

# Optimization of Technical and Technological Solutions for the Development of Offshore Hydrocarbon Fields in the Kaliningrad Region

Pavel Shcherban, Viktoria Ivanova, Alexander Neprokin, Vladislav Golovanov

**Abstract**—Currently, LLC «Lukoil-Kaliningradmorneft» is implementing a comprehensive program for the development of offshore fields of the Kaliningrad region. This is largely associated with the depletion of the resource base of land in the region, as well as the positive results of geological investigation surrounding the Baltic Sea area and the data on the volume of hydrocarbon recovery from a single offshore field are working on the Kaliningrad region – D-6 «Kravtsovskoye». The article analyzes the main stages of the LLC «Lukoil-Kaliningradmorneft»'s development program for the development of the hydrocarbon resources of the region's shelf and suggests an optimization algorithm that allows managing a multi-criteria process of development of shelf deposits. The algorithm is formed on the basis of the problem of sequential decision making, which is a section of dynamic programming. Application of the algorithm during the consolidation of the initial data, the elaboration of project documentation, the further exploration and development of offshore fields will allow to optimize the complex of technical and technological solutions and increase the economic efficiency of the field development project implemented by LLC «Lukoil-Kaliningradmorneft».

**Keywords**—Offshore fields of hydrocarbons of the Baltic Sea, Development of offshore oil and gas fields, Optimization of the field development scheme, Solution of multi-criteria tasks in the oil and gas complex, Quality management of technical and technological processes.

## I. INTRODUCTION

THE development of the hydrocarbon resources of the Kaliningrad region's shelf has moved to the active phase since 2004 when LLC «Lukoil-Kaliningradmorneft» started development of the D-6 «Kravtsovskoye» field. During 2000 - 2015, a complex of geophysical studies was carried out in the coastal zone of the Kaliningrad region. It was found about 15 structures that are promising for hydrocarbon reserves. In 2015-2016 out of all the structures, were identified: D-2, D-9, D-18, D-19, D-29, D-41 и D-6 (southern) (as shown in Fig. 1).

From 2015 to the present, exploration and design works are underway to develop hydrocarbon reserves of these fields. Thus, LLC «Lukoil-Kaliningradmorneft» received

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comprehensive state licenses for geological exploration, exploration and development of these fields. As a result, structures D-33, D-29 and D-41 were approved and placed on the hydrocarbon reserves state balance [2]. In parallel with the work on geological exploration, the engineering-geological and engineering-ecological surveys were carried out, as well as the pre-design work and the analysis of the options for developing the studied structures.

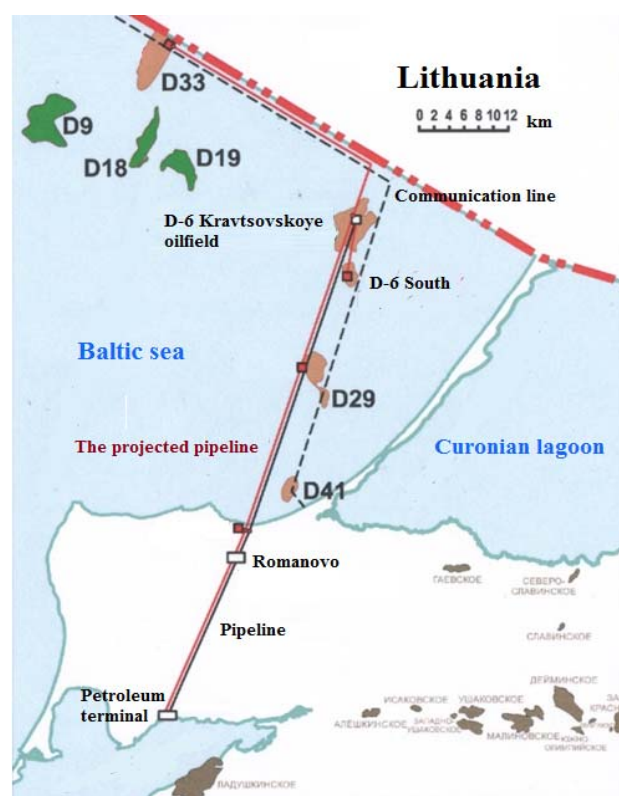


Fig. 1 Deposits of hydrocarbons on the shelf of the Kaliningrad region and the existing infrastructure

As of 2018, additional exploration works are being carried out; projects of stage-by-stage development of deposits are being developed [4]. In the period from 2020 to 2025 it is planned to put into operation 3 oilfields: D-2, D-33, and D-41. In the article presented, we will consider a number of approaches that allow us to form a comprehensive algorithm for managing processes of design and construction of infrastructure for the development of these oilfields.

In connection with to the multi-factorial process and multi-

criteria selection of optimal solutions for the development of offshore, it seems reasonable to construct an algorithm based on the problem of sequential decision making. In order to formulate the conditions of the problem, as well as the main limiting values, it is necessary to decompose it into stages, since for each of them will have its own set of initial data, operating factors, control values and, as a result, the desired optimum [5].

Consequently, we will decompose the whole process of development of oilfields into stages, as well as decomposition and stratification of data in stages. This will allow us to formulate the basic requirements for each of the stages of the optimization problem being solved.

## II. ANALYSIS OF THE MAIN STAGES OF DEVELOPMENT OF THE OFFSHORE HYDROCARBON FIELDS OF THE KALININGRAD REGION

The breakdown of the development of offshore hydrocarbon reserves in the Kaliningrad region can be conditionally carried out in the following main stages:

- A. The stage of geological exploration and approval of reserves of deposits;
- B. Development of a project for work off and development of a field;
- C. Collection of baseline data for the water area under development;
- D. Development of project documentation for field infrastructure;
- E. Development of an environmental impact assessment;
- F. Arrangements for tenders for the manufacture and supply

- G. Delivery of equipment;
- H. Offshore equipment installation and testing;
- I. Drilling, transition to mining;
- J. Field acceptance in operation.

At each stage, the project is affected by a significant number of external factors. In many ways, the rational management of these factors and correcting the initial values and goals allows us to implement the project of development of these oilfields. It should also be noted that in most cases the design and survey work to reduce the time spent become parallel. The project on the development of hydrocarbon deposits on the shelf of the Kaliningrad region is no exception [6].

As a result, in the temporal plan, there is, as it were, the imposition of one stage on another. Reduction of time costs in this case is partially offset by the inaccuracy of the data, the need to make adjustments as they become available in the project documentation, and an increased probability of errors.

Despite this, existing forms of state reporting in the Russian Federation (setting fields in the State Reserves Balance, obtaining positive expert opinions, including sanitary and epidemiological conclusions, the passage of the project of public hearings and the main state expertise) indicate the existence of so-called "reference points" or "optimum points by stage". That is, in this case, we can talk about specific indicators of the optimality of the result for a particular stage. In Table I, we represent the groups of optimal solutions for each of the stages, as well as the result of implementing these solutions [10], [14].

TABLE I  
OPTIMAL SOLUTIONS AND THE RESULTS OF THE STAGE OF DEVELOPMENT OF HYDROCARBON DEPOSITS ON THE SHELF OF THE KALININGRAD REGION

Stage	The optimal solution for the stage	Result
A	The most accurate determination of general geological and recoverable hydrocarbon reserves in the Kaliningrad shelf offshore fields with the establishment of the entire complex of properties of both fluid and host rocks with the least amount of time and financial costs.	Approval of the reserves of the deposit, staging on the state balance sheet.
B	Maximization of hydrocarbon extraction from deposits at a rational level of costs.	Approval of the development project.
C	Obtaining an accurate data set for each of the parameters.	Approval of reports on information data.
D	Rational use of existing infrastructure, technologically and logistically weighted placement of objects, compliance of technical parameters of objects with regulatory requirements.	Formation Technical and Economic Justification, Banking FS. Approval of the project by the main state expertise.
E	Minimizing the possible negative impact, reducing the risk of emergency situations.	Holding public hearings. Receiving approval from the services.
F	Availability of responsible suppliers. Optimal price-quality ratio of materials and equipment.	Obtaining high-quality materials and equipment in time.
G	Short transport shoulder. Absence or minimization of customs barriers. The minimum period of equipment stay in the warehouse.	
H	Reduction of the negative impact of the external environment. Compliance with the installation technology. Minimizing the probability of emergencies. Carrying out a complex of tests.	Correspondence of the infrastructure and installations of the developed design documentation.
I	Drilling operations in accordance with the requirements of normative and technical documentation and regulations. Application of the simulated mining system. In the presence of process variations prompt the adjustment.	Production of hydrocarbon fluid with expected quality and debit. Maintenance of production rates within the project in time.
J	Preparation and quality control of the final technical documentation. Finalizing the documentation. Capitalization of objects.	The act of commissioning. Registration in the register of hazardous production facilities.

It should be noted that alternative (mutually exclusive) solutions can be formed at each of the stages of the implementation of projects for development of the oil and gas fields of the shelf, depending on the entire set of initial data

and the pursued objective. These options are evaluated through an integrated assessment of the quality of decisions.

There are two options for making a decision within each of the stages: through the person making the decision (PMD) -

option, or through a collegial decision (CMD) - option. As a rule, both decision schemes are applied at different levels within each of the stages. The decision is valid if it satisfies all the constraints imposed on the functions under consideration by stage. The decision is optimal (best) if it is at the extremum of the desired function [1].

The generalized characteristic of each of the solutions for the stage is the efficiency, which is determined through the effect of the solution and the cost of implementing the solution.

Speaking about the implementation of projects to develop the offshore hydrocarbon fields in the Kaliningrad region, it is important to note that LLC «Lukoil-Kaliningradmorneft» completed the stage of geological exploration and approval of reserves at a number of fields. At the present time, calculations and simulations of optimal schemes for field development, baseline data collection and infrastructure layout are carried out in parallel. In the case of the collection of input data or the development of a field development project, there is no particular difficulty in view of the existence of a basic example of a previously discovered and refined D-6 oilfield, but there are a large number of options for infrastructure deployment [3]. Let us consider them in more detail.

### III. INFRASTRUCTURAL AND TECHNOLOGICAL SOLUTIONS FOR THE DEVELOPMENT OF HYDROCARBON DEPOSITS OF THE BALTIC SHELF

The main construction used in the development of offshore fields is a mining device (conductor block, platform or subsea production system), drilling rig (fixed or floating) and pipeline. Consider all the designs that can be used in the development of the Kaliningrad shelf. LLC «Lukoil-KMN», in its concept of shelf development, proposes several options for the development of deposits using various devices, as well as various schemes for the construction of communication and transport infrastructure. Thus, 4 main variants of the general arrangement of the shelf and 6 variants of detailed development with use of various technical solutions of all explored deposits of hydrocarbons of the shelf of the Baltic Sea are considered. The main options for the development of the Kaliningrad shelf are presented in block diagrams that illustrate various communication and transport options for the development of the shelf as a single conceptual project in which all fields are involved. In these variants existing infrastructure complexes, projected objects of the first phase, future projected objects, pipelines, as well as other communication objects are represented [4].

Fig. 2 presents two versions of the concepts under consideration. From the objects represented in the block diagrams, the primary development areas are the D-41, D-33, D6-southern and D-29 fields. Structures D-2, D-8, D-18 and D-19 have a secondary status of importance at this stage of shelf development. Conventionally, the concept can be divided into 3 separate structures of the complex in close proximity to each other: cluster D-6 (D-6 distribution platform, D-6 (southern), D-29), cluster D-41 (D-41, reconstruction of oil gathering point Romanovo) and cluster

D-33 (D-33, D-2, D-8, D-18 and D-19). The D-33 cluster has in its structure not one field, and the D-33 deposit itself is its largest component, therefore, LLC «Lukoil-KMN» offers to install the control platform here.

This platform will control production not only on the D-33 structure, but also on all other fields. The objects are planned to be connected using umbilicals, and transport of hydrocarbons via pipelines from structures D-2, D-8, D-18 and D-19 to structure D33. The control platform D-33 will receive electricity from the existing power plant located on the territory of the Kaliningrad region. Further transport of products takes place on the distribution platform D-6. This platform is a kind of collection point for products from D-33 and D-6 (southern) for subsequent transportation along the old, already built main pipeline to land via D-6 to the oil gathering point Romanovo [5].

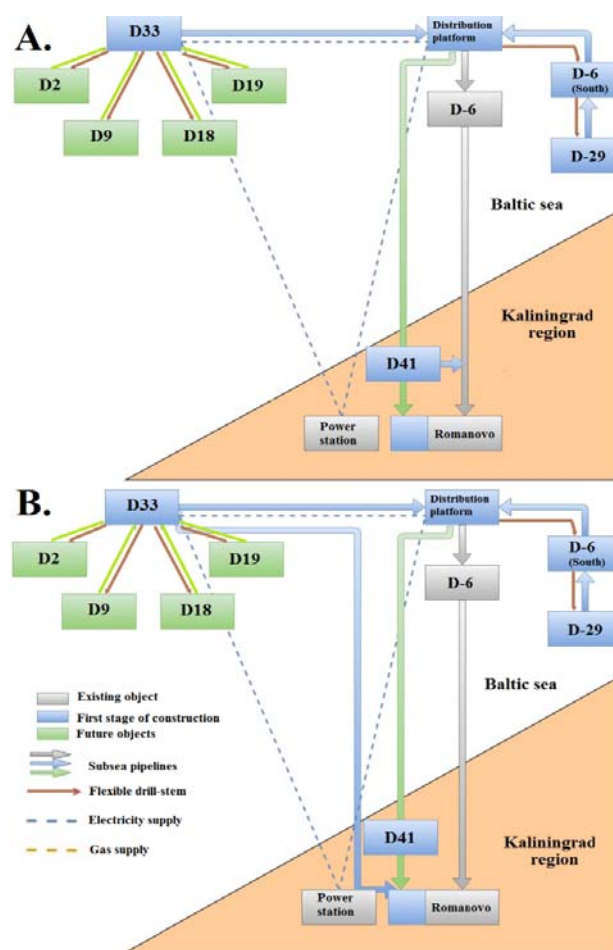


Fig. 2 Variants A and B of the location of infrastructure facilities in the development of the Kaliningrad region

The D-6 cluster includes both existing infrastructure facilities and new designed ones. The new facilities are the distribution platform D-6, D-6 (southern) and D-29. The distribution platform is used exclusively for preparing and transporting the extracted raw materials. D-6 (south) and D-29 are connected in series to the distribution platform. Transport of produced hydrocarbon products is also carried out

sequentially through the pipeline from D-29 to D-6 (southern) and D-6. The source of electricity will be the existing power plant located on the territory of the Kaliningrad region. Further transportation is carried out via the existing pipeline from D6 to the oil gathering point Romanovo.

The D-41 cluster includes a single deposit, but it also includes the reconstruction of the oil gathering point Romanovo, which is necessary for the implementation of this project. The development of the D-41 structure is planned from the land by drilling five wells with a deviation in the horizontal projection. The depth of the wells will be more than 8 km, the deviation from the vertical of about 6 km and the length of the horizontal wellbore - 1-1.7 km. This is reflected in all the presented variants of hydrocarbon field development concepts. To drill this field, a drilling rig in a marine version with a load capacity of at least 650 tons is used. In the future, this drilling is planned to be used to drill wells on the D-33 structure, which will reduce costs when developing this project [5], [6].

The general concept of variant A differs from the concept of variant B in only one single addition. It implies a direct connection of the D-33 cluster with a pipeline to the oil gathering point Romanovo but does not exclude the construction of a pipeline to the D-6 cluster. This solution will increase the maximum volume of transported hydrocarbon products, as well as reduce the wear of pipelines and provide an opportunity to have an alternate route for transporting hydrocarbon products. This is a significant advantage in the event of accidents or overhaul requiring a complete stop of operation of the existing pipeline before the construction of a new parallel threads pipeline scheduled for a later period, and only in the case of development of structures D-2, D-8, D-18 and D-19.

Variants of the location of mining and transport infrastructure C and D, shown in Fig. 3, are clearly different from the previous ones. In these concepts on the D-33 cluster, the SFO vessel (Floating, Storage and Offloading Vessel) is also used to store and ship oil.

In version C, the vessel is used exclusively as a source of additional transport without the exception of the pipeline. However, since the ship can only transport crude oil, a gas pipeline from the D-33 to the oil gathering point Romanovo is envisaged [4].

Elimination of costs for the construction of the pipeline from D-33 to D-6 is presented in the overall concept reflected in option D. In this case, all the products are delivered to the ship via a gas pipeline, and oil products are transported to the D-6 distribution platform via the oil pipeline. However, and this time the company wasn't able to avoid the complete exclusion of the costs for the construction of the pipeline. In total there are approximately 70 vessels of this class in the world, all produced by foreign manufacturers, and the price of each vessel starts from 800 million dollars.

Therefore, options C and D using the SFO vessel are not only economically inexpedient, but also contradict the state's policy of import substitution of foreign technologies in the oil and gas sector. When studying the basic concept of B, one

should pay close attention to the fact that the development of the D-29 field is likely to be frozen due to unsatisfactory data after additional exploratory drilling at the field and transferred to future development projects of the shelf of the Baltic Sea. As a result, option A should be considered the main one at this stage in view of its universality, economic efficiency, logicity and the possibility for further development of offshore oilfields.

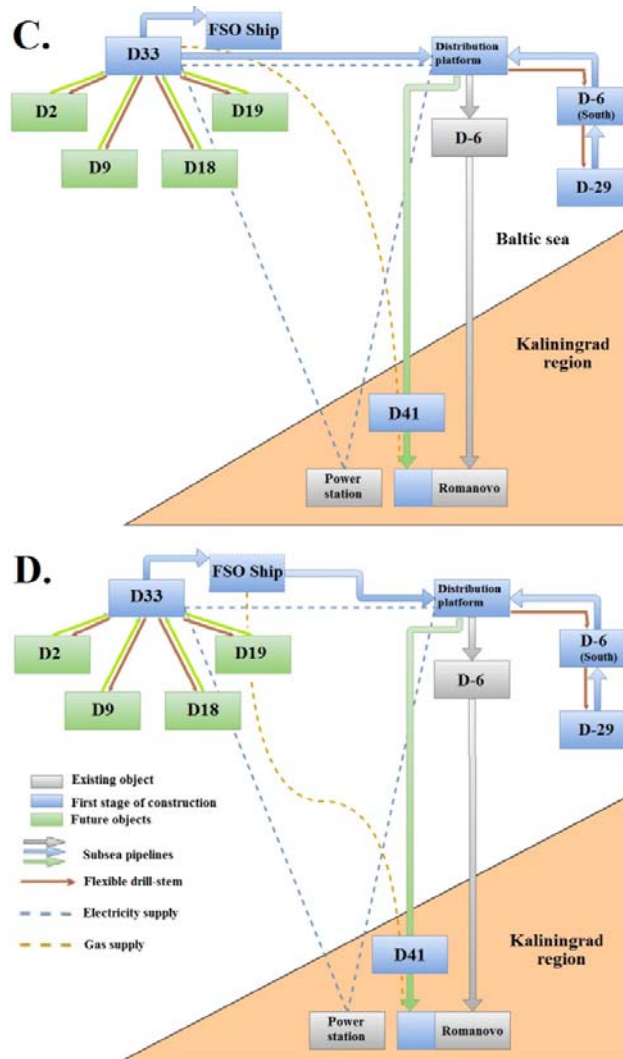


Fig. 3 Variants C and D of the location of infrastructure facilities in the development of the Kaliningrad region

The illustrated infrastructure solutions are a detailed analysis of the stages B, C and D, which were previously presented in Table I in the development of the offshore fields of the Kaliningrad Region. At each of these stages, decision making is limited to a set of parameters and factors. The definition of boundary values for each of these parameters is mandatory to prevent malfunctions and failures in the implementation of the project.



#### IV. EXAMPLES OF DETERMINING THE INITIAL BOUNDARY VALUES AND PARAMETERS FOR CONSTRUCTING AN ALGORITHM FOR OPTIMIZING SUBSEQUENT STAGES OF DEVELOPMENT OF OILFIELDS

As it was noted earlier, the problem of optimization of technological and technical solutions at each stage largely depends on the determined boundary values of the system parameters by the stage. These boundary values delineate the so-called "optimum state zone" of the process. Within this zone, the implementation of the work is possible and does not lead to negative consequences for the project as a whole, outside of this zone, the influence of factors / parameters is added in such a way that the system either immediately fails or runs the mechanism of accumulation of errors and failures, leading subsequently to the failure of the system as a whole. In this case, the system is understood as the whole complex of engineering structures for the development of hydrocarbon deposits in the Baltic shelf, as well as the technological processes that ensure its functioning.

Let's consider both situations of parameter exit beyond the "optimal zone" zone when developing oilfields on the shelf. A vivid example of a sharp malfunction may be the incorrect selection of drilling fluid parameters and drilling regimes, resulting in a drastic increase in the risk of oil-gas-water manifestations and open flowing as a result of environmental pollution and the risk of fire [13].

An example of a gradual malfunction may be incorrect selection of installation and assembling parameters of the pipeline system. As a result, in the underwater pipeline may occur gradually voltage portions with an increased rate of deterioration of corrosion, cracks and eventually disruptions. As can be seen from the presented examples, violation of the boundary values of the system during any stage of its development and functioning can result in fatal consequences.

From the mathematical point of view, the process of functioning and development of the system (development of the hydrocarbon resources of the region's shelf) can be imagined as a complex motion of a point in a multidimensional space with a whole range of limiting values and tolerance zones [7].

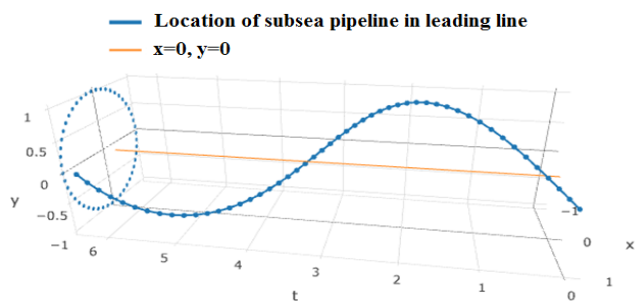


Fig. 4 Simulation of the position of the underwater oil pipeline whip with respect to the boundary values of the track alignment

To increase the accuracy and speed of decisions at each of the selected stages (as shown in Table I), it is necessary to identify the most critical processes, establish tolerance zones

and carry out a comprehensive control over their implementation in time.

So, for example, we will present a graph reflecting the process of laying an underwater oil pipeline to new deposits. One of the leading parameters in the process of pipeline laying is the accuracy of getting into the target of the route. The boundary value is the boundary of

the tolerance zone for the deviation from the track alignment. As a result, the following picture can be obtained in dynamics (as shown in Fig. 4).

Summarizing the above provisions, we can say that within each of the identified stages of project development (as shown in Table I), a set of differential equations describing the main critical processes along the stage and their boundary values should be created [7], [12].

The more detailed this complex will be, the lower is the failure risk. In the article it is impossible to display sets of equations for each stage, but as an example of creating a system of differential equations, we take the previously mentioned process of laying an underwater oil pipeline. So, the process (graphically presented in Fig. 4) in a formalized form can be displayed as:

$$\begin{cases} \int_{-\infty}^{\infty} \delta(x - x_i) dx = 1; \\ \int_{-\infty}^{\infty} f(x) \delta(x - x_i) dx = f(x_i); \\ \int_{-\infty}^{\infty} f(x) \delta'(x - x_i) dx = -f'(x_i); \end{cases} \quad (1)$$

where:  $x_1, x_2, \dots, x_6$  – horizontal coordinates (abscissa) of the location of pipelayers vessels at the initial time  $t = 0$ ;  $\delta(x - x_i)$  - delta function.

$$\delta(x - x_i) = \begin{cases} 0, & x \neq x_i \\ \infty, & x = x_i \end{cases} \quad (2)$$

Solving presented system, it is possible to obtain the equation of oscillations of the laid offshore oil pipeline in the XOY coordinate system:

$$\begin{aligned} & \left\{ \frac{EJy''}{[1 + (y'^2)]^{3/2}} \right\}'' + \sum_{i=1}^6 c_i (y - y^*) \delta \left[ x - x_i - \int_0^t v_i(t) dt \right] \cdot \\ & * (y - y^*) + C^* y l(y) l(x - vt) + C^* y l(y - h) \cdot \\ & \cdot (-x + vt) + m \frac{\partial^2 y}{\partial t^2} = P \end{aligned} \quad (3)$$

where:  $E_y$  – cross-sectional bending stiffness;  $c^*$  - coefficient of adhesion of the pipeline with the bottom;  $m$  is the line mass of the pipeline;  $p$  - line weight of the pipeline;  $y_1, y_2, \dots, y_6$  – vertical marks (deflections) of the pipe hose highlighting position of pipelayer ships' hooks;  $y = y_0 + y$  – complete deflections;  $y_0$  - deflections caused by deformations from sea waves, currents and deviations of pipelayer vessels from the route;  $y^*$  - initial pipeline deflections caused only by vertical marks of impacts;  $V_i$  – speed of I-th pipe-laying vessel ( $v_i = v + v_i^*(t)$ );  $U$  – the average speed (same for all ships);  $u^*(t)$  – deviations caused by random processes;  $h$  - depth of pipeline laying;  $c_i$  - rigidity of ship's submersible

cables;  $l(x) = \begin{cases} 1 & \text{при } x \geq 0 \\ 0 & \text{при } x < 0 \end{cases}$  – unit Heaviside function.

By solving the reduced equation, it is possible to calculate the position of the underwater oil pipeline being laid and control the process. Similar calculations and approaches with the construction of boundary conditions and systems of differential equations are required at other stages of project implementation. However, it is important to notice that the optimization principle consists not only in controlling the compliance of certain processes and parameters with acceptable values, but also in selecting the most rational solutions from the available permissible alternatives. In this case, we can talk about some kind of "tactical" decisions in the control of processes and "strategic" decisions within the framework of the stages or the whole project [7], [15]. Adoption of strategic decisions and search for optimal in their environment requires the creation of a certain mechanism - an optimization decision-making algorithm for each of the stages in the implementation of the project of development of the offshore hydrocarbon fields of the Kaliningrad Region.

#### V. CONSTRUCTION OF AN OPTIMIZATION ALGORITHM FOR THE DEVELOPMENT OF OFFSHORE HYDROCARBON FIELDS IN THE KALININGRAD REGION

Each of implemented stages can be viewed as a task of finding an optimum using given initial data. So, as an example, the optimum of the first stage (geological exploration of reserves of deposits) is the most accurate determination of the geological and recoverable reserves of hydrocarbons in the fields along with the calculation of properties of both the fluid and the host rocks, processed with the least amount of time and financial costs (as shown in Table I). Each stage of development of deposits process is the solution for the problem situation L0. The solution to this problem situation is impossible without a complete description and collection of initial data (in case of geological exploration stage it is data on the structure of the deposit), considering imposed time constraints T and restrictions on the available resources M (for example, the number of drilling vessels /installations). These parameters are the basic for the problem on the stage [7].

After that, within the framework of the optimization algorithm, a transition to the solution of the problem occurs. In this part of algorithm it is possible to form a complex of differential equations, comprising:  $\alpha$  – set of objectives,  $\beta$  – set of constraints,  $\gamma$  – set of alternative solutions,  $\eta$  – the preferred solution. The solution of the system of equations allows us to establish a set of acceptable solutions –  $\Delta$ .

When a set of acceptable solutions is established, the next stage of the algorithm is the choice of the solution. Formation of the selection criteria - F, (in the case of the geological exploration phase it is the sequence of the opening of fields or the selection of drilling parameters). Established "effective solutions" -  $\omega$ , (for example, a rational scheme for moving drilling vessels). The final decision is being selected. The final decision on the stage is an alternative with the most favorable overall consequences. From Fig. 5, it is clear that almost in

each stage of algorithm realization it is possible to return to the previous stage to update either initial input data or pursued purposes. This algorithm allows to search for the optimal solution on each step of the project. Each stage is optimized in order to optimize whole process (i.e. time and material costs are reduced, technical and technological risks are reduced) [10], [15]. At the same time, despite the considerable amount of initial data for each stage, as well as the presence of boundary values of various parameters regulated by normative documentation, in the process of implementation of such a large-scale project as the development of several offshore fields, number of stochastic processes emerges. Those processes cannot be accounted for and solved by means of the previously presented mathematical apparatus. Thus, for example, it is impossible to determine weather conditions during the installation of structures, the behavior and accuracy of workers, drillers and equipment adjusters, the durability of various structures and equipment in the course of exposure to aggressive environment. As a result, in a number of cases, project managers have to make decisions in conditions of incomplete data. We will present the most weighted and adequate approach, which allows to find the best solutions to specific problems in conditions of uncertainty.

#### VI. SEARCH FOR OPTIMAL SOLUTIONS FOR THE STAGES OF DEVELOPMENT OF OFFSHORE HYDROCARBON DEPOSITS OF THE KALININGRAD REGION IN CONDITIONS OF UNCERTAINTY

The previously considered approach to determine the leading processes by stages, determine their boundary values and control parameters, as well as the formation of a set of equations describing a particular process, becomes impossible or difficult in the presence of incomplete data or under the influence of random variables. System contains more variables than the number of equations in it. As a result, system has no mathematical solutions. In this case, the process cannot be optimized by the previously proposed approach, and as a result it is impossible to optimize the stage using the above-mentioned algorithm.

In such case (under uncertainty conditions) it is reasonable to use the method of expert assessments. This makes it possible to fill the lack of data based on expert opinions and experience [8].

Application of the method of expert evaluation, based on the ranking of options for the process/problem under investigation, consists in creating an expert group of m experts  $\{j = 1, \dots, m, m \geq 2$  and analyzing the set of solutions for the process  $V = \{v(i), i = 1, \dots, n\}$ . The objective function of decision-making is formulated in the form of criterion q or goal C. An example of such a target function and a problem situation may be selection of the optimal equipment supplier for offshore development (stage F from Table I).

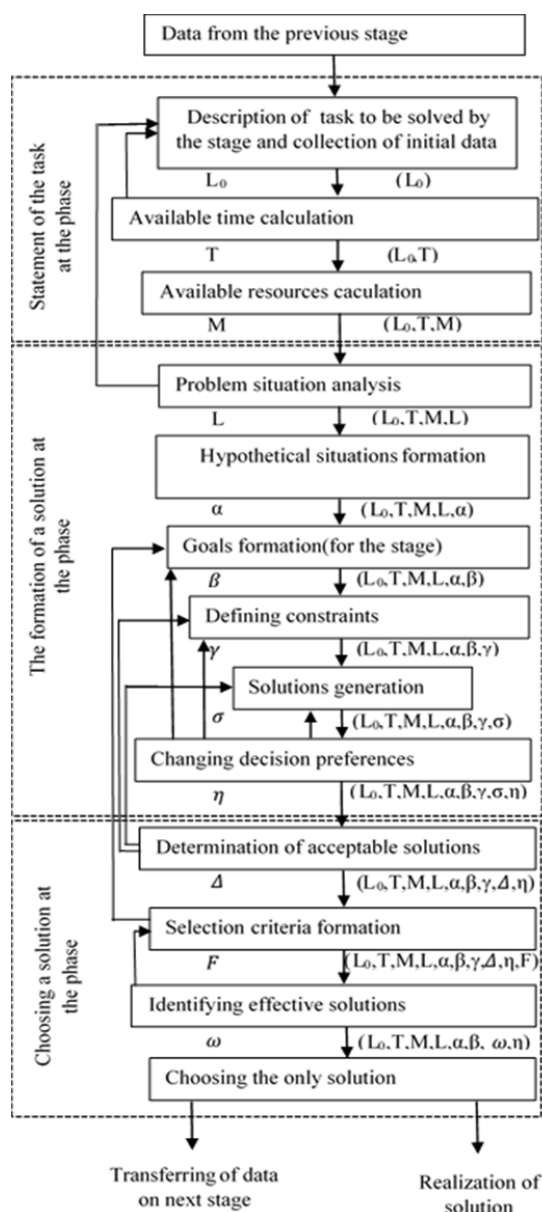


Fig. 5 Optimization decision-making algorithm for the stages of the project implementation for the development of the offshore hydrocarbon fields in the Kaliningrad Region

As a result of comparison between the options according to the  $q$  criterion (based on the accumulated experience and professional knowledge), each expert determines the initial vector of the ranks of the options, for the  $j$ -th expert this vector  $y(i)$  has the following form:  $y(j) = (y(j,1), y(j,2), \dots, y(j,n))$  where  $y(j,i)$  is the rank of the variant  $v(i)$  or  $i$  of the solution assigned by the  $j$ -th expert, with  $y(j,h) < y(j,t)$  if variant  $v$  is preferable to variant  $t$  by the criterion  $Q$ . Vectors  $y(j), j = 1 \dots m$ , create  $(m \times n)$ -rang matrix:

$$Y = \|y(j,i)\|_{m \times n} \quad (4)$$

where  $y(j,i) \in \{1, 2, K, n, -\}$ . Using values of the components of matrix  $Y$  it is possible to determine:

- ratings of options (that is, in the case of the choice of the supplier, formation rating of preferences);
- the degree of agreement between the experts' opinions (calculating the concordance coefficient  $W$  and checking its significance);
- the optimal variant  $v$  or to form a subset of the preferred variants  $V_0$  containing the optimal solution.

It should be pointed out that with the calculations made it is important to determine Spearman rank's correlation coefficient  $K_c$  and the concordance coefficient  $W$ , which will confirm the optimality of the solution obtained [9].

To determine the rank correlation coefficient according to Spearman  $K_c$  (measures of linear connection between random variables) the following formula is used:

$$K_c = 1 - \frac{6[\sum_{i=1}^n (x(j,i) - x(h,i))^2]}{n(n^2 - 1)} \quad (5)$$

In the course of the expert study, it is important to involve experts with varying degrees of competence in order to obtain a more balanced and comprehensive result. In this case, when calculating the concordance coefficient, the following formula should be used:

$$W = \frac{12 \sum_{i=1}^n d(i)^2}{[m^2 n(n^2 - 1) - 12 m \sum_{j=1}^m T(j)] [\sum_{j=1}^m c(j)/m]^2} \quad (6)$$

The concordance coefficient  $W$  evaluates the degree of agreement between the opinions of  $m$  experts ( $m > 2$ ) when ranking options. If all experts have equally ranked the options, i.e. their opinions completely coincide, then  $W = 1$ , if there is no connection between the series  $x(j), j = 1, K, m$ , i.e., the opinions of experts differ greatly, then  $W$  is close to zero. Thus, the values of the coefficient  $W$  belong to the interval  $[0, 1]$ .

Based on the application of the expert method to the analyzed process or problem, a pro-rated list of decisions should be obtained. Solution that received the highest evaluation of experts (provided that the concordance, covariance and mathematical expectations are met) is optimal [11].

In particular, with the help of a group of experts, equipment suppliers can be ranked and based on the obtained results, appropriate managerial decisions can be made - on the terms of tenders for the purchase of equipment and materials. In number of cases, the result of the expert method can be verified using heuristic methods [11].

Thus, the presented algorithm in Fig. 5 is obliged to include both calculation of deterministic values for processes and individual steps, and when solving problems associated with stochastic processes and lack of data, use expert methods.

## VII. CONCLUSION

Presented approaches to the process of search for optimal solutions at each development stage of hydrocarbon fields on the shelf of the Kaliningrad region can significantly improve the quality of management decisions and reduce technical and technological risks.

At the stage of design and survey work of LLC Lukoil-Kaliningradmorneft, a deep analytical work was carried out to determine the stages of work, critical processes and basic technological operations. At present, the collection of the necessary initial data is being carried out, expert groups are being formed among the employees and involved specialists.

Formed database serves as a basis for finding optimal solutions in the course of projects for the development of hydrocarbon deposits on the shelf of the Kaliningrad region, for the development of project documentation for the field infrastructure, for calculations on the impact on the environment, and also for the search of optimal solutions for other stages of project implementation.

Proposed algorithm for optimization of individual technical and technological processes at various stages of development of offshore deposits can be used in other oil and gas projects, since it has great versatility.

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