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DEVELOPMENT OF THE METHODOLOGY OF THE CHOICE OF THE ROUTE OF WORK OF PLATFORM SUPPLY VESSELS IN THE SHELF OF THE SEAS

Об'єктом дослідження є організація роботи спеціалізованих суден постачання видобувних платформ (СПП) в шельфах морів. Одним з найбільш проблемних місць є необхідність підвищення ефективності роботи спеціалізованих судів обслуговування для доставки персоналу, будівельних матеріалів і постачання на нафтові платформи в шельфах морів під час експлуатації платформ для видобутку нафти.

В ході дослідження для вдосконалення роботи СПП при розробці методології використовувалися метод варіантів і маршрутизації роботи наземних транспортних засобів. Це дозволило удосконалити роботу СПП при обслуговуванні видобувних платформ, завдяки зниженню собівартості виконання рейсів.

Отримано найкращий маршрут та спосіб організації роботи СПП при обслуговуванні видобувних платформ, на прикладі шельфу Чорного моря (Україна). А саме, складені можливі маршрути роботи СПП при маятниковому і збірно-розвізному способі роботи, а також за обраним критерієм визначено кращий спосіб роботи СПП для найкращого маршруту. Розраховано економічний ефект від роботи СПП за обраним маршрутом і способом, який склав близько 44 тис. дол. за рейс. Це пов'язано з тим, що розроблена методологія щодо вибору найкращого варіанту роботи СПП має ряд особливостей, зокрема вона складається з послідовних етапів:

- вибираються схеми маршрутів по організації роботи СПП;
- складаються варіанти маршрутів роботи СПП за кожною схемою;
- призначається критерій вибору схеми;
- розраховуються показники роботи судів;
- вибирається оптимальний маршрут і схема за прийнятим критерієм оптимізації.

Розроблена методологія забезпечує визначення оптимального маршруту і варіанти схеми роботи СПП, який забезпечує найменше значення собівартості перевезень 1 тонно-км вантажів. У порівнянні з аналогічними відомими методами, які застосовуються в автомобільному транспорті, в морському нафтовидобувному бізнесі подібні методи не застосовувалися.

Ключові слова: спеціалізовані судна постачання видобувних платформ, морські бурильні платформи, варіанти маршрутів роботи.

1. Introduction

According to the State Informational Geological Fund («Geoinform»), as of January 1, 2017, Ukraine is developing

269 objects of combustible gaseous minerals, with a volume of 798.442 million m³ and 135 combustible liquid minerals, with a volume of 121.124 million tons. 3 Gas facilities on the shelf of the Azov Sea, with a volume of

10.534 million m³, and two oil volumes of 5.425 million tons and on the shelf of the Black Sea three gas facilities of 3.7506 million m³, and one oil, with a capacity of 3.222 million tons [1].

In February 2017, Ukrkazvydobuvannya company submitted documents to the State Service of Geology and Subsoil for obtaining licenses for 5 sections of the Black Sea shelf. Ukrkazvydobuvannya is part of the company of the National Joint-Stock Company (NJSC) «Naftogaz of Ukraine», that is, 100 % of the shares of the company belong to NJSC «Naftogaz of Ukraine». Ukrkazvydobuvannya is the largest gas producer in Ukraine and, in accordance with a decree of the Cabinet of Ministers, is obliged to sell all volumes of gas produced by NAK Naftogaz of Ukraine for the needs of the population. From the NJSC «Naftogaz of Ukraine» left the enterprise of the Chernomornaftogaz, which carried out a full range of measures for the extraction and transportation of oil on the shelf of the Black Sea-Azov region with coastal infrastructure in the Crimea. Thus, the development priorities of the Ukrkazvydobuvannya company are the renewal and replenishment of the resource base, the creation of a new coastal infrastructure in the mainland of Ukraine and the arrangement of shelf areas for the organization of the extraction of raw materials. In these areas of the shelf, explored reserves are estimated at between 80 and 300 billion m³ of gas [2]. Ukrkazvydobuvannya expects to start exploratory drilling on the Black Sea shelf in 2019–2020 and to go into industrial production in the beginning of 2021 by 2020, Ukrkazvydobuvannya plans to invest 3 billion USD in the purchase and modernization of new equipment for oil and gas [3]. The process of organizing the extraction of hydrocarbons in the shelves of the seas requires the involvement of complex engineering structures, including the means of extraction, field preparation and transportation of hydrocarbon raw materials, as well as special technical and service vessels [4]. The organization of oil and gas in the shelves of the seas consists of several stages: exploration, development, production, transportation [5]. At each stage, technical vessels are involved, have a highly specialized purpose. Specialized service vessels are used to deliver supplies and personnel during all phases, with the exception of the first – reconnaissance. Thus, issues related to the improvement of the organization of work of specialized supply vessels, including for the company Ukrkazvydobuvannya, by developing new methods and tools, are relevant. This is confirmed by the limited number of publications on this topic due to the narrow specialization of the vessels.

2. The object of research and its technological audit

The main destinations of the vessels (OSV) are:

- seismic survey vessels;
- platform supply vessels (PSV);
- anchor handling tugs;
- handling tug and supply vessels (AHTS);
- offshore construction vessels (OCV);
- ROV support vessels, dive support vessels);
- stand-by vessels, inspection, crew boat);
- maintenance and repair vessels (IMR) and variable combinations among them.

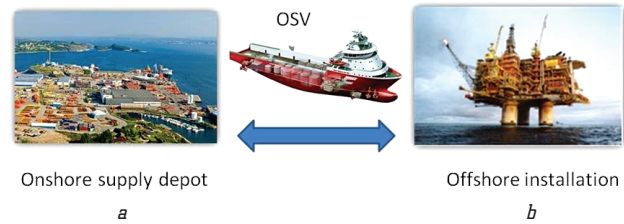


Fig. 1. Interaction scheme:
a – coastal infrastructure with; b – production platform

The main technical and operational characteristics of the SPV vessels:

- loading capacity from 1500 to 7000 t;
- length from 60 to 90 m;
- speed from 12 to 14 knots
- cargo deck area from 400 to 1100 m²;
- vessels are equipped with cranes with a lifting capacity of about 6 tons;
- equipped with a special retention system at the point;
- can carry up to 70 passengers.

Accumulate, as a rule, for the transportation of crews, the supply of water, fuel, refrigerated containers, various lubricants and chemicals, bulk and liquid cargoes necessary to provide oil platforms.

One of the most problematic places is the need to improve the efficiency of specialized service vessels for the delivery of personnel, construction materials and delivery to oil platforms in the shelf of the seas during the operation of platforms for oil production. Vessels 25 % of the time are in the port under loading, 40 % of the time are at sea, at a speed of 14–16 knots approach mining platforms, and 35 % are unloaded at sea often under bad weather conditions: strong winds, high waves. Therefore, to reduce the time of loading and unloading, it is necessary to develop an optimal variant of the scheme and route of operation of vessels.

3. The aim and objectives of research

The aim of research is development of a methodical approach to substantiating the route of operation of specialized supply vessels that serve mining platforms in the shelf of the seas. To achieve this aim it is necessary to perform the following tasks:

1. To characterize the types of specialized vessels serving oil platforms.
2. To analyze the functions and types of operations performed by specialized vessels serving the offshore drilling platforms (ODP).
3. To identify the criterion for evaluating the choice of a variant of the scheme and the route of operation of specialized supply vessels, when servicing offshore drilling platforms.
4. To carry out experimental calculations on the choice of the optimal scheme and route of the SPV operation and to obtain the economic effect from the introduction of the methodology for the organization of the SPV operation.

4. Research of existing solutions of the problem

Among the main directions of solving the problem of improving the work of platform supply vessels, due to the prospects of developing new sources of oil and gas

in the shelves of the Black Sea-Azov section, identified in the resources of the world scientific periodicals, can be highlighted [1, 2]. But in these works the types and characteristics of technical means for the extraction of hydrocarbons in the shelf of the seas are not considered. Optimistic prospects, in terms of gas production in the Ukrainian shelf of the Black Sea, which are specified in [3], make it important and necessary to develop new approaches for arranging infrastructure and organizing specialized vessels. These vessels are involved in the extraction of oil and gas in the shelf of the seas. The work [4] is devoted to the development of oil and gas fields, but there is an unresolved question about the features of the organization of operation of specialized technical means in the shelf of the seas. The authors of [5, 6] provide a classification of the technical means involved in the development of fields in the shelf of the seas, and also presented a method for determining the required number of vessels serving offshore drilling platforms. But there is no attention to the issues of developing and determining the route of the vessels to optimize the costs of servicing platforms.

An alternative solution to the problem of improving the work of supply vessels, outlined in [7], provides for new approaches in designing vessels according to the authors of [8], the SPV operation efficiency is achieved through the use of an online enterprise resource planning system. However, the parameters described have actual confirmations only for the SPV operating conditions in Campos Basin, Brazil. Stochastic models are also determined in [9, 10] for choosing a scheme of work for vessels serving air farms on the shelf of the seas, but no attention is paid to developing the route of operation of such vessels. This highlights the inaccuracies in the obtained results.

In [11, 12], the importance of taking into account natural factors in the SPV operation is emphasized. Although this statement may be considered by other technical means used in the construction of mining platforms in the shelf of the seas.

Thus, the results of the analysis allow to conclude that the question of developing a method for routing the operation of specialized vessels serving stationary mining platforms is promising and requires further study.

5. Methods of research

To improve the SPV operation, the same method is used as the method of options and the method of routing the operation of vehicles.

To arrange delivery of SPVs to oil platforms located on the shelf of the seas, it is necessary to apply the classic version of the routing task, modifying it to the working conditions of offshore vessels.

SPV routing is the most efficient way to organize the optimal movement of cargo traffic through logistic channels and chains. The formation of rational routes allows to accurately determine the volume of cargo transportation in the territorial and time context, to calculate the number of vehicles required to ensure cargo traffic, to achieve a significant reduction in rolling stock idle time for loading and unloading [13].

Routing is one of the methods to improve speed productivity while reducing the number of active rolling stock while maintaining traffic volumes and improving the quality of transport services.

When working supply vessels, according to the concept of logistics, it is necessary to develop such routes that could provide a minimum of empty runs and timely return of vehicles. This task, according to the task of transport logistics, is solved on the basis of the criterion for minimizing operating costs or a ton-kilometer run.

In drawing up the routes of rolling stock, it should be borne in mind that different loads can be transported along the same route, the following conditions must be met: they can be transported using the same rolling stock. So, transportation routing can be made only if there are groups of goods that require the same type of rolling stock for transportation. Routes are compiled for each group of goods.

6. Research results

Specialized vessels serving the ODP, can be classified according to the types of processes that they are intended to perform, Table 1.

Table 1

Classification of vessels of specialized fleet depending on the purpose of the types of processes

base vessel	Processes that vessel performs
tugs	Technological, rescue, fire, towing
supply vessel	Transport, technological, rescue, firefighters
icebreaker	Icebreaking, transport, technological, rescue, firefighters

Thus, from Table 1 it is possible to show that specialized vessels that are involved in the ODP maintenance are multifunctional, but have a basic characteristic of the purpose and the main process. By basic purpose, a basic specialized vessel is selected, on the basis of which other processes are implemented.

The list of operations that ensure the implementation of a process by specialized vessels serving the ODP, depends on the ODP type.

By ODP design features [5, 12]:

- self-elevating drilling platforms (SDP);
- semi-buried drilling platforms (SBDP);
- gravity drilling platforms (GDP);
- drilling vessels (DV).

The principal difference of a particular platform lies in the method of fixing it above the well. As a result of a review of the ODP maintenance process and the formulation of the relevant tasks, the main types of vessels are identified to ensure the smooth ODP operation (Table 2).

When servicing an ODP, physical models of the vessel operation can be divided into the following:

- the vessel goes to its destination for the performance of the tasks set and the operation performance or after the end of autonomy, it returns to the base. Supply vessels and icebreakers operate according to this model;
- the vessel goes to the place of work, after performing the set scope of work in one area, without going to the base, moves to another area. Tugs and rescue vessels are working according to this model.

On the basis of physical models, models of operation are developed, representing a list of operations that the vessel should perform according to its purpose. Models of functioning are formalized by mathematical dependencies, allowing to calculate the performance of vessels.

The main types of operations that support the SPV operation processes

Processes	SDP	SBDP	GDP	DV
Technological	Towing structures to the place of drilling. Ensuring safe mooring of vessels to the ODP terminals	Towing non-self-propelled installations to the drilling site. Ensuring safe mooring of vessels to the ODP terminals	Towing non-self-propelled means of extraction to the drilling site. Ensuring safe mooring of vessels to the ODP terminals. Mounting and installation of anchors IBE	-
Transport	Delivery of supplies and people			
Icebreaking	Exemption of platforms from ice and other infrastructure facilities	Do not use in ice		Have their own icebreaking properties
Rescue	Continuing duty near drilling areas. Fire-fighting on the ODP. Rescue people from emergency ODP. Oil spill response			

Table 2

the mainland of Ukraine. In the Black Sea – these are three gas fields developed by Odesa, Bezymenne and Galitsinske.

For the maintenance of oil platforms, due to the loss of the base in the Black Sea, the prospects for building a base for an offshore fleet in the area of the port of Ilyichevsk in the Black Sea.

The solution of this task is important when planning the SPV operation to supply drilling platforms with building materials and equipment, while carrying out the process of oil and gas production in the shelf (Fig. 2).

When the vessel operates according to the first or the second of the physical models, the process of functioning is divided into time intervals (time of work, stops, transitions, etc.). This determines the SPV execution time and the tasks assigned and affects the number of vessels.

The task of organizing the work of offshore vessels is related to the task of routing vehicles when organizing the route of road transport of goods. This is explained by the fundamental difference in the SPV working conditions from the operation of ordinary sea transport vessels.

First of all, this short distance of transportation, the limited range of the ODP's installation and the SPV operation range, as a rule, does not exceed 200 miles. Secondly, restrictions on the work of crews on an 8-hour working day, which determines the number of possible trips per shift, and accordingly, the number of transported goods and therefore the organization of the route of operation of offshore support vessels.

When organizing the SPV operation work, the main task is transportation of stocks between the ODPs – this is the transport task of delivering small-scale cargo from the distribution center (DC) to the supply facilities (production platforms). For example, from the base or pier, where SPV are loaded in the production platforms located in the delivery area, in the shelf.

Delivery or collection of cargo from one sender or to one consumer. The SPV movement pattern is similar to that of a small system with a circular movement of vessels, in which the support vessel makes several stops at one base and at oil platforms for unloading cargo. At the same time, during one circular drive (turn) during the delivery mode, there is only one SPV load on the base and its gradual unloading at several points during the delivery of goods. With the collecting method, there is a gradual multiple loading on the production platforms, and one-time unloading at the base (Fig. 1).

SPV operation is carried out on pendulum and ring or on combined-distribution routes. Since the roundabout is part of the collecting and distribution route, the SPV operation along two routes are considered: a collection and distribution and pendulum.

Using the map of the location of oil platforms in the Black Sea-Azov region, taking into account the geographical location, let's define the wells relating geographically to

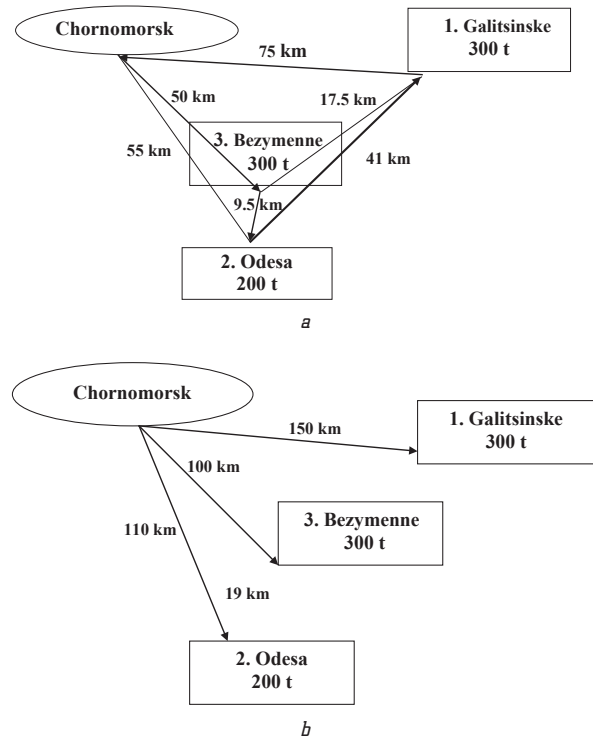


Fig. 2. Schemes of work of vessels supplying platforms: a – collection and delivery route; b – pendulum route

In the first scheme of work (Fig. 1, a), the number of possible routes for detour points of delivery points is $3! = 6$.

According to the second delivery option (Fig. 1, b) there are three possible routes. To select the route option, the performance of two SPVs of the Fedor Uriupin type is calculated at 800 tons of payload and at a speed of 14 knots or 25.9 km/h.

The methodology for choosing a route for SPV operation consists of successive stages:

- options for the ODP detour routes for each scheme;
- the operational performance of vessels is calculated, namely: the vessel's work on the carriage of goods along the delivery route ($W_{g,r}$) the length of the running of one SPV, km (L_r), the length of the running with cargo, km ($l_{r,c}$), the share of running with cargo in total

mileage of the vessel, (β) travel time of the route (n_r), the volume of traffic per vehicle for one day per trip, t-km (Q_{trip}), Cargo turnover per day, (QI), t-km;
– economic indicators are calculated according to a certain optimization criterion, namely: expenses (R), dollars, cost value, (C), dollars/t-km.

The results of calculations of indicators for the variants of the SPV operation when delivering cargo for each of the possible options are given in Tables 3, 4, 5.

Table 3

The results of the calculation of indicators for the collection and distribution route

No.	Variant	Vessel operation	Running length	length of the running with cargo	share of running with cargo
		$W_{g-r}=QI$	L_r , km	I_{rc} , km	β
1	1-2-3	83 350.00	175.50	125.50	0,72
2	3-2-1	57 050.00	175.50	100.50	0.57
3	1-3-2	81 600.00	177.00	122.00	0.69
4	2-3-1	60 000.00	177.00	102.00	0.58
5	3-1-2	71 050.00	183.50	128.50	0.70
6	2-1-3	75 750.00	183.50	133.50	0.73
mimumum		57 050.00	–	–	0.57

Obviously, the minimum cost of resources will be achieved at the least mileage of SPV (I) and the transport work performed in this case (W). The second variant meets these conditions (Table 3).

With the pendulum route, the following options for the SPV operation (Table 4) are obtained:

1. Chornomorsk – Galitsinske – Chornomorsk.
2. Chornomorsk – Bezymenne – Chornomorsk.
3. Chornomorsk – Odesa – Chornomorsk.

Table 4

SPV performance in the development of cargo traffic in the Black Sea

No.	Variant	Running time, h	Running number	volume of traffic per one SPV, t	Cargo turnover, t-km
		T_r	N_r	Q_{trip}	QI
1	C-G-C	5.79	–	800	60000
2	C-B-C	4.25	–	800	44000
3	C-O-C	3.86	–	800	40000
Total for SPV		13.9	1	2400	144000
Total		27.8	2	4800	288000

Calculate the cost of the SPV operation for each variant of each scheme.

Freight turnover per day:

$$QI_{day} = QI_{running} \times n_r \times n_v,$$

where n_v – the number of vessels serving the production platforms. At the company's disposal in the Black Sea there are 2 «Fedor Uriupin» type vessels with 800 tons of payload and a speed of 14 knots or 25.9 km/h.

Costs:

$$R = (C_m \cdot t_m + C_p \cdot t_{l-u}) \times n_r \times n_v,$$

where C_m, C_p – the cost of maintaining the vessel per day, on the move, in the parking lot, dollars/day; t_m – time of movement of vessels, hours; t_{l-u} – loading unloading time, hours.

Cost value of shipping 1 ton-miles of goods:

$$S = \frac{R}{OI_{day}},$$

In terms of the minimum cost of transportation is determined by the optimal route (Table 5).

Table 5

Calculation of indicators for transportation options when specialized supply vessels operate on oil platforms in the Black Sea

Variant, No.	Cargo turnover per running, $QI_{running}$, t-km	Cargo turnover per day, QI , t-km	Costs, R , dollars	Cost value, S , dollars/t-km
Collection and delivery variant				
Variant No. 1: 1-2-3	63900	344418	707418	2.054
Variant No. 2: 3-2-1	46500	235742	707418	3.001
Variant No. 3: 1-3-2	83900	334329	707111	2.115
Variant No. 4: 2-3-1	78000	245831	707111	2.876
Variant No. 5: 3-1-2	50000	280793	705840	2.514
Variant No. 6: 2-1-3	61500	299367	705840	2.358
Pendulum variant				
Total	144000	288000	547764	1.902

The route with the lowest cost value is selected. In this example, this is a pendulum route with a cost price of 1.902 USD/t-km. In the collection and delivery version, the lowest cost of transportation when vessels operate in the first version is 2.054 USD/t-km.

Estimated economic effect:

$$E_{ef} = (S_p - S_{c-d}) \cdot QI, \tag{1}$$

where S_p – the cost of transportation of 1 ton-km of cargo when working on pendulum routes, dollars / t-km; S_{c-d} – the cost of transportation for vessels operating on the collection and delivery routes, dollars/t-km; QI – the work performed by the vessel on the best option per day, t-km

$$E_{ef} = (1.902 - 2.054) \cdot 288000 = 43776 \text{ USD.}$$

Thus, as a result of the developed methodology, it is obtained that the best variant of the SPV operation in the Black Sea region when servicing three fields, namely: Bezymenne, Odesa, Galitsinske with a base in the Black Sea, is a «pendulum route». The cost of transportation for obtained variant is \$ 0.152 USD/t-km less than when working on a pendulum route. This made it possible to save up to 44.000 USD for the transportation of 288 thousand tons of cargo.

7. SWOT analysis of research results

Strengths. The efficiency of the operation and maintenance of facilities located in the shelves of the seas depends on the proper organization of the work of vehicles at the planning stage. The organization of the SPV operation according to the developed methodology allows choosing the best route and the variant of work of such vessels. Compared with peers, depending on the performance criterion, this allows to:

- optimize the work of the vessels;
- minimize the average transportation distance;
- minimize the work of cargo delivery vessels;
- minimize the cost of transportation of goods;
- reduce the cost of transportation of goods to supply mining platforms.

Weaknesses. The disadvantages in the developed methodology are:

- complexity of taking into account the influence of weather conditions on the performance of the SPV voyage;
- requires additional calculations for the development of a cargo delivery plan;
- requires the use of a mathematical apparatus to perform calculations with a larger number of mining vessels, and SPV vessels.

Opportunities. In a further improvement of the developed methodology for determining the optimal route for the SPV operation with a larger number of production platforms, an economic-mathematical model should be developed for various performance criteria.

The introduction of the developed methodology in the enterprise will allow the company to reduce the cost of transportation of supply by specialized supply vessels. This is achieved by choosing the optimal route and the pattern of SPV operation. The developed methodology can be interesting for both Ukrainian and foreign companies.

Threats. When introducing the developed methodology for improving the SPV operation, it is especially important for the company to comply with the chosen route. To do this, an additional schedule should be developed for vessels, taking into account factors affecting the deviation from the established route.

The implementation of the proposed methodology does not require additional costs for the company.

An analogue of the developed methodology can be the methods of organizing the work of vessels servicing sailing farms located in the shelves of the seas.

8. Conclusions

1. The characteristics of the specialized vessels serving the oil platforms allow to determine the operational purpose of the specialized supply vessels of the production platforms (SPV).

2. The analysis of the functions and types of operations performed by the supply vessels of the production platforms makes it possible to determine the specifics of the SPV operation and the shortcomings in the organization of their work. Features consist in the fact that the formation of the route of SPV operation is correlated in accordance with the formation of routes of road transport. The drawbacks in organizing the SPV operation are that 40 % of the cruise time is for the movement of vessels and 60 % for parking under loading and unloading operations.

3. As a criterion for the selection of the route of work of specialized supply vessels when servicing offshore drilling platforms, the indicator of the cost of transportation of goods per day is determined. This helps to formulate the main provisions of the methodology for improving the organization of the SPV operation.

4. Experimental calculations are performed in accordance with the developed methodology for selecting the optimal scheme and route of SPV operation for servicing three oil platforms in the Black Sea shelf. As a result of the calculations, the best route for the SPV operation between the base to the Black Sea and the three oil platforms – Odessa, Bezymenne and Galitsinske is a pendulous route. The resulting economic effect from the SPV operation on the selected route with the best option for the combined delivery route is about 44 thousand USD.

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