PRODUCTION ENGINEERING ARCHIVES 2023, 29(3), 337-347

PRODUCTION ENGINEERING ARCHIVES

ISSN 2353-5156 (print)
ISSN 2353-7779 (online)

Exist since 4th quarter 2013
Available online at https://pea-journal.eu

Ensuring efficiency of technical operation of equipment for workover operation

Andrii Buchynskyi[1], Taras Romanyshyn[2], Myroslav Buchynskyi[3], Lyubomyr Romanyshyn[2], Michał Bembenek[4*]

[1] Yuriy Kondratyuk Poltava Polytechnic National University, Poltava, Ukraine; abuchynskyi@ukr.net
[2] Ivano-Frankivsk National Technical University of Oil and Gas, Ivano-Frankivsk, Ukraine; tarasromanushun@gmail.com (TR); romanyshynl@gmail.com (LR)
[3] LLC «Ekspertnaftogaz», Poltava, Ukraine; mbuchynskti@ukr.net
[4] AGH University of Science and Technology, Krakow, Poland; bembenek@agh.edu.pl
*Correspondence: bembenek@agh.edu.pl Tel.: + 48-12-617-31-20

Article history
Received 30.05.2023
Accepted 14.08.2023
Available online 11.09.2023

Keywords
maintenance
management of machine operation
technical operation
workover rig
workover operation

Abstract
The priority of resources in the management system of influence on the system of technical operation of machines was evaluated. The proposed systemological model of information support for making managerial decisions regarding the technical operation of machines. The given analogy between the factors of technical influence and the resources required for this is substantiated. These are: "action" - "human resource"; "means" - "material resource"; "environment" - "information resource". The priority of the information resource in ensuring the efficiency of the technical operation of the machines is determined by expert evaluation methods. The proposed systemological model consists of the structuring and systematization of information resources of dispatch reports and the procedure for performing further analytical procedures performed by information and analytical maintenance of enterprises with the help of software to obtain relevant information. Such continuous monitoring of equipment operation processes provides engineers with the necessary data for: the analysis and selection of an effective model of technical operation of the equipment; to develop alternative management decisions and make the optimal one; development of individual models and maintenance strategies with their adjustment and adaptation to real operating conditions. Also, this model provides professionals with a tool for comprehensive evaluation of the efficiency of the enterprise's production organization, the dynamics of its development, and the consequences of management decisions in different periods. It makes it possible to make informed decisions regarding the improvement of the management system and the subsequent formation of an effective strategy for the technical operation of machines.

DOI: 10.30657/pea.2023.29.39

1. Introduction

Workover operation is a popular and widespread production process aimed at improving the efficiency of oil and gas field development and ensuring the production characteristics of wells. It is a large-scale workover operation that is characterized by the performance of a wide range of technological operations that are logistically interconnected and interdependent, performed in a strict sequence and usually must be continuous. A wide range of technological equipment is involved in the execution of works, the safety and effectiveness of workover operation depends on the efficiency of its technical operation.

Competent management of production processes is the main task of the enterprise and a complex economic task. An enterprise is an economic system designed to solve certain production and technical and economic problems. And a prominent place in it is occupied by the system of technical operation of the equipment – the system of managing its technical condition. After all, the efficiency of the enterprise depends on its rhythmic and trouble-free work. And with the increase in the number and complexity of equipment, the professionalism of the management system plays a key role in competitiveness and increasing production productivity, economic indicators depend on it.

The system of technical operation of the equipment is one of the most responsible and difficult tasks of the production management system. Its quality level directly affects the quality of execution of technological processes and production activity in general. The effectiveness of the technical operation of the equipment primarily depends on the timeliness and completeness of the technical impact that ensures the equipment's operability. And its improvement is one of the most effective ways to reduce production costs and increase productivity, especially in industries with a continuous production cycle, such as the oil and gas industry. System maintenance is a management task that requires both a lot of resources and a clear understanding of the state of the equipment. The algorithm for solving this and any other technical and economic tasks includes a rational allocation of resources, accounting and analysis of the obtained results with subsequent adjustment of actions. Therefore, when managing technical operations, it is extremely important to know and be guided by the priority of resources, to rely on systematic and structured information about the operation of equipment, and to analyze and correct the obtained results. This is of key importance for the effective production activity of the enterprise and is a prerequisite for the profitability of the firm.

Therefore, the scientific justification of ensuring the effective technical operation of the equipment for workover operations of wells is a technical handover that has significant practical significance - this is the systematic acquisition, processing, accumulation, storage, systematization and operational use of information for standardizing criteria for the development of maintenance.

2. Literature review

Most research papers indicate that proper maintenance is a huge profit center (Jasiulewicz-Kaczmarek et al., 2020; Quatrini et al, 2020; Shaheen et al., 2022). And the policy of managing the technical condition of the equipment should be included in the corporate strategy, as it is a strategic element of achieving the business goal (Hu et al., 2017; Sobaszek et al., 2020). After all, it is the operational equipment that ensures the production activity and profitability of the enterprise (Barré et al., 2017; Pant et al., 2022; Zhang et al., 2022; Zhu et al., 2011). However, unfortunately, compared to the technological processes of product production, machine maintenance receives much less attention.

In particular, papers (Xhemajl et al., 2018; Chiaka Okereke, 2019; Kyi et al., 2019; Naji et al., 2016) consider the concept of equipment maintenance and its impact on the efficiency of production, because this is a strategic issue in the field of equipment operation management. The equipment is the main asset that brings the income of the organization. And if it is not properly maintained, it can lead to frequent breakdowns, and as a result, the organization will not be able to meet market/consumer demand and withstand competitive pressure from other market players (Bousdekis et al., 2022; Nurprihatin et al., 2019; Stenström et al., 2016). It was noted that one of the main factors affecting the quality of management of the technical operation system is the use of information technologies (Henriquez et al., 2013; Polenghi et al., 2022). It is noted that emergency recovery is much more expensive for the enterprise than preventive recovery (Matin et al., 2022; Xiao et al., 2016). In turn, preventive maintenance is more effective when it is adjusted depending on the actual circumstances (Shin et al., 2015; Vogl et al., 2019). Maintenance planning is therefore a key component of effective maintenance delivery (Anh et al., 2018). In the paper (Holomovzyi et al.,2020), the issues of the organization of the maintenance and workover system are considered - the sequence of construction of the system for supporting the operability of the equipment, the conditions of its operation; justified economic aspects.

An analysis of twenty-four maintenance models and ways to increase their applicability in practice is given in the paper (Lundgren et al., 2018). It is noted that the lack of a clear concept of maintenance may be the reason for the low applicability of the maintenance model. And the application of most models requires a lot of data, which is not always available in practice. Since empirical data is limited, it is difficult to make appropriate assumptions. Therefore, it is crucial to practice digitized production to obtain empirical data that will ensure the practical applicability of the models.

The monograph (Dhillon, 2019) emphasizes the ever-widening need for equipment condition management to maintain equipment functions, avoid the consequences of failure, and ensure equipment productivity. Its author discusses maintenance management and life cycle costing, considers organizational functions, focuses on safety and quality of work, corrective and preventive maintenance.

Papers (Douglas, 2018; Mehmeti et al., 2018; Jeong et al., 2019; Oliinyk et al., 2021) examine maintenance costs, including data on the division of these costs into planned and unplanned ones. And an accurate estimate of the future costs of operating the equipment contributes to the efficient distribution of funds. It is indicated that keeping a clear account of the operation of the equipment improves the planning of its operation. It is noted that the wide use of information technologies and the involvement of professional humans in maintenance play a key role in competitiveness in the market and increasing production productivity. The search for new methods of managing human and production costs at the enterprise is also analyzed, it is noted that the efficiency of production cost management is based on the use of automation tools, and the formation of a reasonable flow of information for making management decisions by the enterprise management apparatus.

A comprehensive analysis of various factors affecting the quality of the maintenance and repair system at enterprises is presented in the paper (Kiyanovskyy et al., 2016). Positive and negative factors influencing the right choice of maintenance strategy are identified. The main areas of work to ensure efficiency are highlighted, primarily monitoring and diagnostic support.

3. Methodology of research

To ensure the effective technical operation of well workover equipment, as well as other technical systems, it is necessary to make balanced management decisions for the management of companies. This requires: prioritization of management attention to resources according to their importance in the structure of influence on the system of technical operation of machines; the use of a justified flow of empirical information on equipment status and the results of its analysis for the practical applicability of maintenance models. That is, a rational distribution of resources and practically available and up-to-date information about the operation of the equipment are needed for the application and correction of its maintenance strategies.

To determine the quantitative characteristics of the importance of resources, an expert assessment procedure was used, involving the professional knowledge and experience of experts. The construction of a systemological model of information support was based on a complex of general scientific, experimental, natural science, statistical and mathematical methods and production experience. As a result, structural connections between states have been established, which allows for analyzing the "cause and effect" of events depending on various factors.

This model provides for the collection, accumulation and processing of an array of statistical data – numerical characteristics of technical objects obtained during their operation. It is assumed that data will be collected from each sample unit of the general population - the entire fleet of technological machines operated by the enterprise. As a result, we get large samples for each type of equipment, the volume of which increases with the time of application of the model. It provides quantitative characteristics of properties that characterize the reliability of products. When putting new equipment into operation, for which a sufficiently large array of statistical information has not been formed yet, quantitative characteristics obtained during the operation of similar equipment are used. That is data from a censored sample eg. as with trial designs such as NMT (a test plan, according to which N objects are tested at the same time, the objects that failed during the tests are restored, but not replaced, the object is tested during the production period of T.), NMr (test plan, according to which N objects are tested at the same time, after each failure the object is restored, the test is stopped when the total number of failures for all objects reaches r), or others.

For further calculation and research of reliability indicators, software tools are used that establish and calculate the appropriate distribution laws. The determination of the type of distribution law and the calculation of its parameters are performed when processing the collected statistical data on equipment failures obtained as a result of its operation at the enterprise. Reliability parameters in many cases are subject to the exponential law of work-to-failure. However, as experience shows, it cannot always be applied to electromechanical systems, which are characterized by ageing, wear, adjustment of parameters, etc. Therefore, the Weibull law is mainly used (including partial cases of the exponential law with the form parameter k=1 or Rayleigh k=2, and in some cases the truncated normal). The obtained mathematical dependencies provide forecasting for making decisions on the operation of machines.

The efficiency and quality of software calculations, and the correct operation of knowledge bases, which are the basis for building such a system, provide for:

- obtaining a set of mathematical models that allow obtaining predictive values of the main indicators of the quality of the functioning of machines in a wide range of time intervals;
- implementation of continuous correction (refinement) of mathematical models as statistical information accumulates;
- forecasting and analysis of the efficiency and quality of functioning of technical facilities;

The implementation of the developed methods and algorithms will increase the quality of intelligent decision-making systems in complex organizational and technical complexes, including solving the problems of diagnosing the causes of equipment failures.

4. Results of research

4.1. The structure and importance of resources in the system of technical operation of machines

The system of technical operation is a complex of organizational, technical, technological and other measures aimed at maintaining machines and equipment in good condition by the meaning of technical influence on them. It involves resources, the management of which plays an important role in coordinated, balanced and purposeful use.

The technical impact is a human impact on a technical object that is different in nature, mechanism, duration and intensity to maintain and restore its quality. Let's define it as "maintenance". In turn, "maintenance" is divided into "maintenance", which is aimed at maintenance, and "workover", which is aimed at restoring the quality of a technical object.

The technical impact can be interpreted as a kind of management - a task for the system, which includes the management object, to perform all the necessary actions to transfer the management object to the required state. Such a system, in addition to the object of management to which influence is directed, includes a set of resources used for influence.

Such resources are: human, material and informational. Each of these resources is an integral part of the technical impact. We do not consider energy resources, because we believe that they are always available and in sufficient quantity, therefore they do not affect the implementation of influence. At the same time, it can be argued that technical influence "is carried out by means in the environment." That is, the factors of influence are "action", "means" and "environment".

We will introduce an analogy between the factors of technical influence and the resources required for this.

- "action" is the implementation of impact, i.e. " human resource" that organizes and provides maintenance;

- "means" are technical objects used for impact, i.e. "material resource";
- environment" is the operating conditions of the equipment and its technical condition during the life cycle; work conditions are recorded and influence methods are developed taking into account the technical condition; in this way, we characterize the environment as an "information resource".

Table 1 explains the content of each of the resources.

Table 1. Example Resources for technical impact on the management object

Resource (analogy)	Content of the resource
Human resources (action)	Technical and administrative human of the enterprise participating in the operation and maintenance of technological equipment.
Material resources (means)	Material and technical provision of the repair shop with machines, mechanisms, tools, materials, and spare parts used in maintenance.
Information resources (environment)	Information about operating conditions, productivity, performance and technical condition of technological equipment, methods and algorithms for forecasting and performing impact to maintain technical conditions.

Let's consider each resource in particular and structure it into three components according to the principle "action - means - environment", and fill it with content (Tab. 2).

To assess the importance of each resource and its components, a survey of experts was conducted. The group of respondents was formed from 31 professional industry experts, who own the system of technical operation of oil and gas machines. Each of them has technical, economic and managerial knowledge and skills; experience in the implementation and organization of maintenance and commissioning and commissioning of a wide range of technological machines in various areas of the oil and gas industry. In particular, the expert group is represented by 26 Ukrainian specialists and 5 from Western Europe, North America and North Africa. 13...15 people are considered to be a sufficiently representative group for expert evaluation of complex technical systems (Semenov, 2015). The formed professional group of experts is more than twice this size, which ensures the accuracy and reliability of the survey results, while their number does not reduce its competence. Qualitative characteristics of the expert group by qualification criteria are presented in Table 3.

The expert evaluation was carried out by obtaining the individual opinions of the members of the expert group by ranking the importance of the resources and their components listed in the survey questionnaire in the form of Tables 1 and 2 with the columns resource and content of the resource or structural component of the resource and the column of importance ranking.

Table 2. Structuring of resources for technical impact on the management object

Resource		Structural components of the resource		Analogy
No.	Name	No.	Content	
1	Human	1	Availability of human and their qualifications.	action
		2	Management of human interaction.	means
		3	Working conditions and labor incentive system.	environment
2	Material	1	Sufficiency and quality of the instrumental base (tools and devices) for maintenance and quality control.	action
		2	Quality and sufficiency of spare parts and materials	means
		3	Technological equipment of the repair shop with facilities and technological and lifting and transport machines etc.	environment
3	Informative	1	Maintenance strategies and algorithms for technical impact operations.	action
		2	Automation and system analysis of information flows.	means
		3	Accounting for earnings, working conditions and technical condition of equipment.	environment

The ranking was assigned 1, 2 or 3, where 1 is the most significant impact, and 3 is the least impact of the resource or its structural component on the efficiency of technical operation of oil and gas equipment. The averaged assessments of experts were calculated according to the formula

$$C = \sum_{i=1}^{N} c_i \Big/ N \qquad (1)$$

where:
c_i – evaluation of i expert;
N – the number of experts involved in the survey, N=31.

It should be noted that several experts set an equivalent rating of 1 or 2 for two of the three evaluation positions.

Table 3. Qualitative characteristics of the expert group

No.	Classification sign	%
	1. Areas and specializations of basic higher education	
1.1	Petroleum engineering and technologies	80.6
1.1.1	equipment of oil and gas industries	61.3
1.1.2	drilling of oil and gas wells	6.5

1.1.3	development of oil and gas field	9.6
1.1.4	gas and oil pipelines and gas and oil storage facilities	3.2
1.2	Mechanical engineering	12.9
1.3	Business economics	6.5
	2. Qualification level	
2.1	Specialist	67.7
2.2	Master's degree	32.3
2.3	Among them, Candidate of Technical Sciences, PhD	19.4
	3. Length of industrial experience	
3.1	Over 15 to 25 years	38.7
3.2	More than 25 years	61.3
	4. The field of activity of the enterprise, where the respondent gained the prevailing experience	
4.1	Oil and gas production, including well workover operation	48.4
4.2	Drilling, including well workover operation	22.5
4.3	Oil and gas industry construction	6.5
4.4	Mechanical engineering	16.1
4.5	Expert technical and scientific research work	6.5
4.6	Another experience	
4.6.1	teaching at the university	16.1
4.6.2	experience of a working profession	29.0
	5. Job hierarchy	
5.1	Heads of enterprises	12.9
5.2	Technical managers of enterprises	32.3
5.3	Chief specialists	32.3
5.4	Heads of production units	22.5
	6. The form of ownership of the enterprise where the respondent had the prevailing work experience	
6.1	State	35.5
6.2	Private	41.9
6.3	≈ 50/50 state/private	22.6
	7. The size of the enterprise where the respondent had the prevailing work experience	
7.1	Large (a large range of equipment, over 1,000 employees)	35.5
7.2	Medium (a large range of equipment, 100...1000 employees)	45.1
7.3	Small (limited range of equipment, staff of up to 100 people)	19.4
	8. Age of experts	
8.1	Up to 45 years old	25.8
8.2	From 45 to 65 years	58.1
8.3	Over 65 years	16.1

The value of the averaged estimates is shown in Table 4. The lower the value of the estimate given in the table, the higher the rating and importance of the resource or its component for the effective technical operation of oil and gas machines and equipment.

Also of particular interest is the information on the rating of resources and their components according to the "Olympic principle", that is, the number of awarded first places of importance. This distribution is shown in Figure 1.

In addition to the evaluation of the data of the general population, an evaluation of the importance of resources was additionally performed by stratometrically selected groups, which were formed according to the classification features given in Table 3; group sizes of at least 5 respondents each.

Table 4. Average assessment of expert respondents on the importance of resources and their components

Type of resources	Total rating score: resource	Total rating score: the structural component within the resource (by No. of Table 2) 1	2	3	Average rating score: resource	Average rating score: the structural component within the resource (by No. of Table 2) 1	2	3
Human	60	38	74	67	1.94	1.23	2.39	2.16
Material	69	52	50	76	2.23	1.68	1.61	2.45
Informational	49	52	75	53	1.58	1.68	2.42	1.71

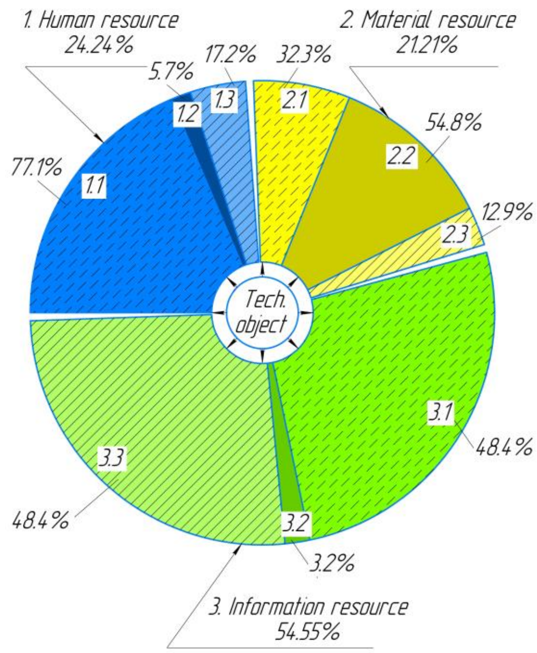

Fig. 1. Rating assessment of the resource and its components: 1.1, 1.2,..., 3.3 (format numbering of structural components «x.y», where x – No. of resource, y – No. of structural components of the resource, Table 2); "value in %" in the fields of the histogram is the rating of the structural component within a certain resource

In most groups, the trends in the distribution of the averaged and ranked estimates of resources are maintained. A significant advantage is given to the information resource. The importance of human and material resources is approximately equal, with a slight advantage for human. Only in groups according to classifications (Table 3):

- "5. Job hierarchy" represented by heads of structural divisions (item 5.4);
- "7. The size of the enterprise..." represented by employees of small companies (item 7.3),

the greatest and approximately equal significance was given to material and human resources, and the least to informational resources. This is probably due to the management of small amounts of equipment and maintenance works characteristic of these groups; simpler strategies for the technical operation of machines; a smaller amount of information about the operation and technical condition of the equipment.

The analysis of subsystems of resources shows that in the general rating of resources, the most significant, in descending order, are the following components of resources:

- accounting of earnings, working conditions and technical condition of the equipment;
- maintenance strategies and algorithms for performing technical impact operations;
- availability of human and their qualifications;
- quality and sufficiency of spare parts and materials.

Among the system of resources, the most important is the informational one - that is, the initial information, the result of its processing and its execution under the technical influence.

We also note that the most important structural components within a certain resource are those in which classifications by analogy coincide – in the resource "action" the most important component is "action", in "means" – "means", and in the “environment” – "environment". This testifies to the logic of building the structure of resources and their classification.

In general, the results of the survey showed that along with the most significant influence on the system of technical operation of information resources, human and material resources also have a significant role. After all, the equipment maintenance system is a complex of actions for coordination, control, planning, implementation and monitoring of proper maintenance of equipment in production. However, advanced production systems are associated with the wider use of information technologies in maintenance management, and information is an important resource for enterprise development. Therefore, considering the system of technical operation of technological equipment in general, it should be noted that for the effective operation of technical systems, special attention should be paid to the information provision of processes that form correct management decisions. At the same time, it is necessary to pay considerable attention to the human potential, because both the management and executive human of the enterprise must be able to and be ready to make decisions in technical and economic situations of varying complexity. And updating the support of the technical enterprise will ensure a higher level of technological processes, which means a lower technological cost of the manufactured products.

4.2. Structuring and analysis of the state of technical objects

Modern maintenance systems are preventive with elements of an individual adaptive approach. Their use presupposes the availability and application of statistical models, which must take into account the differences in operating conditions and reliability indicators of each piece of equipment in particular. However, the industry is well-known for the difficulties in systematic structured accounting, analysis and forecasting of equipment operation for further quantitative assessment of its operational efficiency. And so there is a lack of argumentation for making adjustments in the maintenance strategy.

Therefore, a structured hierarchy of equipment states is proposed below, the information about which will serve for the analysis of production processes, earnings and reasons for equipment downtime, which will be used to make effective management decisions when organizing production and individual planning of maintenance regulations.

We will define the hierarchical levels of the operational life cycle of the equipment.

Operation – human use of a technical object (implementation of its purpose with maintenance and restoration of quality).

Commercial exploitation – the exploitation of a technical object, the result of which is the receipt of income from its intended use.

Production operation - operation of a technical object during the performance of production tasks by the enterprise.

Technical operation – operation of a technical object, during which technical impact is carried out to manage its technical condition.

We will divide each of these levels into states in which the equipment can be and determine their content in Table 5.

The state of the equipment and their contents are described in the table in such a way that takes into account the peculiarities of the technological processes of capital workover operation of wells - the continuity of execution of heterogeneous technological processes, in which some technological machines are engaged, and others are waiting in a state of readiness. That is, there is a technological need for the periodic execution of certain technological processes in a certain sequence with their direct implementation by one piece of equipment, and waiting in a state of readiness for others (for example, lowering and lifting operations, in which pumping units for washing are used periodically, washing or feeding process fluids into a well without performing work with hoisting equipment, etc.).

The duration of a technical object's stay at certain stages of the operational life cycle characterizes its involvement in production processes, shapes its earnings and determines its technical condition. We will call such stages equipment states and structure them (Table 6). Equipment states of different levels are constructed in such a way that each operational state of the previous level is divided into two states of a lower level. Codes are assigned according to the binary numbering system. Code 1 is assigned to a more active and planned state than 0. The duration of the states corresponds to the dependence t_x=t_x1+t_xo,, where x is the state code of the technical object of the highest level of operation.

Table 5. Equipment states of different levels of operation

No.	Equipment status	Content
		Level A. Operation
A.1	Involved	the quality of the equipment is implemented, maintained and restored
A.2	Not involved	the equipment is in storage or conservation due to the cessation of economic activity due to its use, but has the possibility of further restoration of functioning
		Level B. Commercial exploitation
B.1	Active	corresponds to production operation
B.2	Passive	preparation for intended use or further stages after completion of active

		operation. Such states are transportation, assembly-disassembly, start-up-debug, maintenance and easy waiting for decision-making and organization of processes during this period
B.3	Not involved	Similar to state "A.2"
Level C. Production operation		
C.1	Productive	the period of implementation of the direct purpose of the equipment - execution of technological processes
C.2	Alternation	the period of being ready for the intended use. Such periods are waiting for the execution of the technological process by a certain machine during the period of productive production operation of the equipment complex.
C.3	Unproductive	preparation for intended use or transfer to another production facility. Such states are transportation, assembly-disassembly, start-up and adjustment, and maintenance.
C.4	Downtime	waiting for decision-making and organization of processes during the period of passive commercial exploitation.
C.5	Not involved	similar to states "A.2", "B.3".
Level D. Technical operation		
D.1	Maintenance	human impact on the equipment to maintain and restore its quality (technical condition).
Level E. Maintenance		
E.1	Planned	regular preventive maintenance of equipment to prevent failure. They are distinguished by the level of maintenance according to the "total maintenance for the life cycle" schedule of the manufacturer's plant, for example A, B, C...
E.2	Not planned	maintenance actions after detecting a malfunction of the equipment are aimed at its restoration. They differ by the level of complexity, which we will denote by, for example, X, Y, Z...

The proposed structure and status codes of the technical facility can be used to record the duration and moments of occurrence of events, as the information is provided by dispatch maintenance of oil and gas enterprises in daily summaries with hourly detailing of events. However, it is usually focused primarily on technological maintenance supporting production processes. And for strategic evaluation and management of technical operation of equipment, it is poorly structured and only occasionally amenable to systematic analysis, therefore its use in this form is limited.

Table 6. Structure and status codes of the technical object

Level A. Operation				
involved (1)				not involved (0)
Level B. Commercial operation				
active (11)		passive (10)		not involved (00)
Level C. Production operation				
productive (111)	alternation (110)	unproductive (101)	downtime (100)	not involved (000)
Level D. Technical operation				
- Maintenance (1110)	- Maintenance (1100)	- Maintenance (1010)	- Maintenance (1000)	- Maintenance (0000)
Level E. Maintenance				
P* (11101) UP** ([illegible])	P(11001) UP (11000)	P(10101) UP (10100)	P (10001) UP (10000)	P (00001) UP (00000)
A, B, C…*** X, Y, Z…****	A, B, C… X, Y, Z…	A, B, C… X, Y, Z…	A, B, C… X, Y, Z…	A, B, C… X, Y, Z…

* P – scheduled maintenance;
** UP – unscheduled maintenance.
*** A, B, C... - levels of planned technical impacts on the equipment, according to the increasing complexity and volume of work (for example, "A" - daily maintenance; "B" - periodic maintenance; "C" - minor repair; "D" - average repair, "E" - workover operation, etc.)
**** X, Y, Z... – levels of unplanned technical impacts on the equipment, according to the increasing complexity and volume of work (certain analogues of A, B, C..., the necessary volumes of which are determined individually in the event of an unforeseeable failure of the equipment)

5. Discussion

We will introduce dependencies – criteria for determining the efficiency of the technical operation of machines. Guided by the structure of the states of the technical object, for their quantitative assessment we suggest the use of three groups of coefficients characterizing: production activity; availability of the equipment; quality of maintenance system management. Usage coefficients characterize the production activity of the enterprise – the quality of work of commercial and production department and equipment in general, the structure of the production processes of workover operation of wells. Availability coefficients – technical condition and quality of equipment and its service, management of the organization of technical operation of equipment during workover operations. Maintenance coefficients – characterize the quality of management of the maintenance operation system by assessing the schedule of maintenance.

Usage factors k_o**.**

The usage factor is an indicator measured by a system of factors that show the degree of equipment use. For its evaluation, several coefficients are proposed, which provide a comprehensive assessment and characterize the use of equipment according to various criteria.

Coefficient of commercial use:

$$k_{uc} = {t_1}/{(t_1 + t_0)} \tag{2}$$

Coefficient of production use:

$$k_{up} = {t_{11}}/{t_1} \tag{3}$$

Coefficient of technical use:

$$k_{ut} = {(t_1 - t_{mc})}/{t_1}, \tag{4}$$

where:

$t_{mc} = t_{1110} + t_{1100} + t_{1010} + t_{1000}$ – duration of maintenance during the period of operation of the equipment.

Coefficient of use by machine-hours:

$$k_{uh} = {(t_{111} - t_{1110})}/{t_{11}} \tag{5}$$

The coefficient of commercial use – characterizes the efficiency of the work of the commercial department on the use of equipment in the economic activity of the enterprise. The higher the value of the coefficient, the better the commercial activity. It is defined for a certain period as the ratio of the duration of the use of equipment in operation to the calendar time.

The coefficient of production use – characterizes the specificity and organization of the processes of preparation for the operation of a technical object when the enterprise performs production tasks. It serves to evaluate the quality of the organization through technical maintenance of production processes. The value of the coefficient shows the increase in the share of realization of the direct purpose of the equipment. It is defined as the ratio of the duration of active commercial operation to the time of equipment used in operation for the same period.

The coefficient of technical use – characterizes the operational efficiency of the technical object. Used to assess the technical condition of machines. The larger the value of the coefficient, the more reliable the equipment and the more efficient the technical operation system. It is determined by the ratio of the duration of the working state to the total time of operation for a certain period.

The coefficient of use by machine hours – characterizes both the specificity of technological processes and the reliability of equipment and serves to record and analyze the operation of equipment in machine hours. Its value is a share of the period of execution of the technological process by the equipment during its production operation.

Availability coefficients k_a

The availability coefficient is the probability that the facility will be operational at any time, except for planned periods during which the facility is not expected to be used for its intended purpose. Reducing the number of unplanned downtimes ensures an increase in the share of the operational condition of the equipment in an arbitrary period of time (Buchynskyi et al., 2019). Equipment performance is one of the main indicators of the machine's performance and at the same time its properties such as maintainability, reliability and durability. The readiness factor is defined as the ratio of the time of proper operation to the sum of the times of proper operation and forced downtime of the facility, taken for the same calendar period. Therefore, to evaluate the activity of the technical maintenance of the enterprise, it is represented by a system of coefficients that characterize readiness at a certain level of operation and equipment conditions.

Availability coefficients

$$k_a = {t_1 - t_{mp}}/{t_1}, \tag{6}$$

where:

t_{mp} – duration of maintenance work during production operation,

$t_{mp} = t_{1110} + t_{1100} + t_{1010} + t_{1000}$

Coefficient of production availability

$$k_{ap} = {(t_{11} - (t_{1110} + t_{1110}))}/{t_{11}}. \tag{7}$$

Coefficient of technical availability

$$k_{at} = {(t_{111} - t_{1110})}/{t_{111}} \tag{8}$$

Here, the availability coefficient is determined during the period of commercial operation of the equipment. And the coefficient of production and technical availability, respectively, in the periods of production operation (active commercial operation) and the productive period of production operation – execution of technological processes according to their purpose. The coefficient of technical availability is especially important. The greater it is, the higher the operational readiness and reliability of the equipment, and the efficiency of the implementation of technological processes according to its purpose.

Maintenance coefficients k_m.

The quality of technical operation in the system of preventive maintenance is determined by the planning of technical impacts. After all, usually, in addition to planned maintenance work, there are situations where unplanned (emergency) maintenance is required due to unexpected equipment failure. Therefore, we will introduce two groups of maintenance coefficients for evaluation: planning and adaptability.

Coefficients of scheduled maintenance are defined as the ratio over a certain time of the duration of scheduled or unscheduled (emergency) maintenance to the total time the equipment is in maintenance during different periods of operation (e.g. commercial, production, active, passive, shift, etc.) and characterize the quality of the maintenance system operation in general. They have the following general appearance:

$$k_{mp} = {t_{mp}}/{t_m},\ k_{mup} = {t_{mup}}/{t_m},\ k_{mp} + k_{mup} = 1, \tag{9}$$

where:

k_{mp} – the coefficient of maintenance planning;

k_{mup} – the coefficient of unscheduled (emergency) maintenance.

These coefficients are determined for any period as for any levels and conditions of operation. Their duration in the general case (when analyzing all levels and states) is determined by the formulas:

- maintenance

$$t_m = t_{1110} + t_{1100} + t_{1010} + t_{1000} + t_{0000}; \quad (10)$$

- scheduled maintenance

$$t_{mp} = t_{11101} + t_{11001} + t_{10101} + t_{10001} + t_{00001}; \quad (11)$$

- unscheduled maintenance

$$t_{mup} = t_{11100} + t_{11000} + t_{10100} + t_{10000} + t_{00000}. \quad (12)$$

For the most responsible period – productive production operation, when the equipment realizes its direct purpose and its unforeseen malfunction can potentially have the worst consequences (both commercial and technical), these coefficients are determined by the formulas

$$k_{mpp} = {t_{11101}}/{+t_{1110}}, \quad k_{mupp} = {t_{11100}}/{t_{1110}}. \quad (13)$$

And the smaller the ratio of unscheduled maintenance, the more reliable the equipment and the more efficient the technical operation system.

The coefficient of adaptability of the equipment technical operation system is defined as the ratio of the duration of planned maintenance work during the inactive state of the equipment of a certain level of operation (for example, unproductive production operation and simple operation) to the duration of planned maintenance for this entire period (for example, production operation). They look like this:

- coefficient of adaptability during commercial operation

$$\mathrm{k_{mac}} = {t_{10101} + t_{10001}}/{t_{11101} + t_{11001} + t_{10101} + t_{10001}} \quad (14)$$

- coefficient of adaptability during production operation

$$k_{map} = {t_{10101}}/{t_{11101} + t_{11001}} \quad (15)$$

These coefficients characterize the capabilities and skills of the technical department to adjust the performance of maintenance in periods of less active use of the equipment when its downtime brings less damage to production.

The structure of the information model of knowledge about equipment operation should also integrate additional information about the object of technical output. In particular, about the content and scope of maintenance work at levels A, B, C, ..., X, Y....; parameters of the technological process implemented by the equipment (power, supply, pressure, load, speed...) and so on. Each of the events of the transition of the object from one state of technical operation to another should be analyzed according to the "cause and effect" relationship. And for a deeper analysis of the efficiency of the organization of production processes, the states of level C "Production operation" can be further detailed into events, for example: waiting for a technological decision to be made, waiting for cement stone to harden, execution of other technological processes by the complex of equipment, etc.

The proposed structure and volumes of recorded information are integrated into the information and analytical system operating in production, into the single information space of the enterprise.

Since each enterprise is special in terms of its management methods, technological equipment park, etc., integration should be carried out by each enterprise individually, taking into account its specificities.

Identifying technical objects (by type, factory or other assigned number) and coding their states, the information is processed using widely used software. Quantitative values of earnings and proposed coefficients and other indicators of failure-free, maintainability, and durability of equipment are determined (for example, the probability of failure-free operation, the intensity of failures, the probability and intensity of recovery, and others).

In this way, a systemological model is created, which integrates information and allows to describe of the operational life cycle of the equipment. Such software and information support, based on the analysis of performance indicators, allows you to forecast the state of equipment, develop mathematical models and maintenance strategies, evaluate their effectiveness, and implement continuous improvement and adaptation of technical influences and, in general, the use of equipment, taking into account its actual state.

6. Conclusion

The priority of resources in the management system of influence on the system of technical operation of machines was evaluated. The priority of the information resource in ensuring the efficiency of the technical operation of the machines is determined by expert evaluation methods. Its weight is 54.55%.

The proposed system logical model of information support for making managerial decisions on the technical operation of machines. It consists of the use of information resources of dispatch reports with the help of software and technical means for further analytical procedures performed by the information and analytical maintenance of enterprises with the aim of providing comprehensive relevant information for the development of alternative management decisions and making optimal ones.

The structured flow of received empirical information on equipment conditions and the principles and results of its analysis have practical applicability in the subsequent development of individual models and maintenance strategies with their correction and adaptation to real conditions.

At the same time, such an information system also provides monitoring of equipment operation processes, which is one of the methods of controlling the efficiency of the enterprise. The proposed method of using quantitative assessment of several indicators of production activity and technical operation of equipment, in particular, makes it possible to comprehensively evaluate the efficiency of the organization of the production activity of the enterprise, to evaluate the dynamics of the development of the enterprise and the consequences of management decisions in different periods, to apply these values in benchmarking processes, to make decisions on improving management.

The results of the work are intended for oil and gas engineering specialists who operate equipment complexes for the workover operation of wells. This method of information support for the operation of functional subsystems of industrial enterprises provides engineers with the necessary data for the development and selection of an effective model of technical operation of equipment, analysis and correction of management decisions made during the technical operation of machines.

Reference

Anh, D. T., Skrzypek, K., 2018. The predictive maintenance concept in the maintenance department of the "Industry 4.0" production enterprise. Foundations of Management, 10(1), 283-292, DOI: 10.2478/fman-2018-0022

Barré, O., Napame, B., 2017. The insulation for machines having a high lifespan expectancy, design, tests and acceptance criteria issues. Machines, 5(1), 7. DOI: 10.3390/machines5010007

Bousdekis, A., Lepenioti, K., Apostolou, D., Mentzas, G. 2019. Decision making in predictive maintenance: literature review and research agenda for industry 4.0. IFAC-PapersOnLine, 52(13), 607-612. DOI: 10.1016/j.ifacol.2019.11.226

Buchynskyi, M., Buchynskyi, M. Ya. , Vasylchenko, M. I., 2022. Forecasting the technical efficiency of mobile workover rigs. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu. (5): 033 – 038. DOI: 10.33271/nvngu/2022-5/033.

Chiaka Okereke E. 2019. Equipment maintenance strategies on the viability of beverage industries in South-East Nigeria. Strategic Journal of Business and Social Science (SJBSS) #2, 105 pages. Retrieved from www.sjbss.com.

Dhillon, B.S. 2019 Engineering maintenance: a modern approach. Plant maintenance – Management. CRC Press LLC. eBook ISBN9780429132209. DOI: 10.1201/9781420031843.

Douglas, S. T., 2018. The Costs and Benefits of Advanced Maintenance in Manufacturing. Advanced Manufacturing Series (NIST AMS) - 100-18. DOI: 10.6028/NIST.AMS.100-18.

Henriquez, P., Alonso, J. B., Ferrer, M. A., Travieso, C. M. 2013. Review of automatic fault diagnosis systems using audio and vibration signals. IEEE Transactions on Systems, Man, and Cybernetics: Systems, 44(5), 642-652. DOI: 10.1109/TSMCC.2013.2257752

Holomovzyi, V., Kalynovska, N. 2020. Analysis of maintenance and repair systems and the effectiveness of their influence on the technical condition of the factjry system of machines during its operation. Ekonomika ta derzhava, 7, 124–128. DOI: 10.32702/2306-6806.2020.7.124.

Hu, J., Jiang, Z., Liao, H. 2017. Preventive maintenance of a single machine system working under piecewise constant operating condition. Reliability Engineering & System Safety, 168, 105-115. DOI: 10.1016/j.ress.2017.05.014

Jasiulewicz-Kaczmarek, M., Legutko, S., Kluk, P. (2020). Maintenance 4.0 technologies–new opportunities for sustainability driven maintenance. Management and production engineering review, DOI: 10.24425/mper.2020.133730

Jeong, D., Shane, J., Scheibe, K., Nilakanta, S., Alikhani, A., 2019. Optimizing maintenance equipment life-cycle for local agencies. A report from Institute for Transportation Iowa State University (IHRB Project TR-727). Retrieved from www.intrans.iastate.edu.

Kiyanovskyy, M., Dubrovskiy, S. 2016. The TOiR equipment quality of the GOK. Mining Journal, 101, 126-130. Retrieved from http://iomining.in.ua/ua/homeua/journal/101ua/.

Kyi K. S, Zar, C. T., Kyaw M. M., 2019. Maintenance Management Plan of Heavy Machinery. Iconic Research and Engineering Journals. #2, 28-36. Retrieved from https://www.academia.edu/43475688/Maintenance_Management_Plan_of_Heavy_Machinery

Lundgren, C., Skoogh, A., Bokrantz, J., 2018. Quantifying the Effects of Maintenance - a Literature Review of Maintenance Models. Procedia CIRP, 72: 1305-1310. DOI: 10.1016/j.procir.2018.03.175.

Matin, S. A. A., Mansouri, S. A., Bayat, M., Jordehi, A. R., Radmehr, P., 2022. A multi-objective bi-level optimization framework for dynamic maintenance planning of active distribution networks in the presence of energy storage systems. Journal of Energy Storage, 52, 104762. DOI: 10.1016/j.aei.2023.102011

Mehmeti, Xh., Mehmeti, B., Sejdiu., Rr., 2018. The equipment maintenance management in manufacturing enterprises. IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. 51-30, 800–802 DOI: 10.1016/j.ifacol.2018.11.192.

Naji, A., Beidouri, Z., Oumami, M.,, Bouksour, O., 2016. Maintenance management and innovation in industries: a survey of Moroccan companies. International Journal of Innovation, vol. 4, núm. 2, Retrieved from https://www.redalyc.org/articulo.oa?id=499151080014.

Nurprihatin, F., Angely, M., Tannady, H., 2019. Total productive maintenance policy to increase effectiveness and maintenance performance using overall equipment effectiveness. Journal of applied research on industrial engineering, 6(3), 184-199.

Oliinyk, A., Velboi, M., Lukianovets, N., 2021. The role of personnel and production costs in effective management of the enterprise. Agrosvit, vol. 7-8, 94-102. DOI: 10.32702/2306-6792.2021.7-8.94

Pant, H., Singh, S. B., 2022. Availability and cost assessment of systems with dormant failure undergoing sequential inspections. Journal of Quality in Maintenance Engineering, 28(3), 533-544. DOI: 10.1108/JQME-10-2020-0112

Polenghi, A., Roda, I., Macchi, M., Pozzetti, A., 2022. Information as a key dimension to develop industrial asset management in manufacturing. Journal of Quality in Maintenance Engineering, 28(3), 567-583. DOI: 10.1108/JQME-09-2020-0095

Quatrini, E., Costantino, F., Di Gravio, G., Patriarca, R., 2020. Condition-based maintenance - an extensive literature review. Machines, 8(2), 31. DOI: 10.3390/machines8020031

Semenov S.S. Otsenka kachestva y tekhnycheskoho urovnia slozhnykh system: Praktyka prymenenyia metoda ekspertnykh otsenok. – M.: LENAND, 2015

Shaheen, B. W., Németh, I., 2022. Integration of Maintenance Management System Functions with Industry 4.0 Technologies and Features—A Review. Processes, 10(11), 2173. DOI: 10.3390/pr10112173

Shin, J. H., Jun, H. B. 2015. On condition based maintenance policy. Journal of Computational Design and Engineering, 2(2), 119-127. DOI: 10.1016/j.jcde.2014.12.006

Sobaszek, Ł., Gola, A., Świć, A., 2020. Time-based machine failure prediction in multi-machine manufacturing systems. Eksploatacja i Niezawodnosc – Maintenance and Reliability, 22(1), 52-62. DOI: 10.17531/ein.2020.1.7.

Stenström, C., Norrbin, P., Parida, A., Kumar, U., 2016. Preventive and corrective maintenance–cost comparison and cost–benefit analysis. Structure and Infrastructure Engineering, 12(5), 603-617. DOI: 10.1080/15732479.2015.1032983

Vogl, G. W., Weiss, B. A., Helu, M., 2019. A review of diagnostic and prognostic capabilities and best practices for manufacturing. Journal of Intelligent Manufacturing, 30, 79-95. DOI: 10.1007/s10845-016-1228-8

Xhemajl, M., Besart, M., Rrahim, S., 2018. The equipment maintenance management in manufacturing enterprises. IFAC-PapersOnLine 51(30), 800-802. DOI: 10.1016/j.ifacol.2018.11.192.

Xiao, L., Song, S., Chen, X., Coit, D. W., 2016. Joint optimization of production scheduling and machine group preventive maintenance. Reliability Engineering & System Safety, 146, 68-78. DOI: 10.1016/j.ress.2015.10.013

Zhang, C., Zhang, Y., Dui, H., Wang, S., Tomovic, M. M. 2022. Importance measure-based maintenance strategy considering maintenance costs. Eksploatacja i Niezawodność-Maintenance and Reliability, 24(1). DOI: 10.17531/ein.2022.1.3.

Zhu, H., Liu, F., Shao, X., Liu, Q., Deng, Y., 2011. A cost-based selective maintenance decision-making method for machining line. Quality and Reliability Engineering International, 27(2), 191-201.

確保修井作業設備技術操作效率

關鍵詞
維護
機器操作管理
技術操作
修井機
修井作業

摘要
評估了管理系統中資源對機器技術操作系統影響的優先級。 提出的信息支持系統模型，用於做出有關機器技術操作的管理決策。 技術影響因素與所需資源之間的類比得到證實。 它們是："行動"-"人力資源"； "手段"-"物質資源"； "環境"-"信息資源"。 通過專家評估方法確定信息資源在保證機器技術運行效率方面的優先級。 所提出的系統模型包括調度報告信息資源的結構化和系統化，以及企業借助軟件獲取相關信息的信息和分析維護執行進一步分析程序的程序。 這種對設備運行過程的持續監控為工程師提供了必要的數據： 分析和選擇設備技術運行的有效模型； 制定替代管理決策並做出最佳決策； 開發個性化模型和維護策略，並根據實際操作條件進行調整和適應。 該模型還為專業人士提供了綜合評價企業不同時期生產組織效率、發展動態以及管理決策後果的工具。 它可以就管理體系的改進以及隨後形成機器技術操作的有效策略做出明智的決策。