APPLICATION OF PROGRESSIVE TECHNOLOGIES BASED ON DIGITALIZATION IN MECHANICAL ENGINEERING

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Using digital technologies in its activities, an oil producing enterprise is able to gain a success only when a strategic approach is applied and, establishing a balance between actual and actual capability is equal to capability to beneficial transformations. The oil-extracting businesses digitalization of oil producing enterprises fundamentally alters key technologies throughout the entire life cycle from geological modelling, drilling and field development to commercial oil production. Peculiar to each stage of the life cycle, tools appear to evolve and transform themselves in accordance with the development of the enterprise. At the moment, advanced production technologies that are most in demand at oil producing enterprises are digital engineering, simulation modelling, smart manufacturing technologies, industrial Internet of things and artificial intelligence, virtual and augmented reality. Digital technologies enable production losses, mean time between failures, recovery time or downtime to be better foreseen and improve decision-making, early failure detection, calculate capital costs, operating costs and net present value for each particular well or for the deposit or oil field as a whole. The entire implementation of the project with digital technologies occurs according to the order: data collection, data research, modelling, analysis of results, testing the model's performance on other wells, and replication.

KEYWORDS

maturity of technologies, oil production, digital technologies, smart production technologies, oil field

1 INTRODUCTION

Economic activity with digital data as a key factor and the processing of vast amounts of data and the use of analysis, can significantly increase the efficiency of various types of production facilities, technologies, equipment, storage, sales promotion and logistic chains.

Oil production is a complex business process that includes geological exploration, drilling of wells and their rehabilitation, operation and maintenance of wells, refining of produced oil from water, sulfur, paraffin, etc., pumping crude oil and gas to a metering station [Kuznetsov 2020].

Every year, Russia produces about 550 million tons of oil, of which slightly less than half is exported without processing [Tadvizer 2022]. According to The Central Control Administration of the Fuel and Energy Complex (the Branch of the FSBO REA by the Ministry of Energy of Russian Federation), Russia's oil and gas condensate output reached 524.05 million tons in 2021, an increase by 2.2% compared to 2020. The average daily oil production in the Russian Federation in 2021 amounted to 10.52 million barrels. The leaders in oil and gas condensate production in the Russian Federation are as follows [Tadvizer 2022]:

- Rosneft in 2021 produced 170.73 million tons;
- Lukoil - 75.73 million tons;
- Surgutneftegaz - 55.45 million tons;
- Gazprom Neft - 38.57 million tons;
- Tatneft - 27.83 million tons;
- Bashneft - 13.77 million tons;
- Slavneft - 9.85 million tons;
- Novatek - 8.05 million tons;
- RussNeft - 6.68 million tons.

2 DYNAMICS OF OIL PRODUCTION IN THE RUSSIAN FEDERATION

In 2020, the crude oil output with gas condensate in Russia decreased by 8.6% compared to 2019 and amounted to 512.68 million tons. This figure has been the lowest in the last nine years. At the same time, in 2019, Russia set a record for oil production for the entire post-Soviet period - 568 million tons of oil and condensate. The average daily oil production in 2020 was at the level of 10.27 million barrels. In December 2020, oil production fell more than in the whole year. During this month, Russia produced 42.46 million tons of oil with gas condensate, which is 11% lower than in December 2019. Average daily production was 10.04 million barrels. In 2020, oil production was reduced by all the largest companies in the Russian Federation [Tadvizer 2022]: Rosneft - by 8%; Lukoil - by 11%; Surgutneftegaz - by 10%; Gazprom Neft - by 1%; Tatneft - by 13%.

In 2020, oil prices in the world dropped by more than one-third (-35% for Brent, $42). US/bbl) due to a steep decline in demand caused by the COVID-19 pandemic and lock-down around the world. In this regard, in order to address an over-saturation in the global market and strengthen falling oil prices, OPEC + members agreed in April 2020 to reduce crude oil production by 9.7 million barrels per day from May 1 to June 30, 2020 (term the agreement was extended until the end of July 2020). In August 2020, international restrictions were eased (decrease in production by 7.7 million barrels per day). In 2020, U.S. crude oil output (17% of global production in 2020) decreased by 3.4%, while the gap with Saudi Arabia in this area widened again (in 2020 the US overtook Saudi Arabia by 42% to become the world's largest producer of crude oil). In general, oil production fell by 8.8% in the Middle East, including 7% in Saudi Arabia, 14% in Nigeria, it fell by 4.5% in Canada, but rose by 1.6% in China and by 7.1% in Brazil (growth in production in pre-salt deposits) [Enerdata 2021].

According to EIA estimates, oil production in OPEC countries in 2021 increased by 680 thousand barrels per day and amounted to 26.27 million barrels per day.

In 2022, OPEC production is expected to increase by 2.49 million barrels per day, to 28.76 million barrels per day, in 2023 - by 160 thousand barrels per day, to 28.92 million barrels per day.

In non-OPEC countries, oil production in 2021 increased by 0.71 million barrels per day, to 63.93 million barrels per day (mainly due to Russia, Canada and the United States), in 2022 an increase is expected by another 2.84 million barrels per day, up to 66.77 million barrels per day, in 2023 - by 1.65 million barrels per day, up to 68.42 million barrels per day.

In general, world oil output in 2021 increased by 1.63 million barrels per day, to 95.53 million barrels per day, and in 2022 an increase of 5.52 million barrels per day, to 101.05 million barrels/day, in 2023 - by 1.79 million barrels/day, up to 102.84 million barrels/day are forecast to be observed [Neftegaz 2022].

3 PROMISING INFORMATION TECHNOLOGIES FOR AUTOMATION

The introduction of Industry 4.0 technologies in the oil industry will increase production by 20-25%, reduce downtime by 45%, and adjust enterprise strategies in accordance with new realities [Peterka 2008 and 2013]. Digital technologies in oil business include:

Advanced Analytics, when methods and tools are based on lots of processing power and vast amount of analysed data according to given rules, bring new conclusions and recommendations;

Big Data are scalable technologies used to manage large data-sets from various types of sources and in various formats;

Artificial Intelligence, which are self-learning neural-net models that use data that adapt to new inputs and perform specific tasks that previously could only be performed by a human being, while simultaneously controlling and increasing the efficiency of business processes;

Cognitive Computing - technologies that can autonomously answer complex queries, deciding which data to use, how to transform it and in what form to present the results of the analysis;

Digital Twins are the real-time digital counterpart of a field for the analysis and modelling to be carried out;

Intelligent Virtual Assistant are software chat agents and bots that simulate communication with a real person in order to complete and optimize tasks [Saga 2014 and 2019];

Robotics are automatically remotely controlled, reprogrammable, multipurpose manipulators, robots or drones that have full control over a business process or a technological process that makes sparsely manned activities available;

Industrial Internet of Things is the real-time check live machine and corrective maintenance;

Virtual Reality/Augmented Reality (VR/AR) and here VR is immersive virtual environment with high involvement of users, and AR is digital implementation of the real world enhanced by simulated perceptual attributes of real objects;

Smart Workspace is a wide variety of mobile applications and software that facilitate interaction within the work-flow and improve user experience;

4D printing is technology for physical components to be produced based on their virtual three-dimensional computer models;

Blockchain is a system for exchanging information through distributed registries based on a cryptographic hash function.

The maturity of digital technologies for the oil and gas industry is shown in Fig. 1.

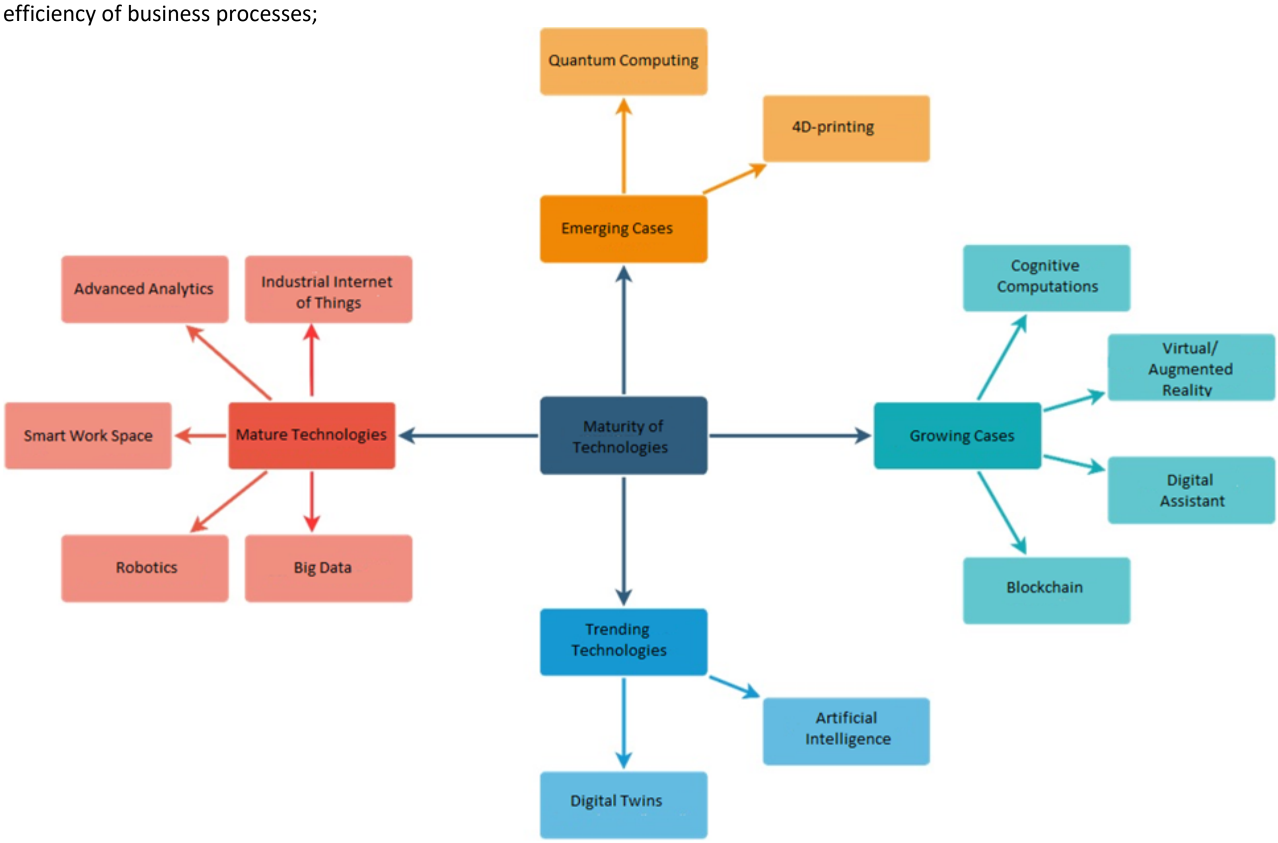

Figure 1. Maturity of technologies for the oil and gas industry

For example, for well workover in integrated information media the forecast of downhole equipment failures can be given allowing for all costs and expenses based on the cases of condition monitoring, equipment fault detection, planning and accounting for the amount of repairs had been performed, monitoring the repairs, managing manipulators / robots, predicting failures / emergency situations and irregularities in the operation of equipment in combination with advanced analytics, artificial intelligence and industrial Internet of things [Sapietova 2011]. Digital technologies make losses, mean time between failures, recovery time or downtime easy to be predicted [Bozek 2016, Jakubowski 2014], improve decision-making efficiency, early failure detection, compute capital costs, operating costs and net present value for each well and for the oil field as a whole [Abd Ali 2021]. The entire implementation of the project with the digital technologies occurs according to the scheme: data collection → data study → modeling → analysis of the results → verification of the model operation capacity on other wells → replication.

4 INFORMATION SYSTEMS USED IN OIL PRODUCTION

Digital information systems (DIS) MekhFond, Tubing Hangers, etc. enable monitoring processes to be unified and improve the efficiency of mechanized well stock control.

DIS MekhFond automates the monitoring, analysis and making technological decisions on the operation of the artificial oil lift well stock; automatically computes the planned operating processes for pumping equipment for variate of operating practices of output oil (electrical submersible pump units (ESP units), sucker rod pump units (SRP units), progressive cavity pump units (PCP units)); calculates the energy efficient designs of downhole and field equipment; controls maintenance of reservoir pressure, oil processing and pumping accounting for energy efficiency; creates and expands a unified catalogue of submersible and field equipment with all characteristics of serial equipment for all company's fields; provides staff from different departments with a unified information field when solving business challenges related to equipment operation management [Cacko 2014], well stock management and technological regimes goes on.

The digital information subsystem Management of the Mechanized Fund consists of modules: management of the mechanized fund; analytics; energy efficiency; complicated fund; monitoring of the simultaneous-separate operation of the WEM; monitoring of technological activities; rating of equipment or services; takes into account the motivation of employees.

Information subsystem Design of Equipment consists of following modules: RosPump; software module of batch processing and optimization; software module of batch calculations of ESP/SRP; module of dual completion and production (DCP) equipment design; training and testing modules that improve the employees' skills.

All of the above modules introduce automation of work in various areas of oil production, thereby increasing performance and staff's qualification and expertise.

For optimal management of well operation and control of oil production in all fields, the engineering of computerized resource management systems of the enterprise is carried out. Global network information and communication technologies and CALS-technologies ensure the creation of a Unified Information Environment (UIS) for interaction and adoption of any series-parallel systems for various types of engineering. CALS-technologies provide successful computerized engineering of complex common projects, separated in time and space, which use various automated (computerized) CAE/CAD/CAM systems: CAE (Computer Aided Engineering) - automated engineering systems; CAD (Computer-Aided Design) - automated design systems; CAM (Computer-Aided Manufacturing) [Bozek 2021] - automated manufacturing systems.

Design for manufacturing (DFM) strategies help companies to develop new products that are feasible to manufacture. In the early stages of design all engineering activities are initiated in computer aided systems [Vasko 2020]. When the design is finished, the process of manufacturing and production planning begins. In lot and mass production where CNC (Computer Numerical Control) [Vopat 2013] machines are used, complex geometry causes a number of difficulties. Thus, it is important to investigate the project carefully in the early design stage from the point of view of whether it will be possible to manufacture [Dyadyura 2021].

Smart manufacturing technologies: MES - (Manufacturing Execution System) is both an executive production system, an automated production control system and an information and computing system (Fig 2).

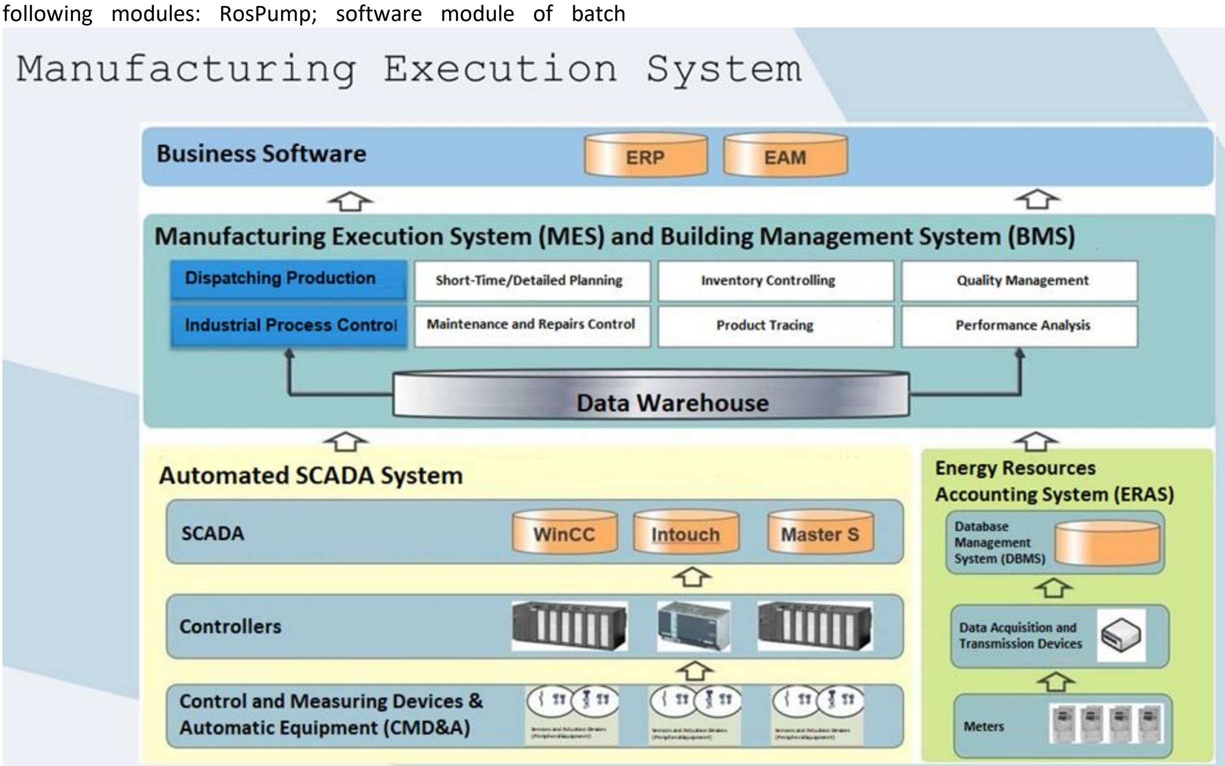

Figure 2. MES scheme (Manufacturing Execution System)

Systems of this class address the issues of regrading to synchronization, coordination, analysis and optimize data for a single well or a field as a whole for the business in real time. There are following 11 typical MES functions [11]:

1. RAS (Resource Allocation and Status): control of the status and distribution of resources: resource, production, equipment, materials, HR (Human Resources), documentation, tools, and work method management;

2. ODS (Operations / Detail Scheduling) - Operational / Detailed Scheduling: production planning based on priorities, attributes, characteristics and methods;

3. DPU (Dispatching Production Units) - Dispatching production: management of operations, orders, batches, series, work orders;

4. DOC (Document Control) - Document management: control of the content and document flow, maintenance of planning and reporting documentation for departments;

5. DCA (Data Collection / Acquisition) - Collection and storage of data: the interaction of information subsystems in order to receive, accumulate and transfer technological and control data in the production environment of the enterprise;

6. LM (Labour Management): HR-management on a daily basis;

7. QM (Quality Management) - Product quality management: real-time analysis of product quality measurement data based on information from the production level, ensuring proper quality control, identifying critical points and problems requiring special attention;

8. MM (Maintenance Management) - Production processes management: monitoring of production processes, automatic adjustment or interactive support for operator decisions;

9. PM - (Process Management) - Management of maintenance and repair: management of maintenance, scheduled and operational repairs of equipment and tools to ensure their operational readiness;

10. PTG - (Product Tracking and Genealogy) - Record tracking: visualization of information about the place and time of work for each well. The information may include reports on performers, technological routes, components, materials, lot numbers and series of equipment layouts, production downtime, current technical environment, etc;

11. PA - (Performance Analysis) - Analysis of oil output: providing detailed reports on the actual results of production for each well, field. Comparison of planned and actual indicators (Fig. 3).

12. i-ERP systems (integrate Enterprise Resource Planning system) - that provide financial management, ensure supply chains, operations, trade, reporting, production and staff, exchange information about the current cost of an order and costs with cost centres and much more;

13. EAM (Enterprise asset management) - is a combination of software, systems and services used to maintain and control operational assets and equipment. The aim is to optimize the quality and utilization of assets throughout their lifecycle, increase productive uptime and reduce operational costs;

13. RTB (real-time bidding) - is a subcategory of programmatic media buying. It refers to the practice of buying and selling ads in real time on a per-impression basis in an instant auction. This is usually facilitated by a supply-side platform or an ad exchange;

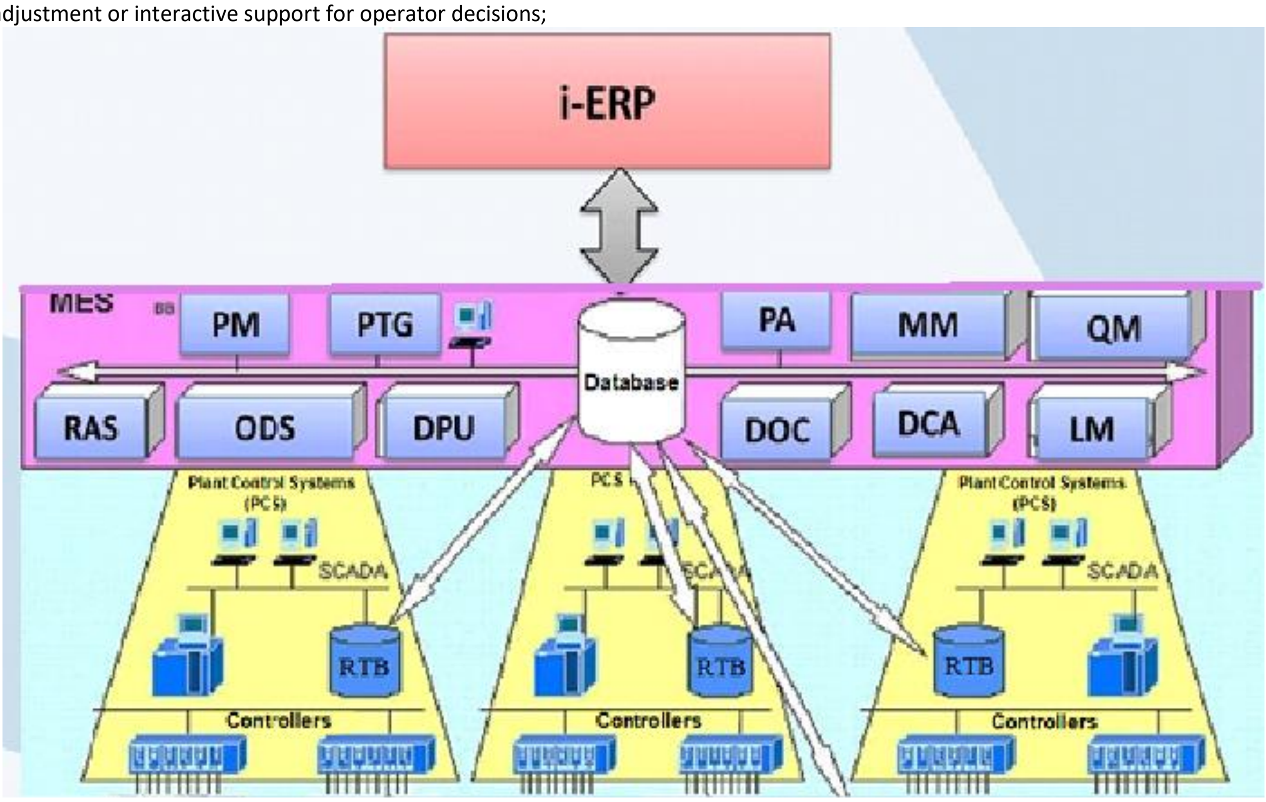

Figure 3. Structure of MES (Manufacturing Execution System)

MES allows the data to be imputed manually from production terminals or automatically collects information from industrial plants, equipment, controllers, flow meters, pressure sensors and other peripheral equipment.

The system is equipped with various hardware for collecting data and displaying the necessary information (sensors, controllers, scanners, printers, barcode equipment, RFID chips, RFID readers, portable terminals, etc.) [Vopat 2014]. The system has a traditional client-server architecture. Client applications are control consoles to be indispensable to the up-to-date personal workstations of chief specialists, as well as terminal software designed to organize a dynamic interactive dialogue with operational and maintenance personnel in the field, manual and automatic collection of data on the production plan implementation, the state of the equipment, the stages of the technological process, the presence and activities of employees, the materials journey, semifinished and finished products, etc.

An integral part of the system is software for the enterprise resource planning system - ERP systems that provide financial management, ensure supply chains, operations, trade, reporting, production and staff, exchange information about the current cost of an order and costs with cost centres and much more.

The standard equipment control module (ECM) is responsible for collecting information about the equipment and its further analysis. At the same time, the following is performed: registration and classification of equipment downtime, their causes and duration; registration and classification of product losses; calculation of equipment operating time; calculation of the overall efficiency of the equipment and other key production indicators [Kuric 2022]. Equipment data comes automatically from the programmable logic controller (PLC). As part of the formation and control of a digital twin of business with the MDE module, it is possible to carry out: tracking the 'status' of equipment (state, quantity, time); equipment monitoring; graphic display of the equipment fleet; cycle time or tact, depending on the type of equipment; interactive schedule of maintenance and repair with the options to customize the types of work and colour alerts [Kuric 2021]. The module, in conjunction with other modules, allows you to manage the loading of equipment by scheduling production tasks to fulfil orders for each resource, and also generates a repair schedule, optimization and predictive maintenance, orders for the corresponding work and the purchase of necessary spare parts.

The manufacturing execution module (ADE) collects, presents and analyses data related to production orders and ensures that they are completed just in time with the required quality. The module provides for checking the feasibility of orders (based on the availability of equipment, personnel and materials), clarifying (changing) orders, combining or splitting orders, optimizing their placement, prioritizing and detailed planning of orders, monitoring their implementation, recording and presenting the causes of violations when executing the orders, operational planning, as well as the management of special, urgent and test orders, the formation of the sequence for their implementation and the demands for materials, and much more. Data for control and analysis is obtained automatically from the top-level of ERP system and the lower executive level. The module performs automatic registration and long-term storage of information about all production orders (both completed and planned to be).

The MPL module submits product genealogy data. Detailed information about the raw materials, materials, technological modes, the results of quality control and the personnel involved in the diagnosis, repair or determination of the chemical composition of oil is available for analysis for any period of time. The data can make available the identification of violations of technological processes at work.

Production personnel management modules include the tasks of accounting for work time, access control, planning the work of production personnel, taking into account qualifications, and automated calculation of incentive wages. The basic functions include accounting for the work of production personnel in the context of operations performed, the number of products produced and spoiled products. The system records information on the personnel who work for a company, as well as the personnel work calendar, types and duration of shifts, day model, etc. Thus, at any time the operational information and a report on the actions of personnel at work are available.

HR modules provide functions for managing, accounting and planning human resources. On the one hand, this is coming and going control and work time count, on the other hand, planning and optimization of the working time of personnel in relation to production resources.

The CAQ module is for product quality measurement data and performs calculations for given models in real time to be analysed on the bases of information coming from a production facility. It is possible to develop and customize schedules for product quality checks and monitor their implementation while recording the outcomes of such checks. For quality control, a quality assurance method is also used, based on the continuous monitoring of key parameters of the production process.

CONCLUSIONS

Thus, smart production technologies MES - (Manufacturing Execution System) provide the use of digital innovations in the management of an oil enterprise, confer the enterprise with reputation of innovative business in the domestic and foreign markets. Combining and integrating all information and production systems into a smart network that generates and processes data using interfaces in real time through various Internet services. This provides an autonomous process of managing the production system and total decentralization of management.

The essential stage of digital transformation, in addition to the development of technical and technological facilities, is the training of personnel for digital systems in the business processes, the development of personnel culture and competencies. The role of personnel and staff is changing. Gathered data should be properly interpreted for the smooth running of production. Of course, difficulties are more likely to be noticed by a real person than a machine. At the same time, thanks to Big Data and analytics services and human-machine interaction technologies, people still are the core of effective management and control in a smart factory with a large increase in performance and labour safety. It is employees who must be able to identify data sources and the most appropriative methods of processing them. Digital capabilities help employees build on the information they have and keep abreast of the actual decisions. And it will depend only on the employee how they can realize their potential in human-to-human, machine-to-machine and man-to-machine communication in order to provide the possibility of exchanging data and information in real time and making independently the strategically right decision for the oil producer. enterprises.

If an oil producing enterprise is able to use digital technologies in its activities, which will bring the best results in the shortest possible time, and automatically, i.e., without human intervention, to implement appropriate measures, then such a high-tech enterprise will become competitive, take the leading position in their niche of the world market. Successful transformation as a key success factor can only be achieved with a strategic approach, with a balance between the actual and planned ability to change. The oil-extracting businesses digitalization extremely alters key technologies throughout the entire life cycle from geological modelling, drilling and field development to commercial oil production. Peculiar to each stage of the life cycle, tools appear which are able to evolve and transform themselves in accordance with the development of the enterprise. At the moment, advanced production technologies that are most in demand at oil producing enterprises are digital engineering, simulation modelling, smart manufacturing technologies, industrial Internet of things and artificial intelligence, virtual and augmented reality. Technologies in interconnection with each other have enormous potential, their combination sets higher demands for the enterprise.

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