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# TOPSIDE OPTIMIZATION METHODS FOR OFFSHORE PLATFORM MASS-SIZE CHARACTERISTICS. UTILIZING MODULAR DRILLING RIGS

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*Offshore oil and gas production is associated with many times higher capital investments in development than onshore projects. In this regard, operators often give preference to less risky and less capital-intensive onshore projects. This, in turn, slows down the development of offshore production technologies and the development of the huge resource base of the Arctic shelf. Significant influence on the value of capital costs of offshore projects is the cost of offshore field development facilities, including the cost of offshore platforms - floating or stationary offshore oil and gas production structure consisting of topside and substructure, designed to accommodate drilling and/or production equipment, utilities equipment, systems and devices required to perform the functions assigned to the structure. One of the ways to reduce capital expenditures on platform construction is to reduce its weight and size, which can be achieved by using more modern compact technological equipment, improving design and construction technologies, as well as changing the platform concept itself. One of the key and largest functional units of topside offshore platform is the drilling complex. The possibility to quit the construction of the stationary drilling module and drill the well stock by alternative means, using jack-up or modular drilling rig, could become a growth driver for the economics of offshore construction projects. In this paper, a comparative analysis of alternative drilling methods and evaluation of economic efficiency of modular drilling rig application is carried out.*
*As a result of the study, the following main conclusions were obtained:*
*The analysis of statistical data has shown that the cost of topside structures linearly depends on the mass and dimensional characteristics, in which regard the optimization issues are highly important;*
*The analysis of studies has shown the following: the studies do not offer a system of specific solutions to reduce the mass-dimensional characteristics of the upper structure of the offshore platform.*
*The development of a solution for year-round drilling of the well stock on offshore platforms without the construction of a stationary drilling complex will significantly reduce the capital costs of development.*

*keywords: topside weight-size optimization, field development, offshore drilling, offshore platform, modular drilling rig, economic efficiency, capital cost reduction*

## 1 INTRODUCTION

Offshore oil and gas production is associated with many times greater capital investmentAs in field development as opposed to onshore projects. That is why field operators often prefer to less risky and less capital-intensive onshore projects. That fact, in turn, slows down the development of offshore production technologies and the development of the huge oil and gas resources of the Arctic shelf.

The cost of offshore facilities, including the cost of offshore fixed and floating platforms, has a major impact on the amount of capital costs of any offshore oil and gas project.

Any offshore platform consists of two functional blocks: topside and substructure. Topside of an offshore oil and gas platform is usually the most labor-intensive functional block due to high level of saturation with equipment and utilities and, as a result, the most expensive item in a cost breakdown. According to Rystad Energy, costs of topsides exceed costs of substructures in 78,5% of offshore projects worldwide.

Cost of a topside depends on a region of construction and a choice of a particular shipyard-contractor, construction method, schedule of personnel and machinery involvement, a choice of project-specific suppliers of materials and equipment. However, one of the most profitable ways to reduce capital costs of platform topside construction is to reduce its mass-dimensional characteristics (not taking into account factor of selection and commercial negotiations with contractors and suppliers). The statistics of topsides costs (in Q1 2015 prices) dependence on their weights in tons for a sample of over 800 fixed and floating platforms worldwide are given below (Fig.1). The Pearson linear correlation coefficient for the sample is 0.91, indicating a strong linear relationship between these parameters. The coefficient of determination ($r^2$) for the power function is 0.89.

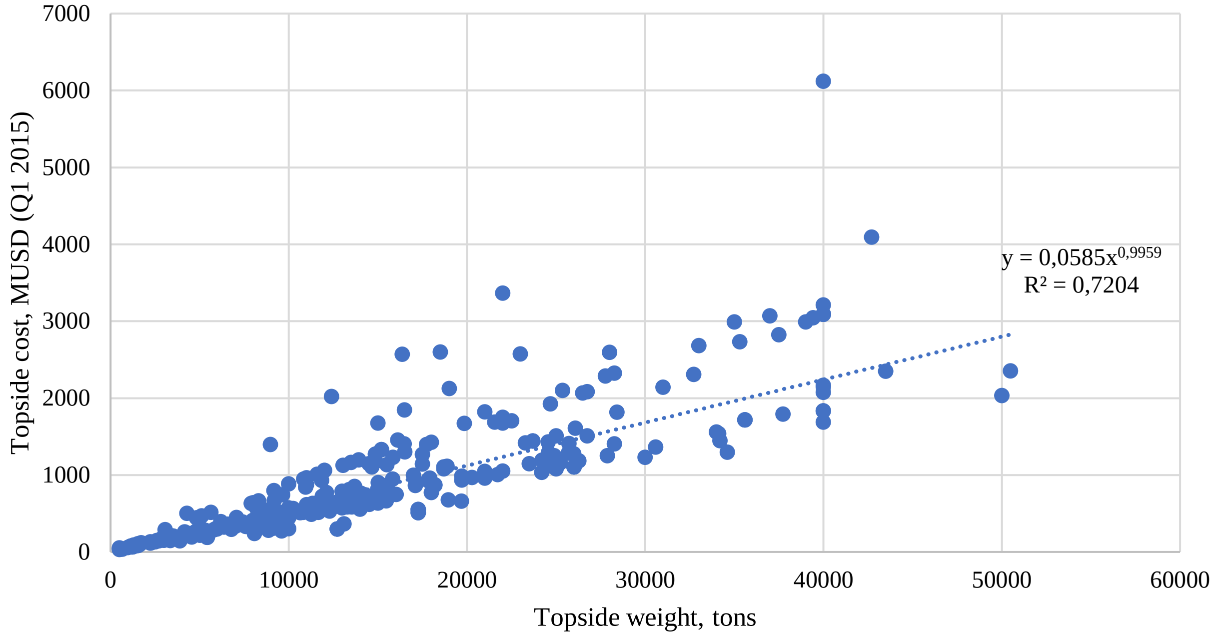


Fig. 1. Dependence of topsides cost on weight

Reduction of mass-dimensional characteristics of a topside can be achieved by using more advanced compact processing equipment, better design and construction technologies, as well as changes in concept and functional of a platform itself. Thereby it is possible to create the potential for achieving required indicators of offshore projects' economic efficiency.

Purpose of the study: to form the basic approaches to optimization of offshore oil and gas platforms topsides.

Research objectives are:

- to analyze state of knowledge in the field of a topside mass-dimensional characteristics` optimization;
- to determine the most relevant optimization criteria;
- to draw up a draft checklist of optimization methods for the mass-size parameters of a topsides;
- to estimate the economic effect of one of the proposed methods` impact.

The scientific novelty of the research is in a new approach to the design of platform topsides based on the systematic consideration of optimization options for all major functional modules. In addition, for the first time on the basis of mathematical modeling the feasibility ranges of modular drilling rigs for offshore platforms have been scientifically substantiated.

## 2 METHODOLOGY

Research has been conducted, therefore sentence construction need change - To achieve the goals and objectives set in the paper, the following main theoretical methods of scientific research were applied:

- analysis of scientific studies on the issue of optimization of mass-size characteristics of topside structures;
- summarizing the results of research on the topic and creating a registry of optimization solutions;
- mathematical modeling in order to estimate the economic effect of one of the proposed optimization methods.

## 3 RESULTS

### 3.1 State of knowledge of the issue

Issues of optimal design of offshore oil and gas field facilities have been considered in their works by Mirzoev D.A., Bogatyreva E.V., Nikitin B.A. [3], Mirzoev F.D. [2,5-7,41], Borodavkin P.P. [1].

P.P. Borodavkin describes approaches to designing layout of topsides, dividing the process into 7 steps, including drawing up a process flow diagram, determining equipment and systems list with specifying areas required for their placement and optimizing their layout. [1].

In the handbook "Methodology for selecting the main design option for offshore ice-resistant platforms", Nikitin B.A., Mirzoev D.A. and Bogatyreva E.V. pay attention to data sufficiency when selecting the optimal platform design option. Selection of an optimal platform design according to this methodology is based on use of expert judgments method [3].

In the field of offshore platform layout design, Jeong et al. [8] proposed a method for optimal layout of FPSO topsides. Park [9] proposed the spatial layout evaluation model (SLEM), a framework for representing expert knowledge using space requirements (area, location, etc.) and relations between spaces (adjacency, level difference, etc.). The multistage optimization problem is based on the feasibility of layout alternatives derived from the arrangement evaluation model (AEM), and it is mathematically formulated and solved using an optimization algorithm. In addition, arrangement template model (ATM) for the layout design of offshore topside was developed to store all data and to effectively interface the data between the expert system and the optimization process. Kim, Roh and Kim [10] proposes an layout method for the topside of an offshore platform based on an expert system and optimization method. The layout design of offshore platform topside was formulated as a two-stage optimization problem that considers safety, operability, and maintainability [11-14].

The studies presented above do not offer a system of specific solutions to reduce the mass-dimensional characteristics of the upper structure of the offshore platform. Within the framework of this study, it is proposed to form such a list of possible optimization solutions.

### *3.2 Topside structures optimization: the basics*

#### *3.2.1 Optimality criteria*

Optimization implies a process of maximizing benefits while minimizing costs. Talking about optimization, it is impossible to avoid the term of optimization criteria, since the problem of finding an optimal solution must always be solved with specified criteria [15, 16].

Key criteria for platform topside optimization can include:

- functional efficiency;
- operational safety;
- economic efficiency [17-19].

Functional efficiency of a designed facility (platform) is defined as compliance of projected result of this facility usage with its purpose - aim of its creation. Process of platform topside optimization during making design decisions should not lead to a change (for a worse side) in its functionality. For example, design solution changes for a drilling module should not have a negative impact on a well completion rate, field production, etc., and changes in processing complex should not lead to lower quality of production treatment, and so on. Thus, one of the optimization criteria will be the preservation of a specified functionality of a platform.

An especially important aspect is offshore platform operational safety. Changing design and layout solutions should not lead to increasing industrial hazard of offshore facilities, especially in cases when the proposed solution contradicts the existing regulatory and legal requirements and calls for development and approval of special technical specifications (STS). Thus, the second optimization criterion will be the operational safety of a proposed technical solution.

The main criteria used to determine optimality of proposed solutions will be economic efficiency, as this indicator is the primary one for making investment decisions. However, it is necessary to note that quantitative assessment of economic efficiency of optimization solution is possible only on an example of a particular project with a particular financial economic model [20, 21].

Therefore, this research is aimed to create a systematic approach that could be used to determine an optimal technical solution for offshore platform topsides design during an economic evaluation of offshore field development. The optimal solution would be the one that allows achieving the greatest economic effect while avoiding a decrease in the functional efficiency and safety of the production facility [22].

#### *3.2.2 Effect of topsides mass-size characteristics on cost efficiency of development projects*

Commercial efficiency of offshore field projects depends largely on capital costs for construction of facilities, a significant part of which is a cost of offshore fixed and floater platform construction [4]. The breakdown of capital expenditures on construction of platform topsides can be presented as follows [23, 24]:

- survey and design work (engineering surveys, feasibility, pre-FEED, FEED);
- detailed design;
- project and construction management;
- insurance;
- procurement of material and technical resources (equipment, materials, etc., including logistics);
- shipyard modernization/preparation;
- construction and assembly work (including fabrication of modules structural steel, installation of equipment and piping, etc.);
- shipyard pre-commissioning ;
- integration with substructure at shipyard or offshore;
- offshore hook-up and commissioning.

Changes in platform mass-size characteristics have the largest impact on the following items of this breakdown:

1) Procurement of material and technical resources:
   - reduction of platform mass-size characteristics leads to weight reduction of primary and secondary structural steel, reduction of piping and cable lengths, which reduces capital costs for procurement of associated materials;
   - application of state-of-the-art and space-saving equipment might lead to a reduction in equipment units to be purchased, as well as lower costs per unit of equipment.
2) Construction and assembly work: estimation of construction costs of offshore oil and gas platforms' functional modules is often determined through man-hours of construction and specific man-hour cost by types of works to be performed. Russian design practice applies the guiding document "GKLI.3210-240-2006. RD. Floating and Ice-Resistant Fixed Platforms. Standard labor intensity of construction" to calculate offshore platform's topside construction labor intensity. According to the methodology presented in the document, labor intensity of construction is determined on the basis of the weight load by positions of the offshore oil and gas field platform topside through relative labor intensity for the types of work (mechanical installation, pipework, manufacturing, etc.). So the labor intensity and, as a consequence, cost of construction works directly depends on a weight of a topside.
3) Integration of topside and substructure: Depending on a type of substructure and weight of a topside, different methods and sites for their integration can be considered. Large and heavy platform topsides may present limitations for towing integrated substructure and topside together (however, it should be noted that the way platform is transported and installed depends not only on the topside, but also on configuration of a substructure). Separate transportation of topside and substructure and their integration afloat or at an operating site requires a larger fleet and, as a result, increases cost of offshore operations.

   Shipyard modernization/preparation: construction of heavy-weight and large-size modules of an offshore fixed platform topsides may require major modernization of a shipbuilding facility in terms of availability of covered workshops for metal structure assembly and painting, ensuring sufficient load-carrying capacity of a site, availability of lifting equipment and floating machinery as well as availability of sufficient covered storage area for materials and equipment. Reducing weight and size of a platform topside allows expanding the range of shipyards considered for construction and potentially excluding or reducing their expensive modernization (however, it should be noted that requirements for modernization of shipbuilding facilities depend on a chosen construction method).

Of course, the foregoing list is not exhaustive, since platform topside's dimensional characteristics have a complex influence on the entire investment cycle of field development, at this stage we aim to highlight the largest and most significant cost items.

The main cost items that are affected by optimization of topsides mass-size characteristics are described above. Hereafter, we should move on to the ways in which it can be achieved [25].

### *3.2.3 The main optimization methods for the mass-dimensional characteristics of the platform topsides*

As a result of the analysis of the offshore platforms realization world experience it was determined that it is rational to consider the issue of topside structure optimization by dividing it into main functional blocks and forming individual optimization recommendations.

The following ways to optimize the offshore platform topsides have been tentatively singled out:

- optimization of the drilling unit;
- optimization of platform technological complex;
- optimization of hydrocarbon storage and offloading module;
- optimization of platform accommodation module;
- optimization of means for personnel and cargo delivery to the platform;
- selection of optimal construction technology for the platform topsides;
- abandonment of certain platform systems with the development and approval of special regulatory requirements;
- serial production of unified modules of the upper structure.

The methods listed above will be discussed in more detail in the following.

1) Drilling module optimization

Stationary drilling complex is one of the largest and most expensive modules placed on the topsides of platforms (can reach a mass of more than 5 thousand tons). Preliminarily, as optimization solutions can be considered a change in the technical solution for carrying out drilling on:

- drilling from the jack-up rig cantilever;
- drilling with modular drilling rig for offshore platforms.

Fig. 2. Example of drilling from the jack-up rig cantilever

The main advantage of avoiding a fixed drilling rig in favor of drilling with an jack-up rig is a significant reduction in the capital cost of platform. Capital expenditures for drilling rig construction are transformed into costs for jack-up drilling, which are incurred at a much later stage of development. Thus, by shifting costs closer to the start of production and reducing capital expenditures, the economic efficiency of the project increases significantly. However, this method has a number of limitations, primarily related to natural and climatic conditions and sea depth at the point of platform deployment.

The use of modular rigs combines the advantages of jack-up drilling (CAPEX to OPEX conversion) with no disadvantages in terms of applicability. The modular drilling rig is mounted on the top structure of the platform, and it is dismantled after the drilling operations are completed. In addition, the advantages of the application include compactness and smaller number of personnel involved in the drilling process in comparison to a jack-up rig.

Fig. 3. Archer Emerald modular drilling rig

2) Technological complex optimization.

The mass-dimensional characteristics of the technological complex as a part of the platform can be significantly reduced by:

- arrangement of technological and auxiliary equipment by skids;
- application of modern more compact models of equipment;
- transferring part of the complex functionality to the onshore infrastructure;
- improvement of traditional technological schemes of product processing;
- change of equipment arrangement schemes on topside decks.

One of the optimization solutions, which has already found application on offshore platforms, is installation of two compressor modules on one operating shaft in back-to-back format. This method makes it possible to significantly reduce the space taken up by the compressors.

3) Storage and offloading module optimization.

The topsides of offshore platforms, the functionality of which involves storage of liquid hydrocarbons, have in their components auxiliary systems that ensure the operation of the storage system, for example - a system of oil-oil-containing water treatment to implement "wet" storage (example: Prirazlomnaya platform, Hebron platform).

Improvement of hydrocarbon storage methods may allow to optimize the composition of auxiliary systems. As one of the options can be considered the use of elastic tanks for storing liquid hydrocarbons without a separating agent (whether water or inert gas). [26]. This concept involves placing hemispherical tanks made of polymeric material underwater on the seabed or directly in the hull of the platform.

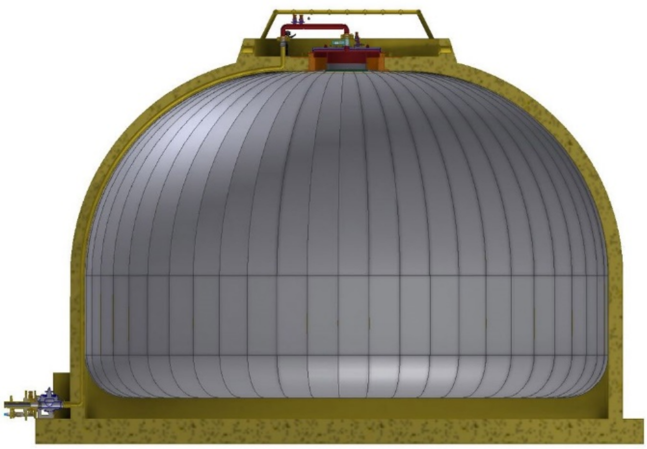

Fig. 4. Subsea elastic oil storage tank

When pumping out the oil storage tank, the volume released in the hemisphere is filled with seawater. The oil and seawater are separated by an impermeable thin-walled membrane.

This type of storage provides a significant reduction in the weight of auxiliary system pipelines on the upper structure of the platform, and also allows to eliminate technological systems, which are placed on the upper structure in case of implementation of dry/wet storage methods.

4) Living quarters optimization.

Development of approaches to optimize the number of service personnel on the platform, automation of technological processes can create the potential to reduce the mass-dimensional characteristics of the platform living quarters.

It should be noted that the mass dimensions of platform living quarters depend not only on the capacity and number of berths, but also on the "comfort level", i.e., the number of people in a stateroom. In Russian practice, the living modules of platforms provide double cabins for most of the working personnel and several single cabins for the managerial staff. However, both single and quadruple cabins are used worldwide to accommodate platform personnel.

Due to the low degree of saturation of the living module with equipment and systems, as well as the low weight of variable loads, the metal structures of living quarters are often recently made of aluminum instead of steel, which allows to significantly reduce the weight of the living quarter while maintaining the total area of living/domestic premises.

5) Cargo and personnel delivery means optimization.

One potential option for optimizing the platform's topside structure could be to eliminate the helicopter deck. Personnel could be delivered to the platform by supply ships equipped with a walk-to-work system. This system is a crossing bridge with a vertical rocking compensation system [27].


Fig. 5. Supply vessel with walk-to-work system

In each individual case, the optimal autonomy of the platform in terms of process supplies and provisions must be assessed, depending on the distance from the shore supply base and the conditions for the involvement of supply vessels. Also, attention should be paid to the placement of minimum and sufficient lifting equipment in the topside design process, giving preference to mobile lifting equipment for the remote areas of the platform.

6) Optimization of the topside systems list

Reduction of the platform's mass-dimensional characteristics can also be achieved by excluding certain systems from the topside structure. However, it is worth noting that such decisions can be made only with a thorough analysis of platform safety issues, as well as with the development and approval of special technical requirements.

7) Optimization of construction methods

The weight and size characteristics of the topsides of the platform depend not only on the composition and layout of the equipment, but also on the method of construction - modular, large-module or integrated construction. However, it should be noted that the construction method has an impact not only on the size of the structure, but also on the construction time, which in turn also affects the cost of the platform. This issue requires a separate study in the field of evaluation and comparison of the effects of increasing the speed of construction and reducing the mass-dimensional characteristics of the platform.

## *4 METHODS TO OPTIMIZE COSTS*

### *4.1 Economical effect estimation from the optimization*

As part of the study, a demonstration calculation of the economic effect of implementing one of the optimization measures proposed above was conducted in order to assess its potential for further study. The authors decided to estimate the potential effect of optimizing the offshore platform drilling module.

One of the key and largest functional blocks of the topside of an offshore platform is the drilling module. A growth driver for the economics of offshore development projects could be the possibility of abandoning the construction of a stationary drilling module and drilling the well fund in an alternative way: using a jack-up rig or a modular drilling rig.

The use of a classic fixed drilling rig on a platform entails high capital costs related to the initial periods of the project (before production begins), which leads to a significant decrease in the potential NPV. Moreover, after finishing the production drilling program (first 2-8 years), the stationary rig will be either mothballed or used only periodically for well workovers, i.e., mostly idle or inefficiently for minor tasks that do not require this class of equipment.

In the case of using a jack-up rig, the obvious advantage is a significant reduction of capital investment for platform construction (due to the rejection of a stationary drilling module), such a solution can significantly affect the economics of offshore development projects and stimulate the development of low-yield fields, however, there are reasons why such a solution has not been widely used in the Arctic shelf, including in the Russian Federation:

1) The design of supporting columns of existing jack-ups does not allow to work in conditions of presence of ice formations, in this connection this type of drilling rig can be used only in the limited season of navigation,

which can be from 7 to 2 months for various Arctic seas of the Russian Federation. Limited drilling season significantly reduces the rate of construction and commissioning of wells in cantilever drilling, which leads to a longer time of production peak performance and underestimation of project efficiency according to NPV and IRR criteria.

2) The jack-up rig has limitations in terms of ground conditions when staging next to the platform: the properties of the bottom soils may not allow safe staging of the jack-up rig near the platform. Moreover, even the most favorable engineering and geological conditions of the site do not allow annual staging (and removal) of the jack-up rig on one point due to craters from the jack-up shoe and risk of tipping of the jack-up rig if the positioning is not accurate enough during installation.
3) Well grid size limitations: the cantilever range does not allow drilling a large stock of wells (more than 15 wells) taking into account the minimum possible normative distance between wellheads (not less than 2.4 m for oil and not less than 3 m for gas and gas-condensate wells while drilling BOP. ) considering the minimum possible normative distance between the wellheads (not less than 2.4 m for oil wells and not less than 3 m for gas and gas-condensate wells if the high pressure valves of production wells are located on the top tier and the slugs of the production wells are on the bottom tier of the platform top structure; not less than 5 m if the high pressure valves of production wells are located on one tier [28]). In particular, on the unmanned platforms of the fields named after V.Filanovsky and Yu. Korchagin fields there are 9 drilling slots.
4) Jack-up rigs have restrictions on sea depth in the point of installation - the deepest in the world today is Noble Lloyd Noble drilling platform, capable of drilling works at depths up to 150 m [29].

The solution to this problem can be the use of Modular Drilling Rig (MDR) modernized for arctic conditions. This type of rigs has proved itself well in the Gulf of Mexico, North Sea and Asia-Pacific.

### *4.2 Modular drilling rig utilizing for topside structure optimization*

Modular Drilling Rigs (MDR) are designed for autonomous operation and perform drilling, completion, well servicing, abandonment. The MDR is relatively easy to install on a platform and just as easy to dismantle for retrofitting and/or relocation to another location.

The most well-known manufacturers and operators of their own MDR are Archer, COSL, Nabors, Bentec, Drillmec. The Norwegian company Archer in partnership with the drilling equipment manufacturer Max Streicher GmbH (Germany) successfully operates two modular drilling rigs with hook load capacity of 363 tons at offshore projects, allowing drilling wells up to 6000 m long:

– Archer Emerald (2012);
– Archer Topaz (2016), see Figure 6. [34]

These two rigs differ by one additional module - Archer Topaz has a tube storage module among other things.

Fig. 6. The main type of MDR Archer Topaz [30]

The Archer modular drilling rig includes more than a hundred individual modules (each weighing no more than 12 tons) and works with a drill string of no more than 363 tons, the total weight of the MDR is about 1,300 tons. In the event of a failure, any module can be quickly replaced. The rig takes up an area of 14 x 12 m without the power generation module, the mast height is 28 m. It takes about four to five weeks to assemble and install an MDR. [30]

Due to the maximum payload capacity of 12 tons, there is no need to hire heavy equipment for the installation. Due to the small size, the blocks can be transported both on the open deck of the barge platform and in the cargo compartments of the dry cargo ship. Large modules are assembled from small blocks in stages. Disassembly is done similarly in reverse order. Figure 7 shows the division of the MDR into large blocks and the division of the blocks into modules weighing up to 12 tons. [38]

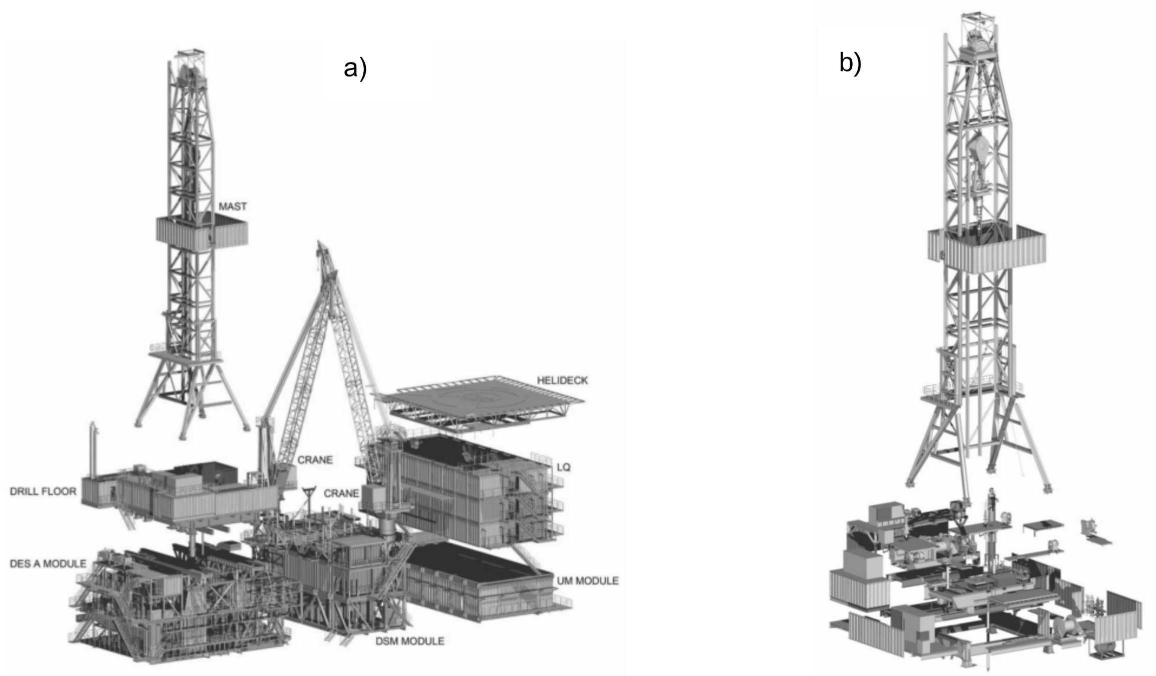


Fig. 7. a) The main modules of the MDR; b) An example of splitting one module into blocks [35]

The modules themselves can be configured in any position relative to the rig, which increases the number of available slots in the MDR workspace without actually increasing it.

Open sources [29, 30, 32] have information about the costs of some of Archer's Topaz and Emerald MDR charter contracts.

Fig. 8 shows data on equivalent daily rates for Archer MDR contracts (Topaz and Emerald), as well as the dynamics of the freight rate index at MODU since 2000 (weighted average index according to Clarksons, IHS Markit, RigZone, Fearnley, Seabrokers).

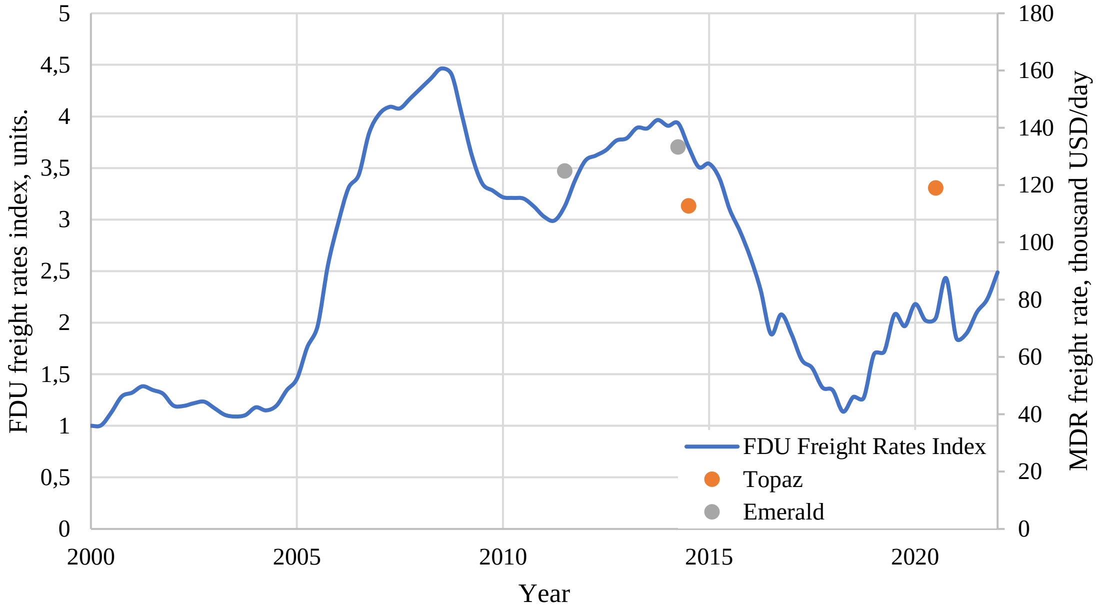


Fig. 8. MDR Archer daily freight rates and MODU freight rates index [30, 32, 33, 38,39,40]

Also, Scivita Inc. (Scivita), together with China Oilfield Services Limited (COSL), developed five MDRs that operated in the Strait of Campeche in Mexico from 2006 to 2015 on PEMEX platforms, with four sets (COSL1, COSL2, COSL3 and COSL4, 2000 hp) having a large block design (LDMR) and the heaviest module weighing about 700 tons. There are eight major modules for each 2000 hp LDMR, which are shown in Table 1 [35]. An example of a large-block design is shown in Figure 7a.

Table 1. The composition of the modules of the LMDR COSL [35]

| № | Module | Equipment |
|---|---|---|
| 1 | DES A Module | Mud treatment system, BOP control, rig skidding |
| 2 | DES B Module | DCR, mast, deadline anchor, drill line reel, drawworks, RT, HP manifolds |
| 3 | Mud Module | MP, sand pumps, mud tanks, diesel storage tank, sack mixing hoppers, potable water tank, cranes |
| 4 | Power Module | Generators, main electric room, emergency electric room, transformer room, air compressors and receivers, fresh water and heaters, sewage treatment unit |
| 5 | LQ & Helideck | Accommodation, helideck, lifeboats |
| 6 | P-tank Module 1 | 3 barite tanks |
| 7 | P-tank Module 2 | 3 cement tanks |
| 8 | Drillwater& Cementing | Drill water tank and cementing unit |

Drilling contractor Nabors in cooperation with Zentech Inc. has built and operated more than 10 MDRs in the Gulf of Mexico, APR and Beaufort Sea since early 2000s, including MDRs for most Gulf of Mexico SPAR and TLP platforms, as well as Arctic MDRs (Nabors Alaska Drilling Rig 19E) operated in artificial island of the Beaufort Sea. Most of Nabors' MDRs are small-module units - with a maximum module weight of up to 25 tons. Separate units, for example, Nabors MASE 805, have the power of 3000 hp and are capable of drilling wells up to 9000 m in borehole length [34].

Based on Scivita's operating experience, the following conclusions can be drawn when comparing large- and small-block modular rig design options:

- Because of the need to lift large modules, the large MDR design is typically heavier than the small MDR with the same equipment and payload capacity. Considering the rig's operating weight is 4,000 to 5,000 tons for the 2,000 and 3,000 hp MDRs, the large MDR ends up using 240-300 tons more steel than the small MDR;
- The average setup time is about 25 days for LMDRs and 60-80 days for SMDRs. Longer installation times also result in higher costs.

Fig. 9. MDR Nabors MASE 805 on a platform in the Indian Sea

#### *4.2.1 Economic effect estimation from the utilization of the modular drilling rig*

For the example the calculations are given for a DR with lifting capacity of 400 t on the hook and maximum achievable length of wells up to 6000 m. Stationary offshore drilling rigs of such class are now actively developed by russian industry and by «Uralmash Holding» in particular. For the platform ISP "A" of the Kamennomysskoye-Sea project the drilling rig 6000/400 ISP in sea version will be built [31]. In this case the process of assembling the main drilling complex (hereinafter - MDC) implies using more than 200 modules with the weight of up to 50-70 t. However, in the case of ISP "A" the modular DR will be manufactured directly for this project, and the necessity of its modular manufacture is conditioned by the technology of transportation and assembly at the shipyard, while the possibility of its subsequent dismantling from ISP "A" is not assumed.

The total mass of the main and auxiliary drilling complex (hereinafter - ADC) is about 4 840 tons. In case of using a similar MDR its weight will not differ significantly from the weight of a stationary drilling rig, accordingly, loads on the upper deck will be the same and replacement of the rig with an MDR will not affect the structure of the upper structure (in terms of the main metal structures of the drilling deck). From the economic point of view, in case of application of a DR the Customer needs to build and incur capital expenses for an US by 4500-5000 tons less than in case of application of a stationary DR. In addition to direct influence of the aircraft weight on the cost, refusal to build own DR on the aircraft can lead to the choice of a transport barge or a vessel of smaller deadweight and cost respectively. Moreover, 40-50 m reduction of the US dimensions by height can make certain shipyards located in the waters, the exit from which is limited by height by underbridge spans - for example, shipyards in the Baltic Sea (the exit is limited by the Danish straits) and the Black Sea (Bosporus and Dardanelles) available for order placement.


Fig. 10. DR 6000/400 ISP for the Kamennomysskaya platform at the control and factory assembly in Tyumen [31]

In order to compare the economic efficiency of MDR in comparison with classic stationary drilling rigs, calculations of accumulated discounted costs (capital and operating costs) were carried out for the variants:

- with a stationary drilling rig - design and manufacture under the project as part of the platform topsides modules, operation and preservation after completion of the drilling program; [37]
- with a modular drilling rig - delivery of modules and installation on the upper deck of the fixed platform at sea, time charter for the period of the drilling program, disassembly after completion of the program.

In terms of capital expenditures, material and technical resources and construction and installation work for the manufacture and installation of DR modules on the substructure in the shipyard conditions are taken into account (northern regions of Russia), development of project documentation, working and design documentation, insurance and certification of MDC and ADC modules during construction, commissioning at the yard and at sea, as well as project management costs on the part of the customer and the contractor. The operating costs include only maintenance and repair costs for the equipment and structures of the MDC and ADC, as well as costs for mothballing of the complex upon completion of the drilling program. The operating costs for the drilling crew payroll, consumables and insurance are not considered since they are the same for a stationary and a modular rig, all other things being equal. [39]

The MDR costs consist of freight rate estimates, installation/dismantling costs, commissioning, insurance and certification, technical repair and maintenance, and project management by the customer. Freight rate is variable depending on the contract duration; the prime rate is based on the Archer Topaz contract rates with the price adjustment to 01.01.2024 and multiplier 1.2 (adjustment for winterization and operation conditions) - 210 thous.USD/day. To calculate the cost of installation and dismantling adopted the assumption that the duration of the transition from the point of mobilization is 30 days, delivery of modules is carried out on one heavy-lift ship, installation is carried out in 5 weeks (according to Archer).

The figures below compare the cost dynamics of a stationary and modular rig for an 8-year production drilling program.

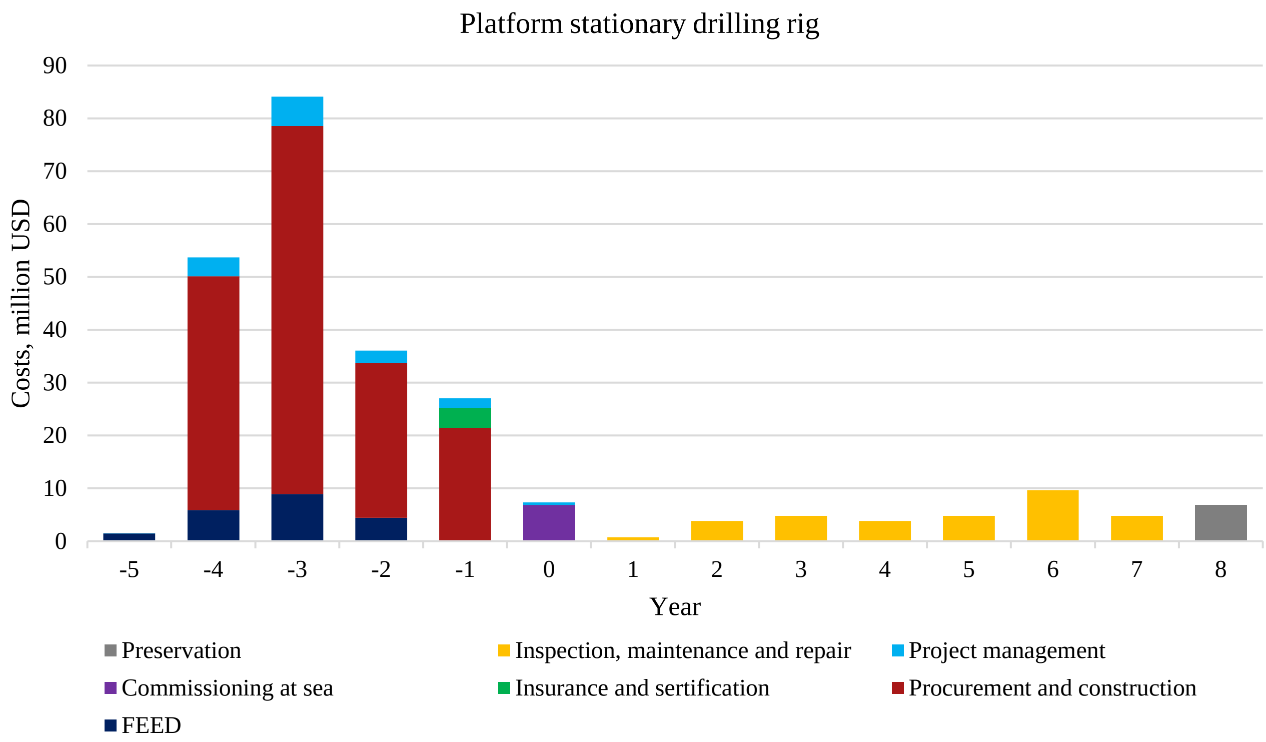


Fig. 11. The dynamics of costs for stationary drilling with an 8-year drilling program

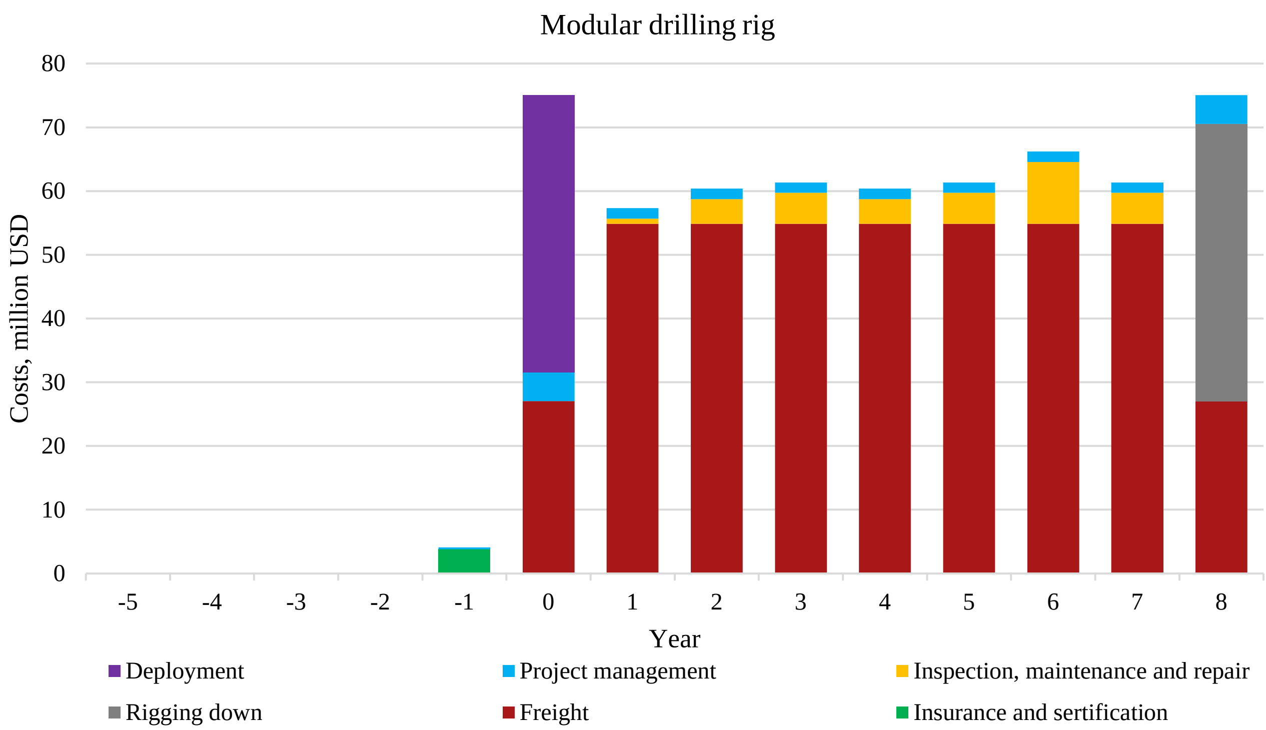


Fig. 12. The dynamics of costs for modular drilling with an 8-year drilling program

Comparative graphs of accumulated discounted costs are shown in the figures below for drilling program durations of 1, 3, 5, 8 and 12 years, and for discount rates of 10%, 15% and 20%.

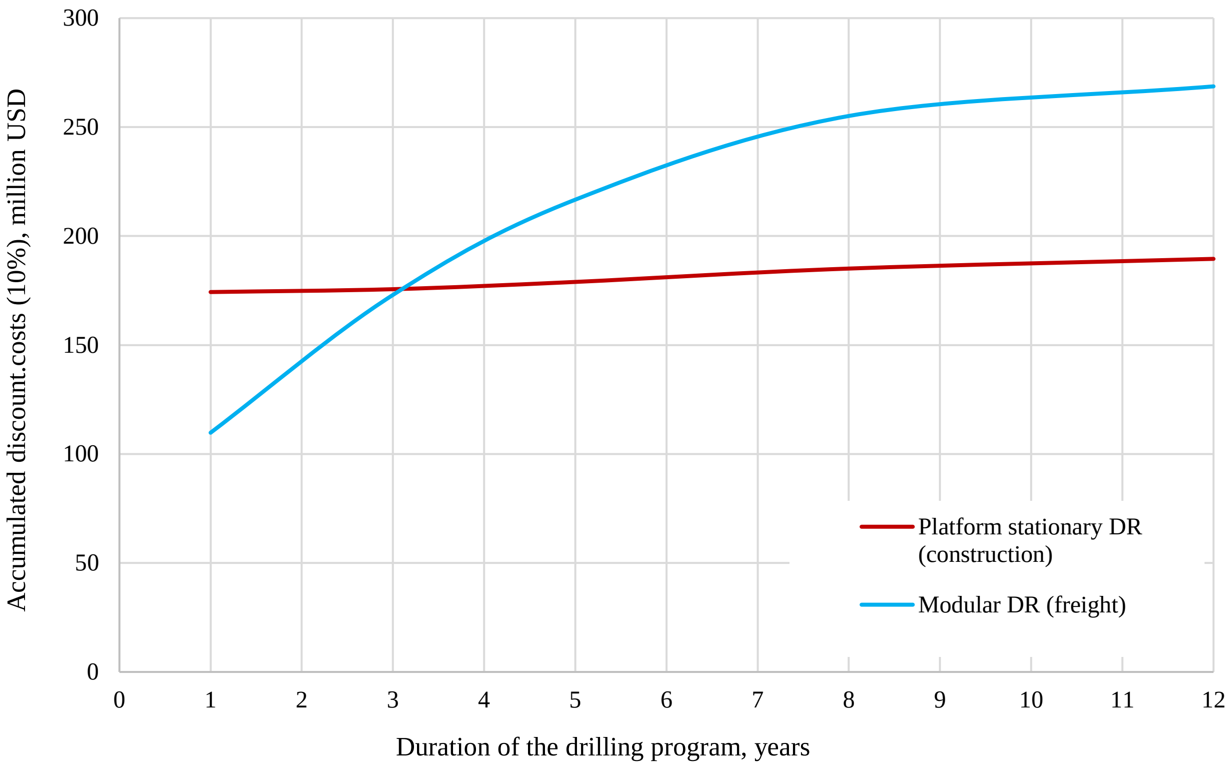


Fig. 13. Comparison of accumulated discounted costs for stationary DR and MDR at a discount rate of 10%

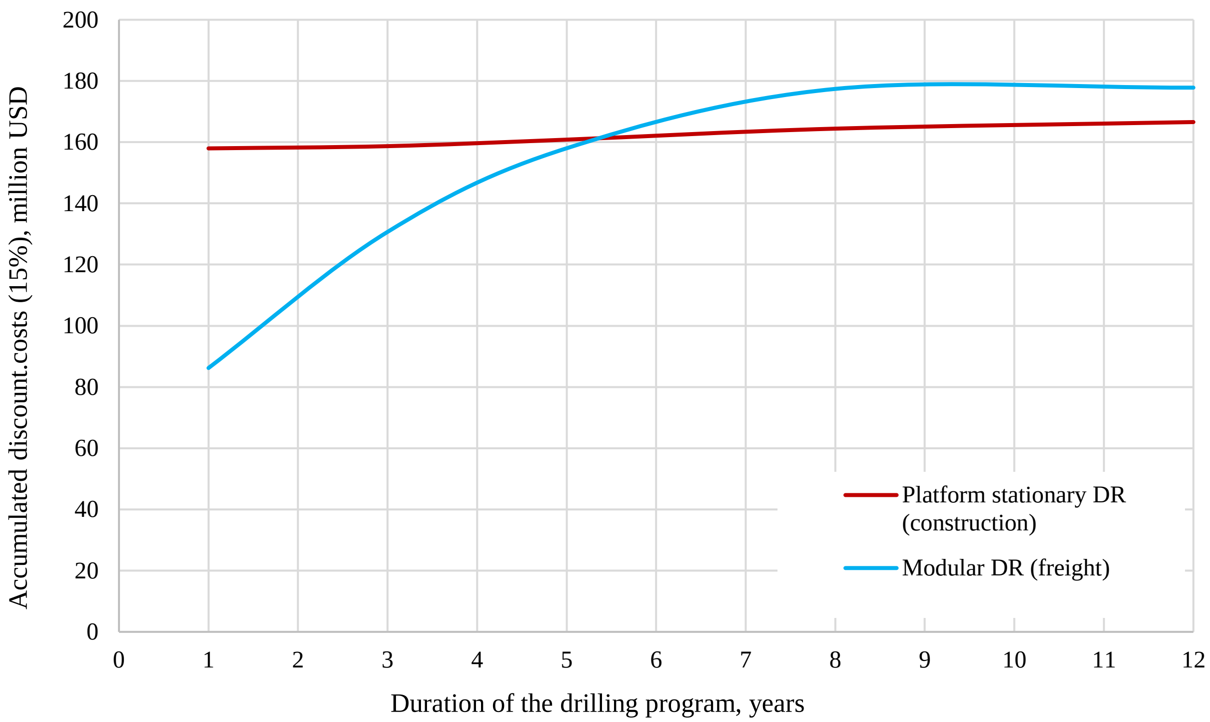


Fig. 14. Comparison of accumulated discounted costs for stationary DR and MDR at a discount rate of 15%

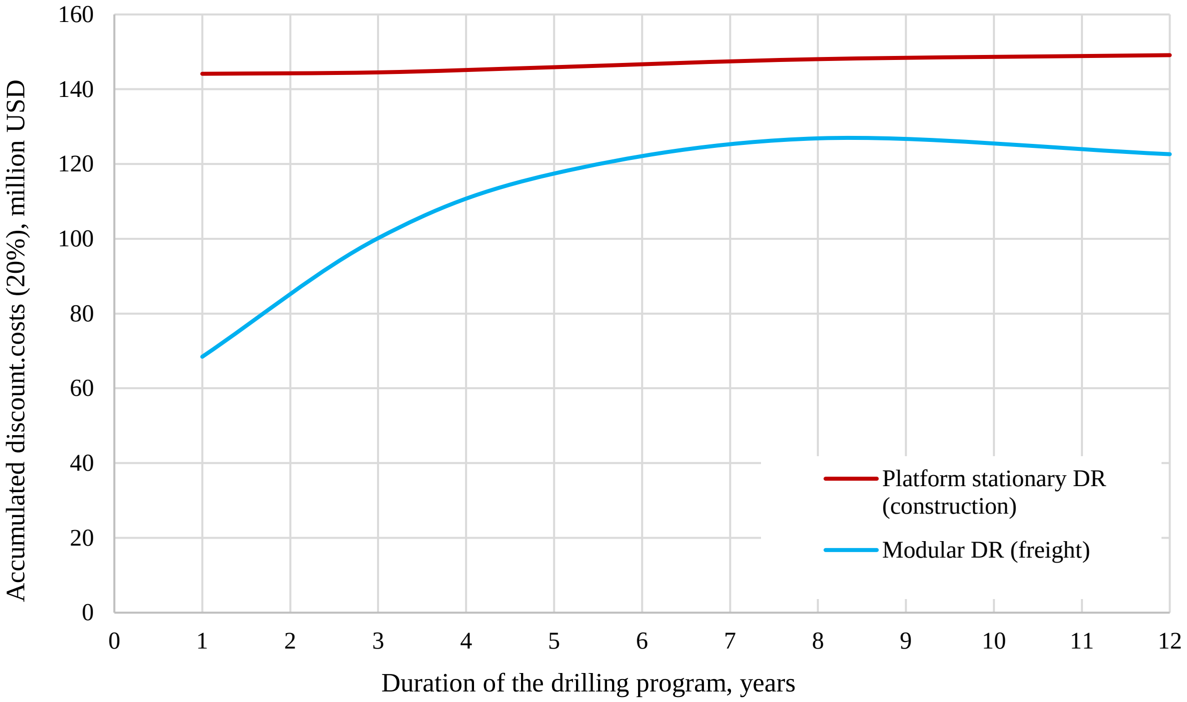


Fig. 15. Comparison of accumulated discounted costs for stationary DR and MDR at a discount rate of 20%

As it can be seen from the above charts, if the IRR requirement for a project is 10%, the use of MDR is justified for the duration of the production drilling program up to and including 3 years. However, the majority of Russian companies impose IRR requirements for offshore projects in the range of 14%-20%. At the discount rate of 15% the use of MDR instead of stationary drilling rig gives positive economic effect in case of the production drilling program duration up to 5 years and at the discount rate of 20% the duration of drilling doesn't influence the expediency of MDR use.

## 5 CONCLUSION

The main indicator in the development of hydrocarbon deposits, whether offshore or onshore, is the economic efficiency of the project. [36] The development of offshore fields is an extremely capital-intensive and technically complex task, therefore, the issues of finding rational technical solutions do not lose their relevance. The issue of reducing capital costs is always a key issue at the design stage of offshore facilities.

As a result of the study, the following main conclusions were obtained:

- The analysis of statistical data has shown that the cost of topside structures linearly depends on the mass and dimensional characteristics, in which regard the optimization issues are highly important;
- The analysis of studies has shown the following: the studies do not offer a system of specific solutions to reduce the mass-dimensional characteristics of the upper structure of the offshore platform;
- A preliminary list of optimization solutions for the upper structures of offshore oil and gas fields has been developed based on the analysis of foreign sources;
- According to the results of the trial calculation of the economic effect of the implementation of the optimization measure, the following was obtained:
  - The development of a solution for year-round drilling of the well stock on offshore platforms without the construction of a stationary drilling complex will significantly reduce the capital costs of development and may contribute to stimulating the development of low-margin deposits of the Russian shelf. Such a solution may be the use of modular drilling rigs.
  - The use of modular drilling rigs combines the advantages of self-lifting rigs with the absence of disadvantages in terms of applicability. By shifting costs closer to the start of production and reducing capital investments, the economic effect of the project is significantly increased.
  - At a discount rate of 10%, the use of a modular drilling rig is rational during the production drilling program for up to 3 years inclusive;
  - If the discount rate is 15%, then the use of a modular drilling rig is rational for an operational drilling program for up to 5 years inclusive;
  - If the discount rate is 20%, the use of a modular drilling rig is rational regardless of the duration of the production drilling program.

Directions for further development:

- Completion of the list of optimization solutions;
- Determination of possible economic effects from the application of the entire list of optimization solutions.

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