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Long-term investment planning methodology for oilfield development efficiency

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Abstract
The relevance of the researched problem based on the need of digitalization of elements in the production chain, implemented in oil companies. The purpose of this process is to obtain benefits in the formation of digital models of physical and economic processes underlies on the application of modern approaches to data processing, that includes the usage of both high-performance computing systems and machine learning. The article presents the method of forming the long - term investment program for the effective development of oilfields. The leading approach to the study of this problem is the use of modern mathematical methods to maximize the automation of this process. The article presents the main guidelines for the automated formation of the investment program methodology, to determine the most efficient geological and engineering activities for the oilfield reserves. It also performs automatic generation of many scenarios with different distribution of the proposed geological and engineering activity numbers by years; calculates the technical and economic indicators of oilfield development for each possible scenario formed and uses high - performance calculations to cover the most complete set of different investment planning options. The developed methodology allows planning investments for the development of all oil fields of an oil producing company using optimization methods and machine learning in the long term.

Keywords: recoverable reserves, investment planning, geological and technical activities, machine learning, neural network

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INTRODUCTION

Oil production differs from other industries by the large capital intensity of implementing projects. The most expensive are operations such as well drilling, hydraulic fracturing, thermal, gas methods of maintaining reservoir pressure and equipping the surface infrastructure of fields. At the same time, despite the high costs, it is these projects that are characterized by high investment returns, which are more than worth the investment. Theoretically, it is possible to form a set of different development scenarios for each oil field, calculating their technical and economic indicators, and eventually, choose the optimal scenario depending on a given optimization target function. It can be short or long - term investment plan.

Then, also in theory, it is possible to combine the selected optimal scenarios for each oil field thus forming a long-term investment plan or investment portfolio. Due to limited financial resources however, the realization of the most optimal project at each oil field is also not feasible in reality for obvious reasons. Moreover, for the same reasons the immediate field drilling according to the design of well grid will be the most optimal decision, which is impracticable. Insufficient study of the geological structure of the oil deposit is another contribution. Therefore, the real investment portfolio differs from the ideal one by the presence of a compromise between profit maximization and limited resources. Compromise oriented investment planning is designed to find the solution to the most important task facing every oil company.

The traditional approach to solving the problem of investment planning is to rank projects according to the degree of decreasing their efficiency by cutting off less efficient ones. This approach though cannot guarantee the optimality of solution obtained, but easy to change without mathematical optimization methods. Thus, the search for new long- term investment program with the

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use of modern mathematical methods (Ismagilov et al., 2018; Mustafin et al., 2018; Katasev, 2019), which allows to automate the process as much as possible is an urgent task.

In the period of 2016-201, a methodology for solving the problem and implemented a software tool for creating an effective investment portfolio of the company under the constraints of production volumes and capital costs was performed by the specialists of the Information Technology Center of OJSC TatNeft (Denisov, 2019). The main difference between the implemented solution and the products available on the software market was that, to formulate the optimal annual plan for geological and engineering works (GEW), the approach of multiple calculation and portfolio reformation was used in the face of changing restrictions on investment areas and target production volumes for the first year effect on activities. The approach allows to significantly increase the density of the production program for the activities taken. It enables to obtain a significant increase in the net present value of the formed portfolio with given restrictions on production volumes for the first year and improves planned investments relative to the basic method of forming the program - ranking of geological technical activities by indicators of their effectiveness (PI, NPV, IRR, etc).

RESEARCH METHODOLOGY

The technical support was provided by the computing cluster at the data processing center of OJSC TatNeft with several hundred cores of central processing units (CPUs). The optimization problem was solved with the help of modifications of genetic algorithms, the branch and bound method, and methods stochastic optimization, depending on the target functionality and the set limits.

However, this solution had the following disadvantages:

- planning a set of measures, based on expert review of reachable additional oil production volumes and performance indicators, was carried out by geological service;
- Solution of the optimization task was limited by the short term and included the first year planning activities;
- The use of a cluster on the CPUs limited the possibility of using stochastic optimization methods, and with an increase in the dimension of the problem, it significantly reduced the probability of reaching the target optimum.

The use of machine learning algorithms, due to the lack of high-performance computing nodes on graphic processors (GPUs) for deep learning, was limited to assessing the effectiveness of measures to maintain oil recovery at the injection well stock based on Bayesian networks. However, that made possible to lay the methodological foundations of a probabilistic approach to the task of selecting geological and engineering works depending on the technology and conditions (Denisov, 2019; Nasybulin et al., 2019).

In parallel with this, a solution to the problem of automatically generating many scenarios for oilfield development was worked out by TatNeft R&D Institute specialists taking into account the given restriction, which included a methodology for planning drilling and arranging project wells, calculating technical and economic indicators in promising options.

As you know, the main way to involve reserves in development is the commissioning of new wells, and it is after drilling that it becomes possible to use methods to increase oil recovery and other geological and engineering activities. Therefore, well drilling occupies a special place in the list of planned activities.

The TatNeft R&D Institute has currently developed the methodology of design wells segregation according to the criteria of applicability for commercial commissioning in automated mode (Zvezdin et al., 2019). It is based on proxy models of the «LAZURIT» geologist’s workstation and is implemented in the software module for the technical and economic assessment of oil reserves, which is included in the hierarchical modeling complex, «KIM-Expert» software package (Akhmetzyanov et al., 2009; Sakhabutdinov et al., 2017).

The program forms an array of planned measures for the wells, taking into account the set limits on the minimum necessary economic efficiency of the geological and technical measures and the acceptable level of geological risks (Nasybulin et al., 2007; Khisamov et al., 2006; Latifullin, Sattarov & Sharifullina, 2017; Sharifullina, Butusov & Sattarov, 2017).

Thus, a set of many scenarios is formed. For each scenario, technical and economic indicators are calculated, the profile of oil and liquid production by years is formed. The next step is the calculation of technical and economic indicators, taking into account the reduction in drilling costs due to the integration of wells. As shown by calculation experiments, the technological and economic indicators of the variant with inclusion are much higher than the similar indicators of the variant without initiation.

The need to involve high-performance computing systems is due to an increase in the number of options:

- planned for the implementation of events and planning periods for years when solving the optimization problem of planning a long-term production program of the geological and engineering works(GEA);
- field development planning when forming options not only on the basis of drilling planning, but also involving other types of measures, including oil recovery enhancement methods, hydraulic

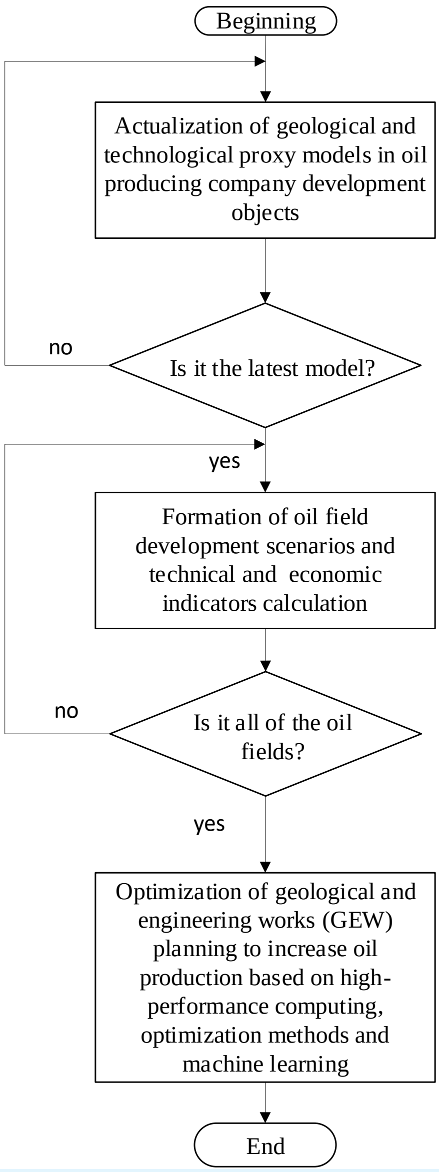

Fig. 1. Oil producing company investment automated programing algorithm

fracturing, measures included in the overhaul and underground well repair circuit.

The formation of long-term plans for the development of an oil field is based both on the basis of licensing obligations of a subsurface user company and on the basis of a geological and field analysis of the current state of development based on the history of experience in conducting geological and engineering works, the uniqueness of the geological and filtration properties of the development object.

Besides, planning within the framework of a large company requires taking into account external economic conditions, limitations of financial resources, differentiation of mineral extraction tax, strategic goals of the company as a whole.

Given that there are dozens of fields under development, for each of which several scenarios of responding to changing conditions are possible, the construction of an optimal production program, and even more long-term, requires the development of specialized algorithms and software tools.

Research Stages

The problem study was carried out in three stages:

– at the first stage, theoretical analysis of the existing methodological approaches described in scientific and technical articles. The problem, the goal, and the research methods had been highlighted;.
– at the second stage, a methodology for long-term investment planning for the effective development of oil fields was developed;
– at the third stage, the theoretical and practical conclusions were clarified and the results were generalized.

RESULTS

Here are the main points of the methodology for the automated formation of an investment program consisting of three stages (**Fig. 1**).

At the first stage, the geological and technological proxy models (models) are updated for all objects of the development of the oil company as of January 1 of the year preceding the first year of geological and technical activities planning.

Database for existing wells is updated, the information on newly drilled wells is entered:

– well number, bottom-hole coordinates, altitudes, elongation;
– results of geological interpretation: the name of the reservoir, the depth of its roof and sole, the depth of the layers, the values of the parameters of porosity, permeability, oil saturation, clay content, oil and water thickness and reservoir type;
– inclinometry data;
– history of perforation and insulation works;
– technological indicators of the well operation;
– the history of previously conducted geological and engineering activities

Based on updated data, a multi-level proxy model has been constructed in the automated mode. Each next level of the model is generated from the model of the previous level.

The first-level model is a geological model of the development object with loaded coordinates and geological and geophysical data for wells calculated by Voronoi regions, initial geological and recoverable reserves.

The second level model was supplemented with technological indicators of development in dynamics annually; the analysis of well stock movement at the facility was performed.

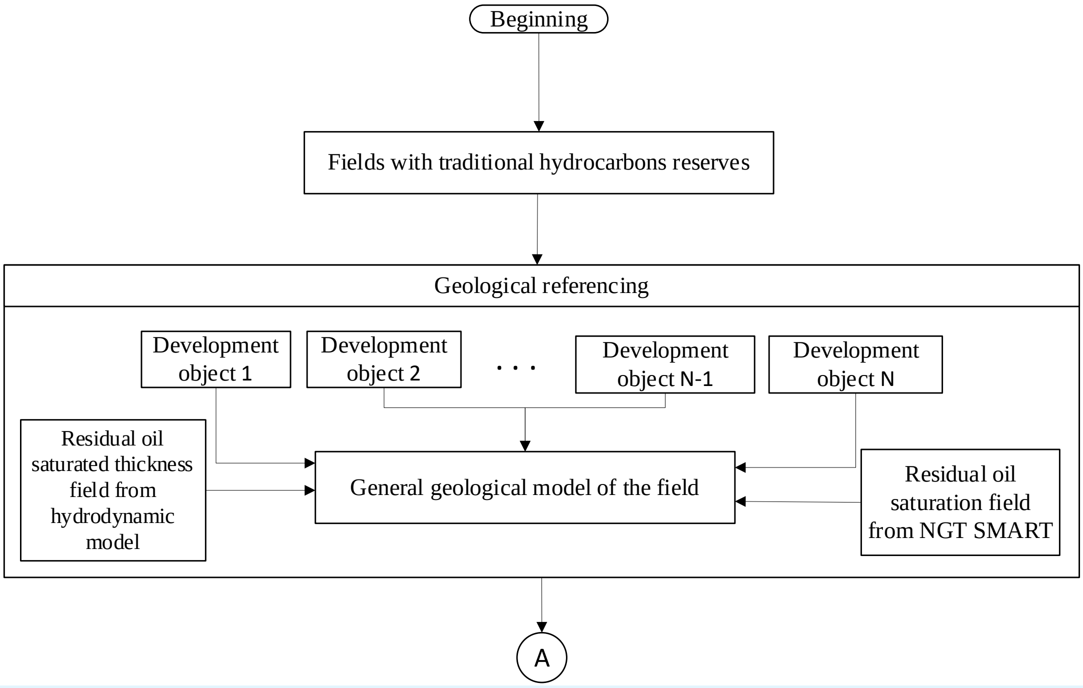

Fig. 2. Algorithm for the formation of many development scenarios for deposits

In the third-level model, an automatic calculation of the percent distribution of oil, water and injection in the reservoirs was performed; analysis of the movement of the stock of wells in the reservoirs.

The model of the fourth level is designed to calculate the structure of residual oil reserves by formations. It calculates final oil saturation, displacement factors, initial movable reserves, water flood coverage coefficients, residual balance and movable and recoverable oil reserves. The model material imbalance is calculated automatic mode. The imbalance formula is seen from below:

<imbalance> = <initial oil reserves> - <remaining oil reserves> - <stocked oil production > (1)

Selection of parameters and multiple modeling achieve the fulfillment of the material balance condition achieved with a given accuracy (less than 0.1%). Thus, the actualization of the geological and technological proxy model of the fourth level is completed.

The fifth level model is supplemented with data, including monthly production (injection), inclinometry and well design, the condition of the column and cement stone, reservoir and bottom-hole pressures, the history of the previously conducted GEA. The reservoir pressure field had been restored in the model.

The model of the fifth level allows selecting priority areas (candidate wells) for various GEA automatically.

At the second stage, oilfield development scenarios are formed and their technical and economic indicators are calculated (**Fig. 2**).

The stage begins with the placement in the automated mode of the planned geological and technical activities in the reservoir zones containing profitable current oil reserves, based on the following conditions:

- plan only the drilling of wells, transfers to other horizons, sidetracking, simultaneous and separate operation of wells;
- the remaining GEA should be taken into account in the base production as a conditionally constant value;
- take into account the relationship between the objects of development of one oil field - the combination of the plan and the possibility of simultaneous development;
- set technical and licensing restrictions (for example, the number of wells to be drilled during a certain period, the minimum volume of production in an oil field, etc.);
- when planning new wells from drilling and transfers for injection (injection), take into account the dynamics of the stock of injection wells to ensure the necessary level of compensation for injection withdrawals;
- take into account the costs of the arrangement through average standards for surface infrastructure;
- consider oil fields with traditional reserves only;
- for target horizons introduced from drilling using methods of intensifying oil production (i.e., followed by hydraulic fracturing and / or cleaning the bottom-hole formation zone), consider the corresponding costs;
- ensure the calculation taking into account the drilling points approved in the investment program;

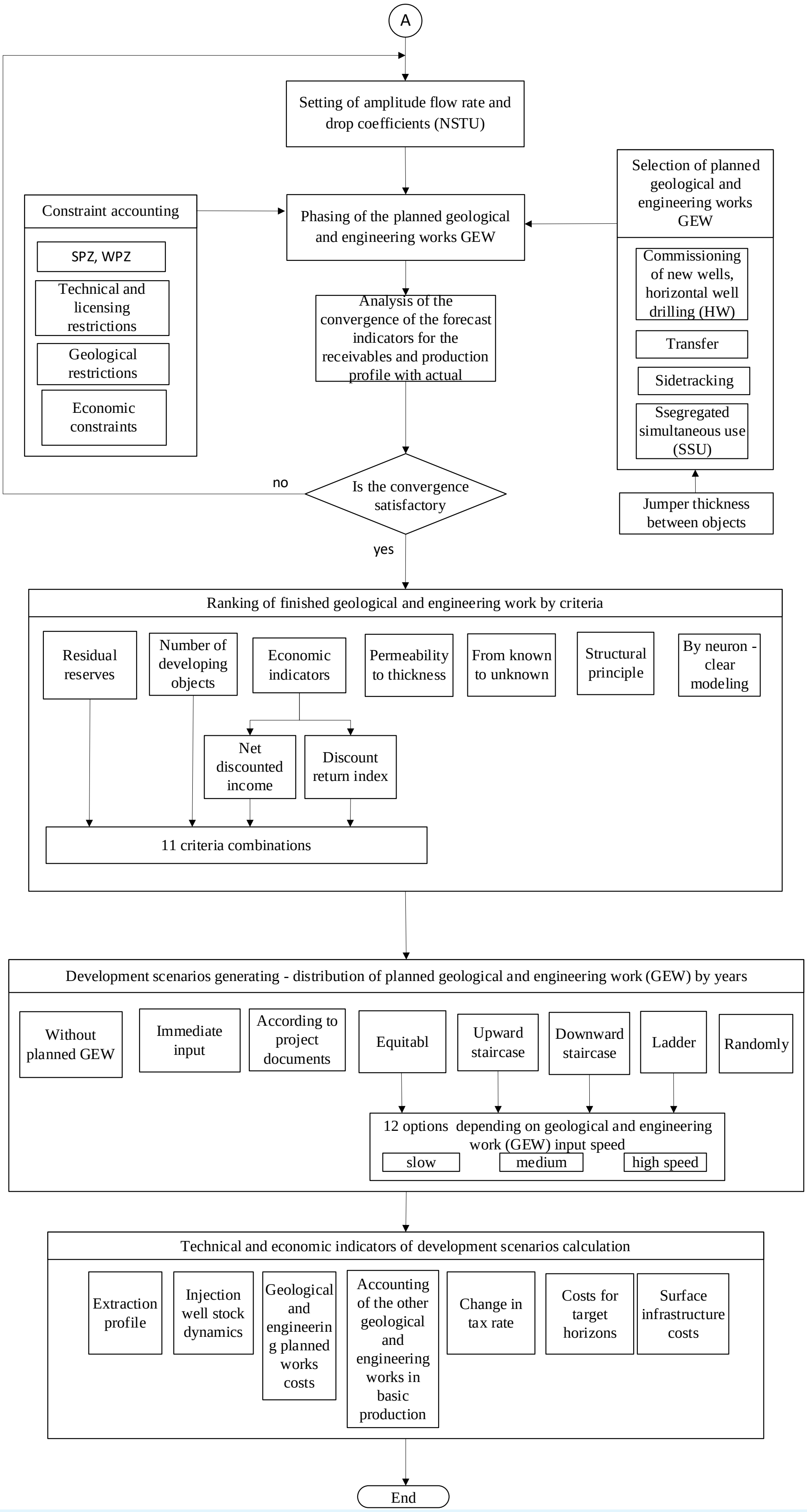

Fig. 3. The algorithm for the formation of many development scenarios for deposits, sheet 2

- to provide a reasonable distribution of design points within the external contour of oil content;
- take into account the thickness of the clay bridge between the development objects to ensure the possibility of installing equipment for simultaneous and separate operation of wells;
- take into account the geological limitations of geological and technical activities;
- ensure the calculation of non-involved oil reserves by reason (economic, geological) and graphical visualization of the concentration of these reserves;
- to ensure for all geological and technical activities the convergence of forecast indicators for the flow rate and profile of oil and liquid production with statistics for the development object or analogues;
- provide variability in the formation of development scenarios with the design of vertical and horizontal wells;
- provide variability in the formation of development scenarios for the short and long term (drilling an entire oil field by the rating of the fields or selective drilling by the best wells in the rating of the wells);
- take into account existing tax rates, as well as changes in rates in the future when choosing an option for planning;
- provide the ability to use the fields of residual oil-saturated thicknesses obtained from the results of 3D hydrodynamic modeling to form development scenarios.

An array of planned activities is formed by wells, taking into account the specified restrictions on the minimum necessary economic efficiency of the geological and technical measures and the acceptable level of geological risks. A phased arrangement of design points is carried out with a sequential increase in the step of the grid of wells. At the same time, at each stage, geological risks and profitability of each well are evaluated; wells that do not meet the specified conditions are excluded.

At each time step, the redistribution of residual oil reserves takes into account their depletion. Because of running the algorithm in an automated mode, an uneven grid of planned geological and technical measures is created that meets geological, technological and economic constraints and has the highest possible density.

The following measures are considered as additional geological and technical measures: sidetracking, transfer of wells to another horizon, the use of technology for simultaneous and separate operation. Taking into account the wells placed for drilling, oilfield development scenarios are formed.

Next, the calculation of technical and economic indicators of the development of oil fields. The basic oil and water production of existing wells is determined taking into account the drop coefficient, statistically based on the history of oil field development. For new wells, based on statistical data, the starting oil and liquid production rate and the drop coefficient by years are calculated.

For each drilled and design well, an oil and liquid production profile is formed by year. Also taken into account are the dynamics of the stock of injection wells necessary to compensate for injection pumping, and the technological criteria for the retirement of wells from development (maximum water cut and minimum production rate).

When calculating economic indicators, changes in tax rates, costs for those introduced from drilling with intensification of target horizons, and the cost of arranging wells through average standards for surface infrastructure are taken into account.

Well calculations are summarized for each oil field and for each scenario of its development. Thus, technical and economic indicators of the development scenarios of all oil fields of the oil company are formed.

At the final third stage, the optimization of geological and technical measures is performed to increase oil production based on high-performance computing, optimization methods, and machine learning. Since the dimension of the optimization problem of forming an investment portfolio is too large, data is clustered using machine learning methods using neural networks based on Kohonen self-organizing maps and Bayesian networks.

The statement of the optimization problem involves the determination of three key components: the objective function (output parameter), input parameters and a set of constraints.

The function that takes into account the objective function is:

- the degree of deviation of the vector of production levels for the planning period (5 years) from the production levels of the generated program, distributed over time to the planning horizon;
- the degree of optimality according to the NPV criterion of the generated program.

Required parameters: washed potential GEA according to the nephritic location are located with a clear profile of the horizon planning and technical-economic indicators.

A set of restrictions:

- total financial resources for each year of planning;
- technological limitations (for example, the number of drilling crews, overhauls of wells, etc.).

The result of applying the above methodology is a long-term investment program for the effective development of oil fields.

DISCUSSION

One of the pressing problems of oil companies in the field of investment is the multi-variance of oil development and production, subject to limited investment. The methods used to form investment portfolios play an important role in the system of managing investment programs of companies. In addition to the existing limitations, it is also necessary to take into account corporate goals, which, ultimately, is a model with the solution of discrete multi-stage tasks of forming investment programs with a dynamic structure (Halikova & Kirichenko, 2016; Avilova & Lamberova, 2011).

The task of effective event planning can be formulated as the selection of events and the sequence of their implementation for the most complete extraction of reserves, subject to a given level of economic payback and no environmental impact (Konoplyanik, 2012; Shayakhmetov, 2004; Akhmetzyanov, Kulibin & Pershin, 2001; Mirzadzhanzade & Salavatov , 2005).

The main problem is the low efficiency of the event planning process, which is associated with the low quality of the initial data on the development status, the imperfection of monitoring and control methods, as well as the human factor (Sudeev & Timonov, 2008; Timonov, 2010; Pyankov, 2004).

To solve difficultly formulated problems, which also include the task of effective planning of geological and technical measures (geological and technical measures), it is proposed to use methods of system analysis (Silich & Silich, 2009).

In order to form an investment portfolio, methods such as E.E. Kolsanov (2015) are used: ranking method (RM) - RunkCut; linear method (LM); simulation method to justify investment programs in the face of uncertainty (including the genetic method) (IM).

The most traditional method is the ranking method. The method is used to cut off projects by a certain parameter and select from them those projects that meet the restrictions imposed (Koltun, 2005). Using the linear programming method allows you to determine the optimal portfolio, because this method is designed to find the best portfolio of events.

Simulation methods are capable of reaching the result of a set of maximum profitable portfolios and are based on the use of sequential conversion of sets of investment program options in the simulation mode (Vorontsovsky, Dikarev & Akhobadze, 2009).

An analysis of the scientific and technical literature in the field of long-term investment planning allowed us to conclude that the economic assessment of reserves, which is a forecast of the accumulated discounted income from oil production, net of taxes, operating and capital costs, is intended to simplify the risk management process in the long-term planning of oil field development.

CONCLUSION

Application of the described methodology for long-term investment planning of an oil company in the development of oil fields allows you to:

- build geological and technological proxy models of oil fields of an oil company;
- assess oil reserves; identify areas of localization of residual oil reserves;
- determine the most effective geological and technical measures for the development of identified oil reserves;
- perform automatic generation of many scenarios for the development of oil fields with a different distribution of proposed geological and technical measures and their number by years;
- to calculate the technical and economic indicators of the development of oil fields for each generated scenario;
- carry out investment planning for the development of all oil fields of an oil company using optimization methods and machine learning for a period of 5 years;
- use high-performance computing to cover the most comprehensive set of different investment planning options.

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