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Application of systematic approach principles for lifting complexes in oil and gas wells

Zastosowanie zasad systematycznego podejścia do zespołów dźwigowych w odwiertach naftowych i gazowych

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ABSTRACT: The application of a systematic approach is crucial in the design, operation, and maintenance of lifting complexes in oil and gas wells. Lifting complexes play a vital role in the extraction of hydrocarbons by facilitating the movement of drilling tools, pipes, and other equipment in and out of the wellbore. The principles of a systematic approach and their significanc in ensuring the safe and efficient functioning of lifting complexes are outlined. The systematic approach involves the integration of various elements, including technology, personnel, processes, and equipment, to achieve desired outcomes. In the context of lifting complexes, the principles of a systematic approach are applied at different stages, from the initial design to the ongoing operation and maintenance. During the design phase, a systematic approach is essential to consider all the factors that influence the lifting complex's performance. This includes assessing the well's characteristics, such as depth, pressure, and geological formations, to determine the appropriate lifting capacity and equipment requirements. Additionally, factors like safety regulations, environmental considerations, and operational efficiency are taken into account to optimize the design. Once the lifting complex is operational, the systematic approach continues to play a crucial role. It involves implementing robust management systems, including quality control, maintenance procedures, and safety protocols. Regular inspections and preventive maintenance help identify potential issues and ensure the reliability of the lifting complex. Furthermore, the systematic approach emphasizes the training and qualification of personnel involved in the operation of lifting complexes. Proper training enables operators to understand the complexities of the equipment, follow standard procedures, and respond effectively to any unexpected situations. Continuous learning and skill development programs contribute to maintaining a high level of professionalism and safety awareness. The application of a systematic approach also includes ongoing monitoring and analysis of performance indicators. This allows for the identification of areas for improvement and the implementation of corrective measures to enhance efficiency, reduce downtime, and mitigate risks. In conclusion, the systematic approach is essential for the successful operation of lifting complexes in oil and gas wells. By considering all relevant factors, integrating technology and personnel, and implementing robust management systems, the systematic approach ensures the safe, efficient, and sustainable extraction of hydrocarbons. Adhering to the principles of a systematic approach leads to optimized designs, improved performance, and increased overall effectiveness of lifting complexes in the oil and gas industry.

Key words: lifting complex, operator, machine, well, control effect, lifting and lowering process, multigraph.

STRESZCZENIE: W projektowaniu, eksploatacji i konserwacji zespołów dźwigowych w odwiertach naftowych i gazowych kluczowe znaczenie ma zastosowanie systematycznego podejścia. Zespoły dźwigowe odgrywają istotną rolę w wydobyciu węglowodorów, umożliwiając przemieszczanie narzędzi wiertniczych, rur i innego sprzętu do i z odwiertu. W niniejszym streszczeniu przedstawiono zasady systematycznego podejścia i ich znaczenie dla zapewnienia bezpiecznego i wydajnego funkcjonowania zespołów dźwigowych. Systematyczne podejście obejmuje integrację różnych elementów, w tym technologii, personelu, procesów i sprzętu, w celu osiągnięcia pożądanych rezultatów. W kontekście zespołów dźwigowych zasady systematycznego podejścia są stosowane na różnych etapach, od wstępnego projektu do bieżącej eksploatacji i konserwacji. W fazie projektowania systematyczne podejście jest niezbędne do rozważenia wszystkich czynników, które wpływają na wydajność zespołu dźwigowego. Obejmuje to ocenę cech odwiertu, takich jak głębokość, ciśnienie i formacje geologiczne, w celu określenia odpowiedniego udźwigu i wymagań sprzętowych. Dodatkowo, uwzględniane są czynniki takie jak przepisy bezpieczeństwa, względy środowiskowe i wydajność operacyjna w celu optymalizacji projektu. Systematyczne podejście odgrywa kluczową rolę także po uruchomieniu zespołu dźwigowego. Obejmuje ono wdrażanie skutecznych systemów zarządzania, w tym kontroli jakości, procedur konserwacji i protokołów bezpieczeństwa. Regularne kontrole i konserwacja zapobiegawcza pozwalają zidentyfikować potencjalne problemy i zapewnić niezawodność działania zespołów dźwigowych. Ponadto systematyczne podejście kładzie nacisk na szkolenie i kwalifikacje personelu obsługującego zespoły dźwigowe. Odpowiednie szkolenie

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pomaga operatorom zrozumieć złożoność sprzętu, postępować zgodnie ze standardowymi procedurami i skutecznie reagować na wszelkie nieoczekiwane sytuacje. Programy ciągłego uczenia się i rozwoju umiejętności przyczyniają się do utrzymania wysokiego poziomu profesjonalizmu i wiedzy na temat bezpieczeństwa. Stosowanie systematycznego podejścia obejmuje również bieżące monitorowanie i analizę wskaźników wydajności. Pozwala to na identyfikację obszarów wymagających poprawy i wdrożenie środków naprawczych w celu zwiększenia wydajności, skrócenia przestojów i ograniczenia ryzyka. Podsumowując, systematyczne podejście jest niezbędne w celu zapewnienia sprawnego działania zespołów dźwigowych w odwiertach naftowych i gazowych. Poprzez uwzględnienie wszystkich istotnych czynników, zintegrowanie technologii i personelu oraz wdrożenie solidnych systemów zarządzania, systematyczne podejście pozwala na bezpieczne, wydajne i zrównoważone wydobycie węglowodorów. Przestrzeganie zasad systematycznego podejścia prowadzi do optymalizacji projektów, poprawy wydajności i zwiększenia ogólnej efektywności zespołów dźwigowych w przemyśle naftowym i gazowym.

Słowa kluczowe: zespoły dźwigowe, operator, maszyna, odwiert, efekt kontroli, proces podnoszenia i opuszczania, multigraf.

Introduction

The process of drilling deep oil and gas wells is a complex and dynamic operation influenced by various external and internal factors. These factors encompass the loads applied to the drilling tool and the duration thereof, the pressure, consumption, and quality of the drilling fluid, the type of drilling solution used, and many others.

The drilling process can be viewed as an integrated system, where all elements work together to achieve efficient well drilling (Director and Rorer, 1974; Dobkin, 1984; Braude and Ter-Mkhitarov, 1985; Aliyev, 2000; 2010; Alekperov, 2015; Aslani and Alizadeh, 2016). This includes preparatory work, pipe installation, lifting and lowering operations, drilling, casing, testing, and other related activities. The stability of the drilling process relies on the continuous involvement of human operators who manage the dynamic properties of the system and ensure the well and equipment are in optimal condition.

During the loading and unloading operations, which are crucial elements of the drilling process, drillers focus on safe and efficient performance. The movement of the drilling tool is characterized by parameters such as speed, acceleration, weight, and bending force of the pipeline. These parameters determine the modes of lowering and raising the tool (Simpson, 1971; Palashkin, 1974; Poqarskiy et al., 1981; Bulatov et al., 2003; Chen, 2014).

The efficiency of the lifting system depends on several interrelated factors, including the structural geometry, material properties, maximum external loads, and their characteristics (duration, number of cycles, etc.), environmental temperature, well depth, kinematic characteristics of the lifting system, and load on the drilling tool. It also depends on factors such as the average travel, lowering and raising speeds of the drilling rig, and lowering speeds of the empty elevator.

The multitude of parameters and factors involved in the process of lowering and lifting the drilling tool necessitates a systematic approach. This approach ensures that all aspects of the operation are taken into account and optimized for safe and efficient drilling. The application of a systematic approach helps to mitigate risks and improve the overall performance of the drilling process (Zeigler et al., 1979; Druzhinin and Kontorov, 1985; Guliyev and Shirinov, 2009; Isaev, 2015; Freitag et al., 2018).

Setting the issue

The purpose of this study is to establish a systematic approach for the lifting complex of a drilling rig, considering the "operator-machine-well" (OMW) system. This involves reviewing and organizing existing theoretical and experimental studies to identify general patterns and principles for tripping operations (Jaber et al., 2017; Sadiq et al., 2017; Gao, et al., 2018; Nwosu and Nwoye, 2018).

The OMW system is a complex system-technical structure that comprises the drilling rig, the operators (including the driller and assistants), and the well itself with its intricate physical, mechanical, and chemical properties. In this system, interactions occur not only within the OMW chain but also among the operators themselves and with other auxiliary workers, such as the 1st, 2nd, and 3rd assistants of the driller, as well as the diesel operator.

Understanding the dynamics and interdependencies within the OMW system is essential for optimizing the tripping operations. By examining the relationships between the operators, the machinery, and the well, this study aims to develop a comprehensive understanding of the system's behavior and establish guidelines for efficient and safe tripping operations

The research will synthesize the existing knowledge and draw conclusions that can contribute to the development of standardized procedures and protocols for the lifting complex of a drilling rig. By considering the human factor, technical aspects, and the characteristics of the well, the study seeks to enhance the overall performance and productivity of the drilling process

In the interaction scheme depicted in Figure 1, the operator is at the center of the system and is in constant contact with both the machine (hoisting equipment) and the object (well).

The operator coordinates and controls the activities of the drilling operation, while the assistants support the operator in executing various tasks.

The machine or hoisting equipment, which includes the lifting complex of the drilling rig, plays a vital role in the tripping operation. It is responsible for the movement and positioning of the drilling tools, pipes, and other equipment in the well.

The well represents the object of the drilling operation. It has a complex structure and encompasses various physical, mechanical, and chemical properties that need to be considered during the tripping operation. The interaction within the system involves a dynamic exchange of information, instructions, and actions between the operator, assistants, machine, and well. This collaboration ensures the smooth and efficient execution of the tripping operation, while also addressing safety concerns and operational requirements.

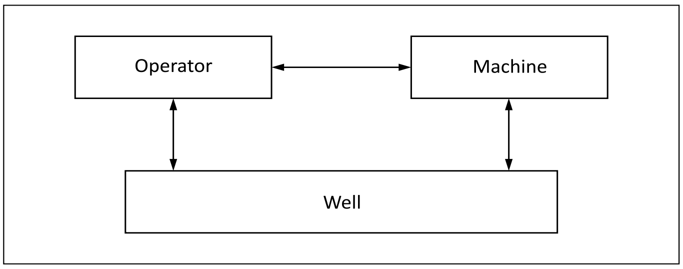

Figure 1. Interaction scheme of the Operator-Machine-Well System

Rysunek 1. Schemat interakcji w systemie operator–maszyna–odwiert

Understanding the interplay between the operator, machine, and well is crucial for optimizing the tripping operation and achieving the desired drilling outcomes. By considering the entire system and its components, it becomes possible to identify potential challenges, develop appropriate procedures, and enhance the overall performance of the drilling process

In Figure 2, the emphasis is on the communication and coordination between the operator, machine, and well during the drilling process.

The operator plays a central role in controlling and overseeing the ongoing processes in the well. They receive information from the well and make decisions and adjustments based on that information.

The machine, represented by the hoisting equipment and other drilling machinery, acts as a tool that the operator utilizes to implement the drilling process. The machine is responsive to the commands and instructions issued by the operator, and it carries out the physical tasks required for drilling the well.

The well, as the target and focus of the drilling operation, provides information to the operator about its conditions, such as pressure, depth, geological formations, and other relevant parameters. This information helps the operator make informed decisions and adjustments to ensure the drilling process proceeds smoothly and efficiently.

The communication between the operator, machine, and well is essential for maintaining coordination and synchronization. The operator receives real-time feedback and data from the well, interprets it, and transmits instructions to the machine

Figure 2. A block that displays the data received by the operator

Rysunek 2. Moduł wyświetlania danych odebranych przez operatora accordingly. The machine, in turn, responds to these instructions and performs the necessary actions in the well.

This continuous communication and coordination between the operator, machine, and well ensure that the drilling process progresses effectively and safely. It allows for timely adjustments and responses to changing conditions in the well, contributing to the overall success of the drilling operation.

The generalized model of the lowering and lifting (OLL) system technical complex, as described by Aliyev (2010), consists of various elements represented by letters. Here is the breakdown of the elements in the model (Figure 3).

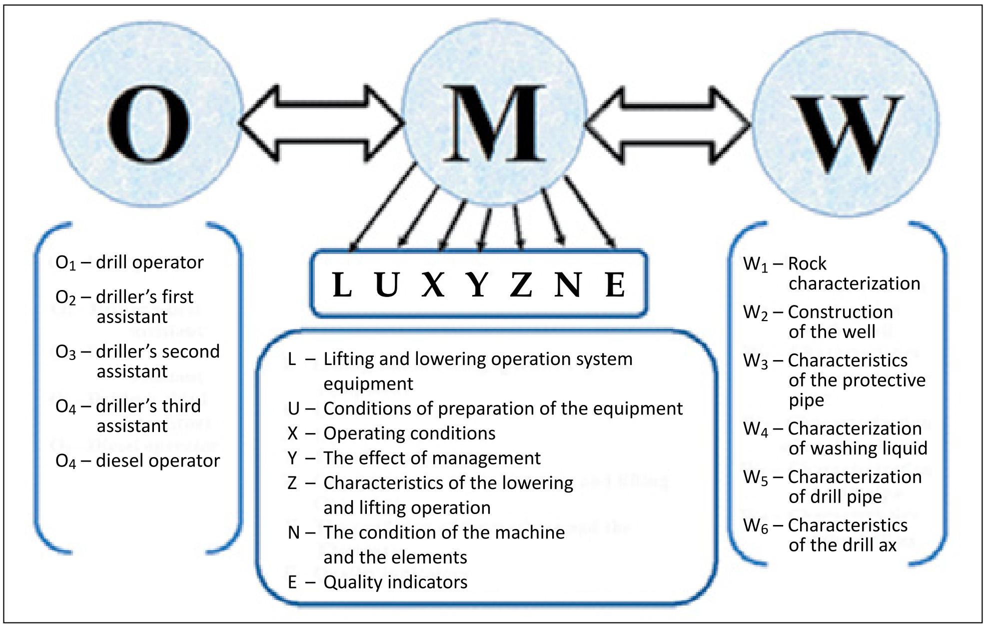

Figure 3. Generalized model of OMW as a system

Rysunek 3. Uogólniony model OMW (operator–maszyna–odwiert) jako systemu

"O" represents the operator's activities and involvement in the OLL system; "M" represents the effect of the machine, including the characteristics of the equipment used in the OLL system; "L" describes the specific characteristics of the equipment within the OLL system; "U" represents the manufacturing conditions of the equipment used in the OLL system; "X" refers to the operational conditions, including factors such as temperature, pressure, and environmental conditions that affect the OLL system; "Y" represents the management effect, which includes the influence of managerial decisions and strategies on the OLL system; "Z" represents the characteristics of the OLL process itself, including parameters such as speed, acceleration, and forces involved; "N" and "E" indicate the state and quality indicators of the lifting complex, which reflect the overall condition and performance of the equipment used in the OLL system; "W" describes the condition of the well, including its geological features, pressure, depth, and other relevant parameters.

The model suggests that each of these elements plays a role in the functioning and performance of the OLL system. The interactions and relationships between these elements determine the overall efficiency, safety, and success of the lowering and lifting operations in the drilling process

Solution of the issue and discussion of the solution

In the solution of the issue and the discussion of the solution, it is necessary to analyze the individual roles and functions of the members involved in the drilling team and their interactions within the "operator-machine-well" (OMW) system.

The operator activity, denoted by O, can be described by the following set:

$$\mathbf{O = \{O_1, O_2, O_3, O_4, O_5\}}$$

$\mathbf{O_1}$ represents the driller, who is responsible for overseeing and managing the drilling operation.

$\mathbf{O_2}$, $\mathbf{O_3}$, $\mathbf{O_4}$ characterize the activities of the 1st, 2nd, and 3rd assistants of the driller, respectively. These assistants support the driller in various tasks and ensure the smooth execution of the drilling process.

$\mathbf{O_5}$ refers to the diesel operator, who operates and maintains the diesel equipment used in the drilling operation.

These members of the drilling team play crucial roles in the overall success of the drilling process. They work in coordination and collaboration, ensuring effective communication and interaction among themselves and with the other elements of the OMW system.

The solution of the issue and the discussion of the solution would involve analyzing the specific functions, responsibilities, and interactions of each member within the drilling team. This analysis would help identify potential areas for improvement, optimize the communication and coordination processes, and enhance the overall efficiency and safety of the drilling operation.

In the drilling or OLL (lowering and lifting) processes, multiple operators with different professional roles are involved, and various mechanisms and equipment are interconnected in a dynamic and evolving manner.

The processes involved in drilling or OLL are carried out in a specific sequence. The primary operator, O_1, receives signals and information from the machine and well. This operator acts as the central control point and is responsible for interpreting and processing the incoming signals.

Operators O_2, O_3, and O_4 directly implement the instructions and signals received from O_1. They utilize their sensorimotor organs and muscle systems to execute specific physical actions. In the context of lifting operations, operators O_2 and O_3 are involved in activities such as holding, opening, and positioning the drilling pipeline.

The coordination and cooperation between these operators are essential for the smooth execution of the drilling or OLL processes. O_1 acts as the coordinator and relays instructions and information to the other operators based on the signals received from the machine and well. O_2, O_3, and O_4, as the executing operators, perform their assigned tasks according to the instructions and signals received.

This division of labor and interaction between operators and equipment ensures the efficient and precise implementation of drilling or OLL operations. By following the established sequence and coordinating their actions, the operators contribute to the overall success of the drilling process and ensure the safety of the equipment and personnel involved.

During the lowering process, operators O_2 and O_3 are involved in tasks such as belt clamping and adding candles. These processes require the use of machine elements L_1, L_2, and L_3.

In addition, operator O_4, positioned on the balcony of the drill rig, is responsible for the positioning and attachment of the drill pipes during both lifting and lowering operations. This operator ensures that the pipes are properly aligned and securely connected.

Operator O_5, the diesel operator, plays a role when working with diesel engines. This operator controls the diesel engines according to the requirements of the drilling technology. Their actions and adjustments are coordinated with operators O and O_1, ensuring that the diesel engines operate in sync with the drilling process.

Throughout the process, operator O_1 acts as the central coordinator, receiving signals and information from the machine and well, and interacts with operators O, O_4, and O_5. Operator O_1 influences the progress of the process by providing instructions, making decisions, and coordinating the actions of the operators.

The interactions and coordination between operators O, O_1, O_4, and O_5, as well as the use of specific machine elements, contribute to the overall efficiency and safety of the drilling or OLL process. It ensures that the equipment is operated in accordance with drilling technology requirements and facilitates the smooth progress of the operations.

Let me clarify the coordination and effects within the "operator-machine-well" (OMW) system.

In the OMW system, the effects and actions of operators O_4 and O_5, as well as the machine elements L_1, L_2, and L_3, are coordinated with operators O and O_1. Operator O_1 acts as the central coordinator and receives signals from the machine and well, while operator O receives and processes these signals.

The coordination between operators O, O_1, O_4, and O_5 ensures that the actions of the operators and the operation of the machine elements align with the overall objectives of the drilling process. Operator O_1, as the coordinator, influences and guides the activities of the other operators based on the signals received and the requirements of the drilling process.

The ultimate impact of operator O_1's coordination and influence is reflected in variable "Y," which represents the progress of the drilling process. The coordinated efforts of all operators and the proper functioning of the machine elements contribute to the advancement and success of the drilling operation.

By effectively coordinating the actions, aligning them with the requirements of the drilling process, and maintaining communication among the operators, the OMW system can optimize the progress and efficiency of the drilling process.

OLL system equipment "L"

In the OLL (lowering and lifting) system, the equipment elements denoted as "L" play a crucial role in facilitating the drilling operation. These equipment elements are designed to handle the lowering and lifting processes of the drilling rig.

The specific equipment elements may vary depending on the drilling rig and the operational requirements, but they generally include components such as:

1. Hoisting System: this includes the winch, draw works, and associated pulleys or sheaves. The hoisting system provides the lifting force necessary for raising and lowering the drill pipes and other equipment into and out of the well.
2. Derrick or Mast: this is a tall structure that supports the hoisting system and provides the necessary height for the lifting operations. the derrick or mast is designed to withstand the loads and stresses involved in lifting heavy drill pipes and equipment.
3. Elevators and Slips: elevators are specialized clamping devices used to secure the drill pipes during lifting or lowering operations. Slips are another type of gripping mechanism that holds the pipes in place while the elevators are being attached or detached.
4. Power Swivel: this is a rotary device that provides rotational force to the drill string during the drilling process. It allows for the controlled rotation of the drill pipes and the bit while drilling.

5. Cathead: a cathead is a powered winch or drum used for handling smaller components or auxiliary operations such as making up or breaking out drill pipe connections.
6. Safety Devices: various safety devices such as overload protection systems, emergency stop mechanisms, and backup braking systems are incorporated into the equipment to ensure the safety of personnel and prevent equipment failures.

These equipment elements are designed and engineered to withstand the loads, pressures, and operating conditions encountered during drilling operations. Their proper functioning, maintenance, and adherence to safety protocols are crucial for the overall efficiency and safety of the OLL system in the drilling rig.

The equipment elements of the OLL (lowering and lifting) system can be further described as follows:

$$\mathbf{L = \{L_1; L_2; L_3\}}$$

L_1 – mechanisms for displacement and control of the drilling pipeline:

$$\mathbf{L_1 = \{L_{11}; L_{12}; L_{13}\}}$$

L_{11} – drilling winch equipped with a gearbox, transmission units, brake structures, and a pneumatic clutch. It is responsible for the descent and ascent of the drilling string, transmitting rotational motion from the drilling motors through pneumatic clutches, gearboxes, and chain drives. It is equipped with main and auxiliary brakes for speed regulation and complete stopping of the lifting shaft.

L_{12} – automatic elevator lift system, designed to pick up and release the drill pipe string during tripping operations. It is suspended from the travel block and operates automatically.

L_{13} – pneumatically controlled wedge holders placed on the rotor. These wedge grips are used to hold the drill string during tripping operations and the casing string during well casing. They provide secure grip and support for the string.

L_2 – mechanisms for holding, lifting, and placing individual drill plugs:

$$\mathbf{L_2 = \{L_{21}; L_{22}; L_{23}\}}$$

L_{21} – candle holding mechanism (CHM) used to grip and release the candles automatically. It consists of a gripping device and a carriage attached to the boom bracket of the candle arrangement mechanism.

L_{22} – candle lifting mechanism, a double-acting cylinder block with a working pressure of 0.6 - 0.9 MPa. It is used to raise and lower the capture mechanism with the candle during its transfer.

L_{23} – candle positioning mechanism designed to transfer the candle from the center of the well to the candlestick and back. It consists of a frame with a trolley moving along guides and an arrow.

The candle positioning mechanism is an important component of the OLL system and is responsible for transferring candles from the center of the well to the candlestick and vice versa. Here are some additional details about this mechanism:

- **Structure**
  The candle positioning mechanism consists of a frame, a trolley, guides, and an arrow. The frame provides support and stability for the mechanism, while the trolley moves along the guides to facilitate the transfer of candles. The arrow is used to accurately position and direct the movement of the candles.
- **Drive**
  The mechanism is driven by electric motors of al ternating current. Each motor has a power rating of 3.5 kW, providing sufficient power to move the trolley and transfer the candles at the desired speed of 0.4 m/s. The electric motors ensure precise and controlled movement of the mechanism.
- **Candlestick**
  The candlestick is a metal structure divid ed into sections. Its purpose is to hold and support the candles during the drilling process. The candlestick is designed specifically to accommodate the candles used in the drilling operations, allowing for easy installation and removal.

By using the candle positioning mechanism, operators can efficiently transfer candles between the center of the well and the candlestick, ensuring the availability of candles when needed during the drilling process. The mechanism's precise movement and reliable electric drive contribute to the overall effectiveness and safety of the OLL system.

L_3 – mechanisms for opening and closing the lock joints of drilling pipes:

$$\mathbf{L_3 = \{L_{31}; L_{32}; L_{33}\}}$$

L_{31} – AKB type pneumatic drill key, used for mechanization and automation of screwing, unscrewing, and building up the string during tripping operations. It facilitates the operations with drill pipes in oil and gas wells.

L_{32} – pneumatic fastener, consisting of a cylinder with a piston and a rod. It is used to unfasten tool joints with machine keys. Compressed air moves the piston and rotates the machine key through a metal cable.

L_{33} – machine switches, used for screwing, unscrewing, reattaching, and unfastening well pipes during the tripping process.

These equipment elements within the OLL system enable the operators to handle the lowering and lifting operations efficiently and safely. They provide control, support, and automation for various tasks involved in the drilling process, contributing to the overall productivity and effectiveness of the drilling rig.

Conditions of preparation of machines and equipment “U”

The conditions of preparation of machines and equipment, denoted by “U”, are essential for ensuring the proper functioning and reliability of the OLL system. Here is a breakdown of the different aspects included in this set:

$$U = \{U_1; U_2; U_3; U_4\}$$

U_1 – provision of machine-building plant with technological equipment This refers to the availability and suitability of the necessary technological equipment at the machine-building plant responsible for manufacturing the OLL system components. It includes the presence of machinery, tools, and resources required for the production process. Adequate technological equipment ensures the efficient and accurate manufacturing of the OLL system components.

U_2 – material and technical supply of the manufacturing process This aspect focuses on the availability and quality of materials and components needed for the manufacturing process. It includes the timely procurement and supply of raw materials, parts, and other necessary components required for the production of the OLL system. Proper material and technical supply contribute to the production of high-quality and reliable equipment.

U_3 – provision of the enterprise with professional personnel, engineering and technical, and scientific workers. The availability of skilled and knowledgeable personnel is crucial for the successful preparation of machines and equipment. This includes having a competent workforce comprising professionals, engineers, technical staff, and scientific workers who possess the necessary expertise and experience to handle the manufacturing process. Adequate provision of qualified personnel ensures efficient and accurate production.

U_4 – organization of production (quality management process) This aspect focuses on the overall organization and management of the production process, including quality management. It involves the establishment of proper production planning, control systems, and quality assurance measures. Effective organization of production ensures adherence to standards, specifications, and quality requirements, resulting in the production of reliable and high-quality machines and equipment.

By considering and addressing these conditions of preparation (U), the manufacturing process of the OLL system can be carried out efficiently, ensuring the availability of suitable technological equipment, adequate material supply, skilled personnel, and well-organized production processes. These factors contribute to the overall quality and performance of the machines and equipment used in the OLL system.

Operating conditions “X”

The operating conditions, denoted by “X”, encompass various factors that influence the functioning and performance of the OLL system.

- **Type of pipeline released into the well**.
  This aspect refers to the specific type of pipeline that is used and released into the well during the drilling or OLL process.
- **Pressure conditions**
  Pressure conditions relate to the pressure exerted within the well during drilling or OLL operations. This factor can vary depending on the depth of the well, geological formations, and the specific drilling or OLL process being conducted. The pressure conditions can impact the performance and reliability of the OLL system, including the mechanisms, equipment, and overall operation.
- **Temperature conditions**
  Temperature conditions encompass the range of temperatures experienced within the well during drilling or OLL processes. The temperature can vary depending on the geographical location, depth of the well, and other environmental factors. Extreme temperature conditions can affect the materials, lubrication, and performance of the OLL system components, requiring appropriate design considerations and material selection.
- **Environmental conditions**
  Environmental conditions refer to the external factors surrounding the drilling or OLL operation. This includes factors such as weather conditions, humidity, presence of corrosive substances, and other environmental elements. Adverse environmental conditions can impact the performance and longevity of the OLL system, requiring protective measures and appropriate equipment selection.
- **Operational parameters**
  Operational parameters encompass various parameters that are specific to the drilling or OLL process itself. This can include factors such as drilling speed, rotational speed, axial load, vibration levels, and other parameters relevant to the specific operation being carried out. Operational parameters play a crucial role in determining the efficiency, effectiveness, and reliability of the OLL system.

Proper consideration of these conditions ensures the performance, safety, and longevity of the OLL system under various operational scenarios.

Here is a breakdown of the different aspects included in this set:

$$X = \{X_1; X_2; X_3; X4; X_5\}$$

where: X_1 is the type of pipeline that is released into the well. It can be further subdivided into specific types, denoted as X_{11} and X_{12}, which represent different pipeline configurations or materials. The type of pipeline used can impact factors such as its strength, durability, and compatibility with other system components:

$$X_1 = \{X_{11}; X_{12}\}$$

X_{11} – drilling pipeline. The drilling pipeline refers to the drill pipes that are used for the process of lowering into a borehole and lifting a rock cutting tool during drilling operations. These drill pipes serve multiple functions, including transmitting rotation, creating an axial load on the tool, and supplying flushing fluid or compressed air to the bottom of the well. The drill pipes are connected to each other using drill locks with a special locking thread. The ends of the pipes are thickened through external, internal, or combined upsetting to enhance their strength and durability.

X_{12} – protective pipeline. The protective pipeline, in this context, specifically refers to casing pipes used in a freshly drilled well. The purpose of these casing pipes is to strengthen the well, prevent soil shedding and slippage, and ensure the uninterrupted operation of the production site. Casing pipes serve two primary technological tasks: preserving the integrity of the well walls and providing a watertight system. The pipes must possess sufficient strength to withstand various mechanical overloads, both static and dynamic, at any impact speed. Additionally, they need to ensure the water tightness of the well, maintaining the integrity of the drilled channel's geometry.

Considering the specific types of pipelines (X_{11} and X_{12}) within the operating conditions (X) allows for the selection of appropriate equipment, mechanisms, and processes within the OLL system. It ensures compatibility, functionality, and safety during drilling or OLL operations, addressing the unique requirements and challenges associated with each type of pipeline.

X_2 – relative mass. The relative mass in the context of the operating conditions refers to the mass of the load being handled during the lifting and lowering processes. It is described by the following subsets:

$$X_2 = \{X_{21}; X_{22}\}$$

X_{21} – relative mass in one lift. The relative mass in one lift represents the weight of the load being lifted during the OLL process. It is important to consider this parameter to ensure efficient use of the drilling motors' power. As the weight of the drill pipe decreases during the lifting process, it is necessary to adjust the lifting speed accordingly. The objective is to maintain a minimum speed that allows the drilling motors to operate efficiently while lifting the load.

X_{22} – relative mass in one download. The relative mass in one download refers to the increasing mass of the load during the lowering process. It is crucial to continuously monitor and control the speed of the tool during lowering. As the relative mass increases, it is important to ensure that the speed is properly regulated and that the auxiliary brake is engaged in a timely manner. This control is necessary to maintain the stability and safety of the OLL process.

Considering the relative mass (X_2) in both lifting and lowering operations allows for the appropriate adjustment of speed and braking mechanisms. By taking into account the changing weight of the load, operators can optimize the efficiency and safety of the OLL system, ensuring smooth and controlled movements during the drilling or OLL processes.

X_3 – technological variant of work, describes different approaches or methods used in the drilling or OLL processes. It is divided into two subsets:

$$X_3 = \{X_{31}; X_{32}\}$$

X_{31} – basic works. Basic works involve the primary activities related to the creation of an oil and gas well. This process requires the use of powerful drilling rigs and precise engineering calculations. Quality control is essential to prevent soil erosion and ensure the integrity of the well during its operation. Guide casing strings are used to secure the space between the soil walls and the pipes, and proper cementing is carried out to prevent water ingress and maintain the stability of the well. The application of proper drilling technology guarantees reliable protection against soil exfoliation and groundwater intrusion.

X_{32} – auxiliary works. Auxiliary works encompass various complications and problems that can arise during drilling or OLL operations. These include rockslides, oil and gas manifestations, water manifestations, tool accidents, accidents with drill pipes and locks, accidents with downhole motors, and accidents with casing strings. These situations require specific measures and precautions to be taken to address the challenges encountered. It involves factors such as monitoring the density of the flushing liquid, preventing a decrease in liquid level, dealing with tool sticking situations, handling emergencies or accidents, and managing well curvature, which can have geological, technical, or technological origins.

Considering the technological variant of work (X_3) allows operators and drilling teams to adapt their approach and implement appropriate measures to overcome challenges and ensure the successful completion of drilling or OLL operations. By understanding the specific conditions and potential complications associated with each variant, they can apply the necessary techniques and precautions to optimize the efficiency, safety, and overall performance of the process.

X_4 – management professionalism. In the context of the OLL system, management professionalism refers to the collective knowledge, skills, values, and attitudes necessary for effective managerial activity. It encompasses the expertise and capabilities required for individuals in managerial roles to fulfill their responsibilities and achieve desired outcomes. The professionalism of management is developed through experience and continuous learning in the field of management.

Management professionalism involves several key aspects:

$$X_4 = \{X_{41}; X_{42}; X_{43}; X_{44}\}$$

X_{41} – special knowledge. Managers need to possess specialized knowledge related to their specific area of management, such as drilling operations, equipment maintenance, safety regulations, and relevant industry practices. This knowledge enables them to make informed decisions, plan and coordinate activities, and effectively allocate resources.

X_{42} – skills. Managers require a diverse set of skills to perform their duties effectively. These skills may include communication and interpersonal skills for effective team collaboration, problem-solving and decision-making skills to address operational challenges, strategic planning skills to set goals and objectives, and leadership skills to motivate and guide their team members.

X_{43} – values. Professional managers adhere to ethical standards and demonstrate values such as integrity, accountability, and transparency. They prioritize the well-being and safety of their team members, promote a culture of fairness and respect, and strive for excellence in their work.

X_{44} – attitudes. Positive attitudes are essential for effective management. Managers should have a proactive and adaptive mindset, embracing change and innovation. They should be open to feedback, willing to learn from mistakes, and continuously seek opportunities for professional growth and development.

By demonstrating management professionalism, individuals in managerial roles within the OLL system can effectively lead their teams, optimize operations, ensure compliance with regulations, and contribute to the overall success of drilling or OLL projects.

X_5 – level of maintenance. The level of maintenance in the OLL system refers to the extent of attention and care given to the various components and systems involved in drilling or OLL processes. Proper maintenance is crucial to ensure the reliable and safe operation of equipment and to prevent potential failures or accidents. The level of maintenance can be categorized into the following:

$$X_5 = \{X_{51}; X_{52}\}$$

X_{51} – adjustment of braking systems. Regular inspection and adjustment of braking systems are essential for safe operation. This includes monitoring the condition of brake pulleys, brake bands, and brake shoes. Cracks, tears, or excessive wear should be addressed promptly, and worn-out components should be replaced to maintain proper braking performance.

X_{52} – replacing worn-out parts. To ensure the optimal functioning of the OLL system, worn-out parts should be identified and replaced in a timely manner. This includes various components such as brake pairs, steel ropes, pneumatic clutches, key plates, drill axes, and retaining wedge plates. Monitoring the condition of these parts and replacing them, when necessary, helps prevent equipment failures and ensures the smooth operation of the system.

$$X_{52} = \{X_{521}; X_{522}; X_{523}; X_{524}; X_{525}; X_{52}6\}$$

X_{521} – brake pairs. Regular monitoring of the brake pulley and segments is necessary to identify wear and ensure the proper functioning of the braking system. If the wear exceeds the permissible limit, the brake segments should be replaced, and the system should be adjusted accordingly (Shakhmaliyev, 1960).

X_{522} – steel ropes. Continuous monitoring of steel ropes is essential to prevent wear and rupture. Any signs of wire wear or breakage should be addressed promptly by replacing the affected ropes. Failure to do so can compromise the safety and durability of the lifting system.

X_{523} – pneumatic clutches Proper maintenance of pneumatic clutches is important to prevent excessive wear and potential failure. Monitoring the working pressure and ensuring it meets the required standards is crucial. If the pressure is below the norm, adjustments and necessary replacements should be carried out to maintain optimal clutch performance.

X_{524} – key plates. Key plates, which are responsible for opening and closing the pipes, are subject to wear and should be regularly monitored. If significant wear is detected, the plates should be replaced to ensure proper functioning and safety.

X_{525} – drill axes. Monitoring the condition of drill axes is necessary to prevent premature failure due to contact with rock and improper load and rotation speed combinations. Timely replacement of worn-out drill axes helps maintain operational efficiency and prevents unnecessary downtime.

X_{526} – retaining wedge plates. During lifting and lowering operations, the retaining wedge plates can experience wear, resulting in increased slips during gripping. Regular inspection and replacement of worn teeth and plates are necessary to ensure safe and reliable gripping of the pipes.

By maintaining a high level of maintenance, operators can mitigate risks, enhance equipment performance, and ensure the safety and efficiency of the OLL system throughout the drilling or OLL processes.

Management influence "Y"

The management influence in the OLL system refers to the actions taken by operators to control and manipulate various components and subsystems of the system. These actions are aimed at achieving specific objectives and ensuring the safe and efficient operation of the OLL system.

The management influence is described by the following set.

$$\mathbf{Y = \{Y_1; Y_2; Y_3; Y_4; Y_5; Y_6\}}$$

$\mathbf{Y_1}$ – operator's influence on the command controller of winch engines. The operator has control over the command controller of winch engines, which allows them to adjust and regulate the operation of the engines. This includes influencing the steering wheel of fuel pumps in diesel transmission to control the fuel supply and engine speed.

$\mathbf{Y_2}$ – impact on the working and emergency brake of the drilling winch. Operators have the ability to control and influence the working and emergency brake of the drilling winch. This includes applying and releasing the brake to control the speed and movement of the winch. Hydraulic disc brakes are often used in OLL systems due to their advantages such as high lifting power, heat-resistant attenuation, easy operation, fast response, and less downtime compared to band-shoe brakes.

$\mathbf{Y_3}$ – Effect of the operating tire-pneumatic coupling on the crane. The operator can influence the operation of the tire-pneumatic coupling in the crane system. This coupling is responsible for providing the necessary force and control for lifting and moving heavy loads. Operators can engage and disengage the tire-pneumatic coupling as needed to perform lifting operations.

$\mathbf{Y_4}$ – effect on the pedal controlling the wedges. Operators have control over the pedal that controls the wedges in the OLL system. The wedges play a crucial role in securing and gripping the pipes during lifting and lowering operations. Operators can manipulate the wedges by applying pressure to the controlling pedal, ensuring proper gripping and release of the pipes.

$\mathbf{Y_5}$ – periodic impact on the gearbox. Operators periodically influence the gearbox in the OLL system. The gearbox is responsible for transmitting and controlling the rotational power from the engines to the winch and other components. Operators can adjust and maintain the gearbox to ensure optimal performance and efficient power transmission.

$\mathbf{Y_6}$ – connecting and disconnecting the auxiliary brake. Operators have the ability to connect and disconnect the auxiliary brake system in the OLL system. The auxiliary brake provides additional braking power and control when needed. Operators can engage the auxiliary brake to enhance the braking performance and ensure the safety of the system during various operations.

By exerting their management influence, operators can effectively control and manipulate the different subsystems and components of the OLL system, ensuring its proper functioning, safety, and efficiency throughout the drilling or OLL processes.

Characteristics of the OLL process "Z"

The characteristics of the unloading operation process are described by the following set:

$$\mathbf{Z = \{Z_1; Z2; Z_3; Z_4; Z_5; Z_6; Z_7\}}$$

The drilling rig is equipped with a set of mechanisms and tools for capturing, lifting, holding the rotor of the drill or casing string on weight or on the table during the screwing and unscrewing of pipes extracted from the well or lowered into it.

To perform these operations, elevators, clip grips, safety belts, mechanical, machine and circular keys are used.

The process of lifting the drill string from the well consists of cyclically repeating operations in a certain sequence:

In the characteristic set Z, the step Z_1 refers to gripping the drill string as the loaded elevator is lifted. This step involves securely grabbing and holding onto the drill string using the elevator, a tool specifically designed for lifting and suspending the drill string.

During the lifting process, when the elevator is loaded with the weight of the drill string, it is essential to ensure a firm grip to prevent any slippage or accidental release. This is crucial for maintaining control and stability during the lifting operation.

By gripping the drill string effectively with the elevator, the subsequent steps of the unloading process can be carried out smoothly and safely. The gripping action ensures that the drill string remains securely held during the lifting and handling operations, reducing the risk of accidents and facilitating the overall efficiency of the process.

$\mathbf{Z_2}$ – stopping the empty elevator – at this stage, it is necessary to stop the movement of the empty elevator. Stopping the elevator ensures that it remains in a stationary position, preventing any unintended movements or potential hazards. This step allows the rig operators to safely proceed with the subsequent actions in the unloading process, such as releasing the drill string from the elevator or preparing for the next operation;

$\mathbf{Z_3}$ – stopping the loaded elevator – stopping the loaded elevator serves multiple purposes. Firstly, it allows the rig operators to stabilize the elevator and securely hold the drill string in place. This is crucial for safety reasons as it prevents any unintended movements or potential accidents during the subsequent operations.

Secondly, stopping the loaded elevator creates a controlled environment for the release of the raised leading pipe from the tensile load. This step ensures that the tension on the drill string is appropriately managed before proceeding with unscrewing the leading pipe from the column.

$\mathbf{Z_4}$ – catching the drill string when lifting the empty elevator – this step is crucial as it allows for the controlled handling and manipulation of the drill string during the unloading process. Proper alignment and catching of the drill string with the empty elevator ensure stability and prevent any accidental disengagement or damage to the equipment.

$\mathbf{Z_5}$ – lowering the loaded elevator – Lowering the loaded elevator requires controlled and precise movement to ensure the safety of personnel and equipment. The elevator is gradually lowered, allowing the drill string to descend at a controlled rate. This step is important for positioning the drill string at a desired depth within the well.

During the lowering process, operators need to closely monitor the descent speed and ensure that the elevator and drill string remain stable. Adequate communication and coordination among the rig crew are necessary to maintain control over the operation and prevent any sudden movements or accidents.

The speed of lowering the loaded elevator should be carefully regulated to prevent excessive tension or impact on the drill string, which could lead to damage or loss of control. Operators may need to adjust the lowering speed based on the specific conditions and requirements of the well.

$\mathbf{Z_6}$ – adding or opening three drill pipes – this step is crucial for extending the length of the drill string, allowing for deeper drilling or reaching specific target zones within the well. Proper execution of this step ensures that the drill string remains intact and allows for continued drilling operations without interruptions.

After the three drill pipes have been added, the unloading operation process can proceed to the next step, which may involve stopping the elevator, capturing and lifting the drill string to the next desired length, and continuing the unloading process in a systematic manner.

$\mathbf{Z_7}$ – grabbing the drill string and raising it to the length of the next three pipes, opening it and placing it in a special place. Proper execution of step Z_7 is essential to ensure the safe and efficient unloading of the drill string. By carefully grabbing, raising, opening, and placing the drill string, the rig crew can maintain control and minimize the risk of accidents or damage to the equipment.

The descent of the column – in the reverse order.

Condition of the machine and its elements "N"

The condition of the machine and its elements, represented by the set "N" includes the following characteristics:

$$\mathbf{N = \{N_1; N_2; N_3; N_4; N_5; N_6; N_7\}}$$

$\mathbf{N_1}$ – stability of individual elements of the drilling rig and the LLO. This involves ensuring reliable storage, the ability to operate without maintenance, ease of installation and dismantling, convenience of equipment servicing, and safety of the service staff. Two limit states are considered to determine possible collapse or total deformation of the drilling rig's details.

$\mathbf{N_2}$ – consideration of tensions arising in responsible details. Design stresses are determined for the largest loads, taking into account the maximum torque, load, and pressure given to different components of the lifting complex.

$\mathbf{N_3}$ – wear in parts. Wear is the main defect leading to machine failure. Understanding wear phenomena and their causes is crucial for effective maintenance and prevention of equipment breakdown.

$\mathbf{N_4}$ – heating of details. Overheating of bearings, clutch parts, and brakes can occur due to high shaft speeds, excess lubricating oil, or increased viscosity, leading to accelerated wear.

$\mathbf{N_5}$ – thermomechanical loading. The dynamic nature of loads on the lifting complex elements results in thermal and mechanical loading. The process of lowering and lifting drill pipes generates kinetic energy, converting into heat through friction between brake and clutch elements. This leads to thermal stresses and the appearance of thermal spots and microcracks.

$\mathbf{N_6}$ – deformations of the lift complex details. Deformations can occur in response to mechanical loading, thermal stresses, or other external factors, affecting the performance and structural integrity of the lifting complex.

$\mathbf{N_7}$ – corrosion resistance of lifting complex details. The resistance to corrosion is essential for maintaining the durability and reliability of the lifting complex components, considering the corrosive nature of the operating environment in oil and gas wells.

These characteristics highlight the importance of monitoring and maintaining the condition of the machine and its elements to ensure safe and efficient lifting operations in oil and gas wells.

Quality indicators "E"

The quality indicators of LLO (Lifting, Lowering, and Operating) machines and equipment, represented by the set "E" include the following characteristics:

$$E = \{E_1; E_2; E_3; E_4; E_5; E_6; E_7; E_8; E_9; E_{10}\}$$

E_1 – mass – designing, manufacturing, and operating equipment with minimum weight and dimensions using modern technologies to optimize efficiency and portability.

E_2 – productivity – factors such as the compatibility of drilling pumps' pressure and efficiency with drilling technology requirements, appropriate power and speed for lowering and lifting the drilling belt, and the ability to handle axial load and rotation frequency contribute to increased productivity.

E_3 – reliability – measures to reduce loads, improve operating modes, increase the strength of elements, simplify construction, eliminate vibrations, and minimize dynamic loads to ensure reliable and consistent operation.

E_4 – precision – factors influencing precision include machine tool characteristics (motion, geometric precision, temperature, hardness, and wear), tool design and cutting speed, layout considerations, worker skills, working conditions, and quality control measures.

E_5 – energetic – energy indicators measure specific energy consumption per unit volume of work performed, taking into account resistance forces encountered by the machine's working components. This includes specific resistance of machines, power requirements, and related factors.

E_6 – ergonomic – ergonomic indicators assess the properties of machines and units that affect the working conditions, including cabin type, seat comfort, heating, ventilation, ease of maintenance, occupational safety, and aesthetic aspects.

E_7 – economic – economic indicators evaluate productivity and operating costs associated with machine operation as part of larger systems. This includes unit performance, labor costs, and financial considerations.

E_8 – aesthetic – aesthetic indicators encompass the quality of product design, ensuring an attractive outer appearance that aligns with market expectations and user preferences.

E_9 – patent law – patent and legal indicators assess the degree of patent protection and patent purity of the product. These indicators measure the level of patent protection and the compliance with patent regulations.

E_{10} – transportation – transportation indicators involve optimizing the method of transportation, selecting the appropriate mode of transport, and optimizing transportation process parameters to ensure efficient and cost-effective logistics.

These quality indicators aim to address various aspects of LLO machines and equipment, including performance, reliability, energy efficiency, ergonomic considerations, economic viability, intellectual property protection, and transportation optimization.

Well "W"

The vertex "W" in the multigraph is defined by the following set:

$$W = \{W_1; W_2; W_3; W_4; W_5; W_6\}$$

Here are the characteristics represented by each element in the set:

W_1 – Rock characteristics. Determining the rock characteristics is crucial for drilling operations as it determines the type of drill bit, axial force, and torque applied to the drilling pipeline. Rocks are classified into three main types: sedimentary, igneous, and metamorphic. Sedimentary rocks include organic (such as oil, gas, coal) and inorganic rocks (chemical and clastic origin). Igneous rocks are further categorized into effusive and intrusive types. Metamorphic rocks result from the alteration of existing rocks due to high pressure and temperature.

W_2 – well depth and drilling step diameters. Well construction is characterized by the initial and final diameters, the number and lengths of protective pipes, barrel diameters at different points, and the well's inclination angle. The specifics of well construction depend on various factors such as the drilling purpose, geological conditions, depth, drilling technique, and field development method.

W_3 – characteristics of casing pipes. Casing pipes are used to complete casing strings, providing well fixation and separating permeable horizons. Key considerations for casing pipes include geometrical parameters, connection type, and pipe material and strength characteristics. During the lowering of casing strings, components and parts like connections, the derrick's centricity, tackle system, preventer, and mud pumps need to be checked.

W_4 – characteristics of flushing fluid. The choice of flushing fluid type and properties depends on the hydrogeological conditions of the well section and technical requirements. Factors to consider include the mineralogical composition of the rocks being drilled, presence of reservoir fluids, and the need to prevent complications during drilling.

W_5 – characteristics of drill pipes. Drill pipes serve as working tools for transmitting torque, breaking rocks with the chisel, and supplying flushing solution to the well. Their characteristics include wall cross-section, length, types of locks used, as well as parameters to withstand mechanical, temperature, and chemical loads. Drill pipes can be spliced to form a multi-meter route, and their ends are thickened and equipped with drill locks.

W_6 – drilling speed. Drilling speed is influenced by energy costs and the proper selection and properties of drilling tools. The material and properties of the drilling tools are important factors, and the actual service life of the equipment determines its overall usefulness and resistance to mechanical damage. Equipment operability and durability depend on usage conditions and operational modes.

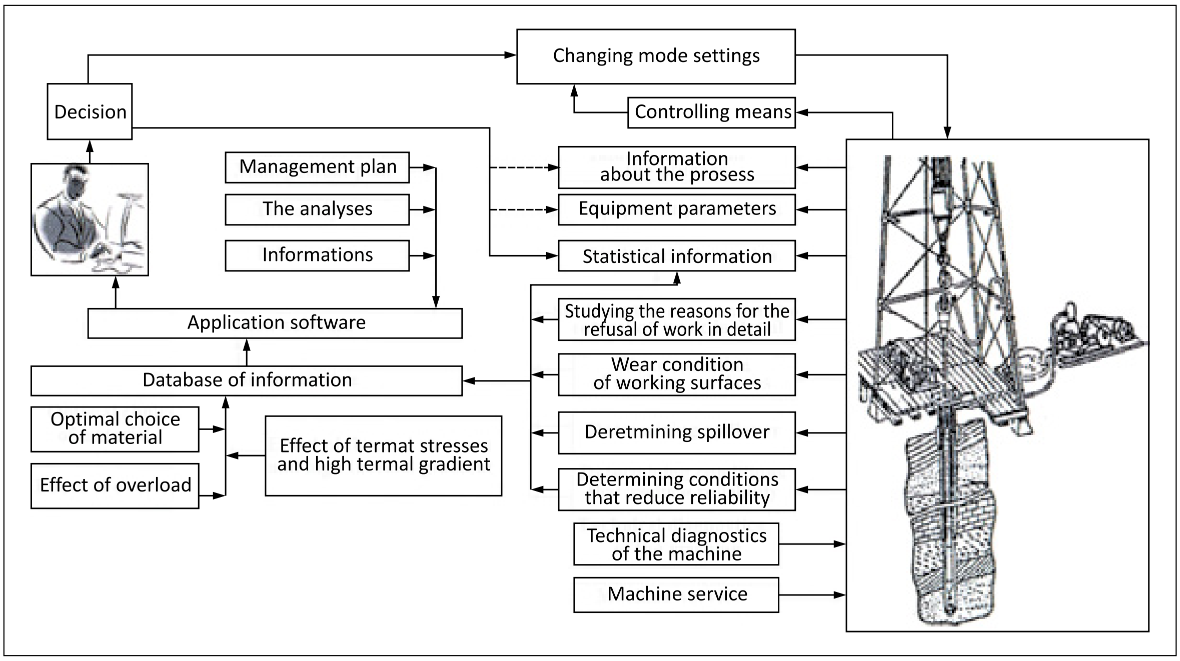

Figure 4. Interconnection diagram based on a systematic approach to the management of the modern drilling process
Rysunek 4. Schemat połączeń oparty na systematycznym podejściu do zarządzania nowoczesnym procesem wiercenia

These characteristics of the rock, well, protective piping, flushing fluid, drill pipes, and drilling speed play essential roles in the drilling process. A systematic approach to managing the drilling process involves considering these factors and their interactions, as depicted in Figure 4.

In this scenario, the operator-machine-well system operates at full capacity. The information received from the well and the process is entered into the database, processed on scientific basis and finally applied to the well and the process with the help of the lifting complex (machine) through the operator in the form of a decision. The correctness of the decision is checked by measuring and control devices. In such an approach, subjectivity is eliminated and the process is controlled based on current information. In this way, both the drilling process and its management can be performed on the basis of optimality criteria. In this case, the applied power is used to the maximum, which makes it possible to properly operate the equipment and benefit from its service resource to the maximum extent.

Results

The application of a systematic approach in the selection of an optimal solution involves considering all significant relationships and predicting the consequences of the decision on the behavior of the entire system, rather than focusing solely on individual parts. It is important to evaluate how different options for solving a specific problem can impact the system as a whole.

By adopting this approach, decision-makers can gain a comprehensive understanding of the interconnectedness and interdependencies within the system. This allows them to assess the potential outcomes and effects of different decisions, taking into account the broader implications on the system's performance and functionality.

Considering the system as a whole helps in avoiding suboptimal solutions that may address one aspect of the problem but negatively impact other components or the overall system. It enables decision-makers to identify potential trade-offs and make informed choices that optimize the performance, efficiency, reliability, and safety of the entire system.

By evaluating the consequences of different options on the system as a whole, decision-makers can minimize risks, anticipate potential challenges or limitations, and identify opportunities for improvement. This holistic perspective facilitates a more effective decision-making process, leading to solutions that align with the goals and requirements of the system as a whole.

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