Questionnaire



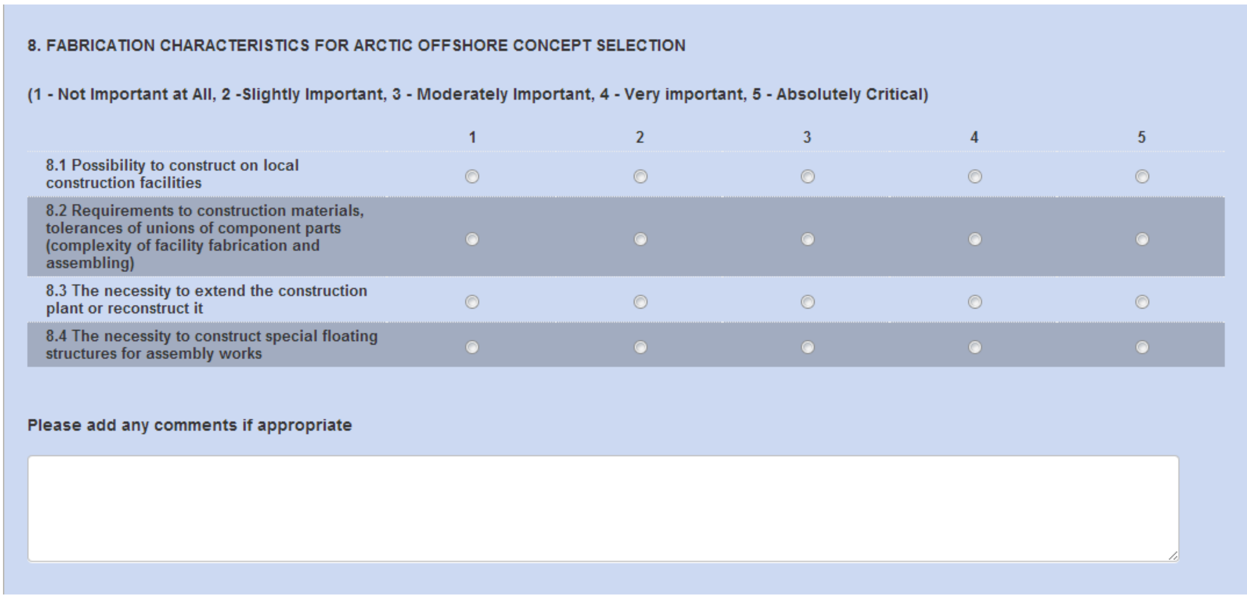
7. TRANSPORTATION, ASSEMBLY & INSTALLATION FOR ARCTIC OFFSHORE CONCEPT SELECTION

(1 - Not Important at All, 2 -Slightly Important, 3 - Moderately Important, 4 - Very important, 5 - Absolutely Critical)

	1	2	3	4	5
7.1 Complexity of equipment layout (single stage or multi stage structure, existing of access for assembly and installation works)	○	○	○	○	○
7.2 Requirements to perform marine operations and possibility to perform them in short period	○	○	○	○	○
7.3 Complexity of facility installation (difficult installation and transportation technology, huge number of blocks)	○	○	○	○	○
7.4 Complexity of facility decommissioning	○	○	○	○	○
7.5 Safety of equipment during transportation, assembly and installation (e.g. risk to drop an equipment)	○	○	○	○	○

Please add any comments if appropriate

Figure B. 10 Questionnaire



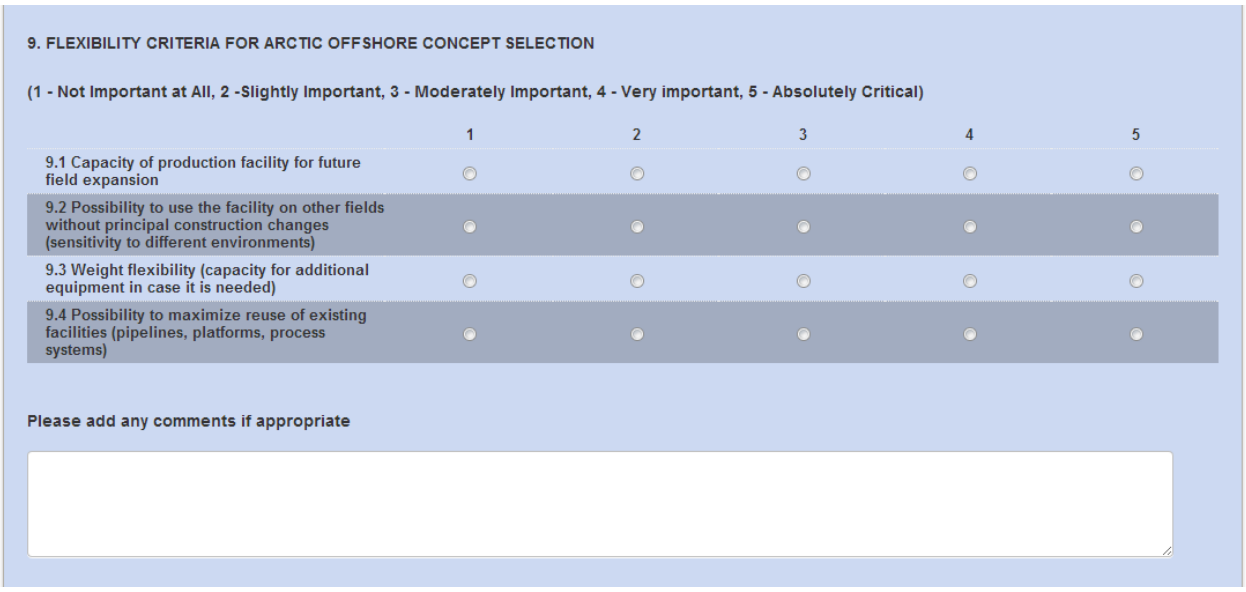
8. FABRICATION CHARACTERISTICS FOR ARCTIC OFFSHORE CONCEPT SELECTION

(1 - Not Important at All, 2 -Slightly Important, 3 - Moderately Important, 4 - Very important, 5 - Absolutely Critical)

	1	2	3	4	5
8.1 Possibility to construct on local construction facilities	○	○	○	○	○
8.2 Requirements to construction materials, tolerances of unions of component parts (complexity of facility fabrication and assembling)	○	○	○	○	○
8.3 The necessity to extend the construction plant or reconstruct it	○	○	○	○	○
8.4 The necessity to construct special floating structures for assembly works	○	○	○	○	○

Please add any comments if appropriate

Figure B. 11 Questionnaire



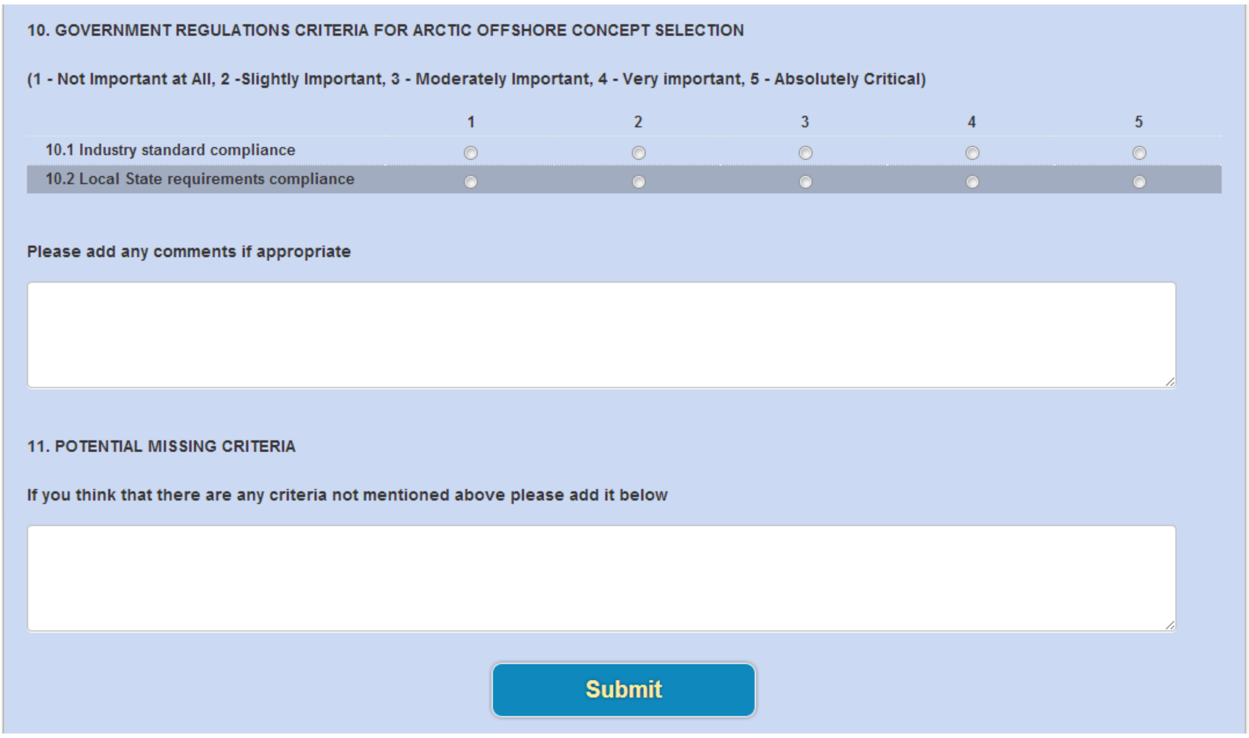
9. FLEXIBILITY CRITERIA FOR ARCTIC OFFSHORE CONCEPT SELECTION

(1 - Not Important at All, 2 -Slightly Important, 3 - Moderately Important, 4 - Very important, 5 - Absolutely Critical)

	1	2	3	4	5
9.1 Capacity of production facility for future field expansion					
9.2 Possibility to use the facility on other fields without principal construction changes (sensitivity to different environments)					
9.3 Weight flexibility (capacity for additional equipment in case it is needed)					
9.4 Possibility to maximize reuse of existing facilities (pipelines, platforms, process systems)					

Please add any comments if appropriate

Figure B. 12 Questionnaire



10. GOVERNMENT REGULATIONS CRITERIA FOR ARCTIC OFFSHORE CONCEPT SELECTION

(1 - Not Important at All, 2 -Slightly Important, 3 - Moderately Important, 4 - Very important, 5 - Absolutely Critical)

	1	2	3	4	5
10.1 Industry standard compliance					
10.2 Local State requirements compliance					

Please add any comments if appropriate

11. POTENTIAL MISSING CRITERIA

If you think that there are any criteria not mentioned above please add it below

Submit

Figure B. 13 Questionnaire