APPLICATION OF DIGITAL TWINS FOR MAINTENANCE IN THE GAS AND OIL SECTOR

Lappeenranta–Lahti University of Technology LUT

Master's Programme in Software Engineering

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ABSTRACT

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The process of digitalization comes to all spheres of human activity including industrial production. One of the digital transformation tools is the digital twin which helps to collect data, process, and thereby analyse the production process or equipment state and simulate various outcomes of optimal scenarios. Keeping expensive equipment running without interruption or shutdown significantly saves resources and costs, increasing the efficiency of operational processes. This raises the relevance of this topic and attracts the attention of stakeholders in the oil and gas sector. This paper is based on a review of scientific sources and gives the concept of equipment maintenance, also discusses about the impact of digital twins in this area, and the advantages and disadvantages of using modern technology when switching from the old one. Positive application prospects face some difficulties that can be overcome with an awareness of the implementation steps, the company process and role methodology, and the integration aspect of the architecture. According to theoretical background, the study work provides a business case for visualizing the possible use of digital twins. A real example can help to understand how technology can be implemented in the company with certain characteristics. The importance of the study lies in assessing the economic utility and evaluating operational benefits for company. As a result of the work, open questions and directions for further research were identified.

ACKNOWLEDGEMENTS

There are always things you do not know, thus, in my opinion, it all depends on you and the desire to continue learning throughout your life. I am almost sure that only those people who help me broaden my horizons and teach me something new come across on my way. This is an important process that develops you not only by increasing your level of knowledge but also you as a person. I would like at this stage to express my deep gratitude for the support and guidance of Annika Wolff. Sometimes my thoughts are too wide, and it is difficult to systematize everything, my supervisor always approached my work as creativity that needed to be set in the right direction. In addition, to do some kind of research, motivation is very important, and my environment contributed to this, my parents and friends support me throughout my life, and I want to say thank these people, without them I would not have been inspired to all my achievements and overcoming challenges.

ABBREVIATIONS

DT	Digital Twin
CPS	Cyber-Physical System
CBM	Condition-based maintenance
ESP	Electrical Submersible Pump
IoT	Internet of Things
ROI	Return on investment

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1. Introduction

Digital twins are becoming more popular as a new generation of technologies on the way to digital transformation. The combination of physical hardware and a digital platform allows the collection of sensor data for real-time processing and improves operational efficiency and strategic importance. Regarding industrial facilities, the digital twin helps to choose the most productive operating scenarios and implement experiments in the virtual form, which may be associated with the risk of equipment damage in real life. The rapid development of technologies already makes optimization of processes in existing systems and infrastructure. Thus, the technology trend arouses the interest of companies to invest more money in smart equipment, benefiting more and remaining competitive from the opportunities of digitalization. Analysts predict that 85% of IoT-enabled platforms will feature digital twin functionality by 2022(Digital Twinning: The Future of Manufacturing, 2017).

Industry 4.0 technologies can be applied throughout the entire product life cycle, for instance, this research work considers equipment maintenance in an industrial area. One of the important industrial sectors is gas and oil which annually generate revenues of $2 trillion (IBISWorld,2021). For leading countries such as Russia, Saudi Arabia, the United States of America, China, and Canada, this sphere is critical to the global economy. Thus, oil and gas production has a significant impact on the micro- and macro- economies of countries, although the pandemic situation due to COVID-19 has led to the disruption of supply chains, a slowdown in production, and a decline in global oil demand. In this regard, investors believe in success of modern technology and adaptation to it, which will help to stabilize the production position in the near future and reduce costs. For example, remote equipment sends status data without operator routine inspections and servicing, thereby increasing the commercial value of digital twins in service.

Following this, the first part of research work will highlight the topic, key research questions, and methodology, as well as the relevance of the problem and related work. The second part will give a theoretical overview of the digital twin aspects. The third part will be based on a real case and explain the benefits of using digital twins for equipment maintenance. As a result, based on the considered theory and a practical example, conclusions and prospects for the future will be drawn.

1.1. The relevance of research

The oil and gas industry has one of the most significant roles in the life of society(IBISWorld, 2021). The Oil & Gas Exploration & Production Market size in 2022 is estimated about $5,0 trillion and 27,5% global growth. The country's competitiveness in this area affects its economic development and energy independence. Nowadays, the effective implementation of oil and gas production is especially relevant since these natural resources are the main ones in the energy supply of industries and could be exhausted. The traditional growth factors of these industry leaders are production volumes and technologies for the development of oil fields. However, in conditions of oversupply, production is no longer a competitive advantage.

Now the key to success is the ability to adapt and increase the production of those resources that create the most value. Leaders are those companies that own digital technologies for effective interaction and optimization of the continuous value chain. For example, companies after digitalization in existing business models are moving towards more active productivity growth, in contrast to those that do not use the benefits of smart technologies. Priority attention to digital technologies and process optimization allow oil and gas companies to achieve high results. More and more companies are turning to digital transformation by implementing technologies Industry 4.0 which streamlines processes, redesigns business models and cuts costs across all lifecycle product processes oil(Akberdina and Osmonova, 2021). The transition to the development of fields with particularly complex geological conditions of occurrence of reserves, which often takes place, pushes for the search and adoption of new solutions in the design and construction of technical facilities. Ensuring the smooth operation of equipment is one of the most important tasks of any industrial enterprise. Even a small-unscheduled shutdown of the production complex, caused by equipment failure, can lead to significant financial costs and environmental problems. Reducing losses from equipment downtime helps companies stay competitive in the marketplace. However, it is important not only to eliminate equipment failures that paralyze the entire field, but also to create an organizational foundation for the company that can become the basis for further development in difficult external conditions. The complexity of working at remote sites, expensive downtime and equipment breakdowns can be solved using digital twins. Thus, the service aspects, in particular the oil and gas sector, make the research topic relevant. The master's thesis explains how digital twins can improve operational efficiency and reduce equipment maintenance costs in gas and oil production. In contrast to the studied literature sources, scientific studies describe the methodology of digital twins in various fields, but do not fully cover equipment maintenance, special aspects in this area that may affect the successful implementation, and economic evaluation in energy sector.

1.2. Research questions, goal and limitations

Over the past few years, digital twins have been introduced into the industry in various areas, for example, the production part, the design area, as well as technical services. The main business value comes from equipment maintenance in meaningful sectors such as energy and large-scale production where the damage to a small part leads to a complete shutdown, for example, of a production line or an entire pumping unit. Consequently, this entails large losses not only of the produced elements but also monetary losses.

Thus, the goal of the research work is to describe the applying digital twin to maintain the technical infrastructure in the gas and oil sector.

The purpose of this study is to answer the most important question related to technical maintenance: *What are the benefits of using smart technologies such as digital twins in the field of oil and gas in the maintenance of the equipment?*

To achieve the main goal in this paper, research questions were identified covering the issues of maintenance:

Q1. What are the key opportunities/ challenges of the digital twin implementation in the gas and oil industry?
Q2. How are digital twins deployed? What are the infrastructural features?
Q3. What are the areas of application of digital twins in the service industry? How does digital twin help in condition-based maintenance?

Q4. What is the economic efficiency of the introduction of digital twins for servicing an electric submersible pump?

These questions can provide a clear and satisfactory explanation for the implementation of digital twin and its benefits. The novelty of the work lies in providing not only the theoretical theory but also the economic component considered in the example of a company.

The limitations of the work consist of a systematic review of literature sources and a description of the theoretical part. The master thesis will not include the creation of something new, not previously described in scientific articles, however, a business case will be described to visually present the benefits of the research work and the application of digital twins in the real-life field of maintenance.

1.3. Research methodology and structure

To obtain the results of the research, it is necessary to apply a systematic approach. To carry out the work, the method of deduction study is used. The theoretical structure is first studied, developed, and then tested by empirical observation, as such an observation, the business case of a real company will be described and the economic efficiency of implementing digital twins for equipment in the gas and oil sector will be calculated. Thus, from general conclusions, there will be a path to specific cases.

Focused on a deductive, qualitative approach to the topic under study, the research plan aims to review the literature on the research work related to the problem and then analyse the specific situation.

This master thesis proposes the following research plan, which is presented in Figure 1:

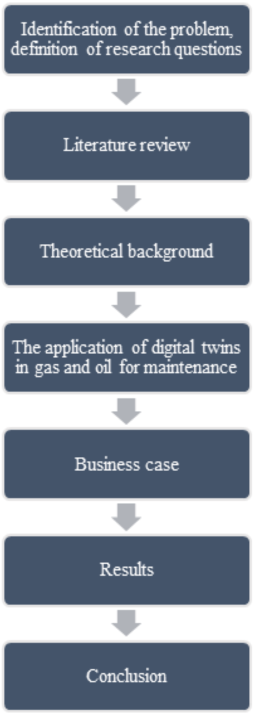

Figure 1. Research plan

Since one of the final stages is the consideration of a specific case and the results of the study itself, the paper will present such important points as:

1. Determining the features of the infrastructure of digital twins.
2. Economic efficiency parameter of using smart technology for remote data collection and information processing.
3. Determination of recommendations for the correct deployment of DTs and improvement of the service process.

1.4. Related work

The oil and gas industry is characterized by a rather high degree of conservatism. The culture and established approaches to management formed over the past decades in the industry determine a very cautious attitude towards the use of new technologies and tools. Especially, this applies to innovations which requires the necessary changes in the enterprise management system.

The difficulty of incoming decisions leads to high uncertainties, the level of expensive cost risks, the danger and complexity of production, as well as human factors. However, it is obvious that the change in the industry is inevitable, and the sooner companies change their approaches to strategic management, skills, and technologies, the more successful they will be in this highly competitive market.

Key literature description in the gas and oil field helps to identify current research gaps such as economic efficiency, the way of digital twin application, infrastructure features, benefits, and opportunities and to frame the main problem. A related work section on the research topic is necessary to analyse the existing materials and theory, provide a new approach to the problem and evaluate the results and conclusions based on own research. Special attention to the significance of the research, and the depth and relevance in the chosen field makes it possible to see the status of the issue.

A review was conducted in an international source with publications on selected keywords.

Source for reviewing:

Scopus - information base and citation tracking tool for articles published in scientific journals.

Keywords: digital twin, maintenance, gas and oil

The query was searched by the following request:

"TITLE-ABS-KEY (digital twin AND maintenance AND gas and oil)"

Thus, the search machine turned up 34 relevant articles including works from 2017 to 2022. The results of the search are presented in Appendix 1. Several articles were reviewed to understand the current state of the research area.

Professors at Norwegian University of Science and Technology, Adil Rasheed and Trond Kvamsdal, presented in October 2019 their work about the opportunities and challenges of Digital Twins including the Energy sector (Rasheed, San and Kvamsdal, 2019). The paper considers five areas of application, including the field of medicine, meteorology, education, manufacturing, transport, and energy sectors. It also describes the key values for companies of digital twins, for example, the ability to assess risks, maintain equipment, more informative decision-making systems, improved documentation, personalization, and product customization.

And in “Digital Twin for the Oil and Gas Industry: Overview, Research Trends, Opportunities, and Challenges” the authors open challenges: lack of standardization, cyber security, data ownership and sharing, validity, functionality, people and policies (Wanasinghe et al., 2020). The article is considered the main ten enabling technologies for digital twins, such as 3D/4D modelling, big data, machine, and deep learning. The capabilities section highlights the benefits of managing the productivity of an existing asset, information acquired from digital twins can be collected in a management system and applied later for good development. In addition, it enables the development of a procedure for restoring the operation of the asset to the level that complies with the regulatory requirements of labor protection and safety precautions. Thus, it monitors the facility and sends warnings to responsible parties including regulatory authorities.

One more article discusses the use of digital twins in oil and gas production (Eremin and Eremin, 2018). The author emphasizes that the digital twin as a tool helps companies to increase production volume and efficiency of resource use by 10-15%, optimize investments and operating costs. The digital twin technology helps to collect all information about the state of physical objects and connects it with information about the state of this object from contractors and service companies, providing support in making further decisions on the development of a physical object. Ultimately, the "digital twin" technology contributes to an increase in the efficiency of using a physical object. This technology is well suited for the oil and gas industry, as it uses high-tech equipment and systems in the form of subsea factories, offshore platforms, and oil and gas pipelines. Oil and gas high-tech equipment is often located in sub-ice, underwater and remote locations where it is difficult or unsafe for operators to physically control it. The digital twin technology makes it possible to reproduce and improve the efficient by using artificial intelligence and predictive analytics. The article describes the business case of Shell company which became the first gas and oil operator registered as a participant in a digital production implementing offshore platform digital twin technology. The goal of the project is to improve the asset management, increase the safety of operations and debug preventive maintenance. Author also draws attention to the fact that several experts consider digital twin technology as a maintenance tool based on the actual state (condition-based maintenance) which allows to model and simulate different types of failures, both complete and partial, scenarios for the operation of equipment, the influence of environment and different levels of wear.

At World Economic Forum the idea was presented that in the future, most of the value will be driven by modern analytical models, the industry's ability to rapidly adapt processes and digitalization, customer relationships, and implementation innovations.(World Economic Forum Digital Transformation,2017). The report presents a likely estimate of the global industry's operating profits from 2016 to 2025, as well as the benefits of digital transformation for customers, the environment, and society over this period.

Four central directions on the path of the digital transformation in the gas and oil sector in the coming years:

Digital asset life cycle management. The emergence of new business models and structures through the use of modern technologies with analytical data that leads to the transformation of operations, helps to make strategic decisions and increase flexibility.

Circular collaborative ecosystem. Digital twins are an integrator of systems that allow to expand collaboration between their participants and accelerate the process of innovation and reduce operating costs.

Beyond the barrel. Synergistic interactions with customers provide flexibility and personalization and open up opportunities for the oil and gas operator to increase revenue and introduce new services to the market.

Inducing new energies. Digitalization advances modern vitality sources and supports the marketing of the energy complex and innovative approaches to working with equipment.

The paper considers in detail cases with the economic calculation of the digital technologies business benefits for the energy industry, such as Robotic Drill Floor for Unmanned Operations, Cognitive Computing in Upstream Operations, also Predictive Maintenance to Anticipate Critical Equipment Failure. The figures are given in a generalized form without detailed calculations and implementation architecture.

Another existing work discusses not only the value chain but also shows the dependence on the levels of development of companies and the readiness to start digitalization(Digital

Technologies Enable Methane Reduction Efforts at Scale, 2019). The readiness of the company for the process of digitalization and transformation is classified by the level with certain characteristics and drivers. From the 0 to 3 stage, which describes the degree of process automation, standardization, and organizational structure, as well as level of systems integration. The process of accelerating the shift to digital could be determined. The description of the steps helps to understand what steps need to be taken to integrate and implement digital twins in the company's activities.

Currently, most energy companies building a development strategy rely on digital technologies. According to the reviewed articles, less modern forms of production process control lose to actual digital models in almost all respects. Not every oil company manages to fully use the possibilities of new solutions - and this is due not so much to the budget of the project, the quality of the development, or the time allotted for its implementation but to the lack of expertise and clear ideas about what specific goals the company plans to achieve. For a deeper understanding of the benefits case study will be described within the framework of the master's thesis. For this, a specific area of application was chosen - the maintenance of equipment. It will help to generalize prior theory, make conclusion and recommendations for implementing digital twins and basis architecture, and future opportunities and prospects.

2. Theoretical foundations for digital twin implementation in the industrial sector

This part presents a general theory which is the basis for the study and will help to consider a separate case in the future. The theoretical background describes what a digital twin is, what architecture and components it has, where it is used in the oil and gas sector, and how it is used for equipment maintenance. Moreover, it includes benefits and challenges, specific issues for applying the digital twin in the industrial area.

2.1. Digitalization process in energy industry

There are more and more digital technologies in the modern world. In the future, it will affect all industries and contribute to the emergence of new types of business. Responding to the demands of society and the global trend towards decarbonization, the global energy sector is also transforming. Digital technologies and big data processing technologies will become important factors contributing to changes in the energy sector.

The technologies that will have the greatest impact on the energy transformation include advanced data analytics, including artificial intelligence, cloud computing, robotics, wearables, and others. Thus, new roles and business models will appear. Digital skills are likely to be among the most sought after in the market but other non-technical competencies will also be required, such as problem-solving under uncertainty and risk management.

The global energy industry is transforming in response to societal demands and increased climate requirements. In 2015, the United Nations adopted the 2030 Agenda for Sustainable Development (Transforming our world, 2020). The program consists of 17 global goals including those related to energy. The International Energy Agency has noted the main changes that will need to be made to achieve these goals. The main vector of energy development for the next 2-3 decades will be aimed at reducing hydrocarbon emissions into the atmosphere to achieve zero emissions by 2070.

According to the forecasts of the United Nation Sustainable Development Scenario, in 2040, despite the growth of the global economy by an average of 3.4% per year, there will be a significant decrease in demand for hydrocarbon energy: the oil market of 65-70 million barrels will return to the level of the early 1990s (*Allen, 2017*).At the same time, there will be the investment reallocation from fossil fuels to renewable energy sources: investments in fossil fuels will decrease by almost 50%, while spending on renewable energy sources will increase by 25%.

One of the most important technological shifts in the energy industry, which will lead to significant improvements in efficiency and profitability, will be digital transformation. Attempts to implement digital transformation have been made since the mid-90s, but a breakthrough in this area became possible only with the advent and development of such technologies as the industrial Internet of things, Big Data, and cognitive computing(The rise of Digital Challengers, 2018). In a broad sense, digitalization is the transformation of information and measurement results into a numerical format, after which they can be processed, stored, and transmitted electronically.

Digital technologies imply(Industry 4.0: Clustering of concepts and characteristics, 2022):

1. Deep data analytics, which includes predictive analytics, big data, and data mining based on machine learning and artificial intelligence. Data mining and artificial intelligence are already influencing how energy companies make decisions and will change the status quo for all participants in the energy supply chain in the future. In terms of exploration and fossil fuel production, the development of digital technologies will facilitate the emergence of new methods of oil and gas exploration.
2. Augmented and virtual reality based on which can companies create various expert systems, interactive electronic technical manuals, and display information about the operating modes of equipment (including telemetry). As a result of the introduction these technologies, productivity increases labor by reducing the time for performing operations, the time to prepare for operations, and optimizing the movement of personnel.

3. Digitization of business processes make it possible to optimally redistribute personnel across projects, reduce the number of errors and accidents, and ensure the transparency of commercial decisions.
4. Cloud computing - providing network access on-demand to a certain common fund of configurable computing resources (servers, storage, databases, software). Cloud computing enables faster innovation, resource flexibility and economies of scale. The cloud will also become a valuable resource for energy buyers, allowing firms to implement initiatives aimed at attracting consumers, for example, by promoting a “green” company image.
5. Cyber security - a set of methods and practices to protect against intruder attacks on computers, servers, mobile devices, electronic systems, networks, and data. Typically, "cyber attacks" are aimed at gaining access to data, changing or destroying confidential information, and disrupting business processes.
6. Blockchain and Distributed Ledgers - shared and distributed data structures or ledgers that can securely store information about digital transactions without the use of a central point of control. Blockchain and distributed ledger technology can be used for risk management or green certificate trading.
7. The Internet of Things is a vast network of connected things and people who collect and share data about the environment, the device itself, and how it is used.
8. Digital twin - a virtual copy of a technical object that reproduces and sets the structure, state and behavior of the object in real-time.
9. Drones and unmanned aerial vehicles are unmanned vehicles powered by technologies such as computer vision and artificial intelligence. Today, technology is used, for example, for scheduled diagnostics and inspection of the state of power lines, emergency recovery work, the creation of digital and cadastral plans, support for the construction and reconstruction of power lines, and many others. others
10. Robotics significantly changes the energy industry, transforming processes such as the production, operation and diagnostics of various equipment. For example, using robots that can navigate a gas distribution system and use sensors to measure wall thickness and stresses can significantly reduce the amount of earthwork required to inspect a pipeline system.

In the short term, the digital transformation of the energy sector will be able to increase the company's revenues in the industry by 3-4% per year(Światowiec-Szczepańska and Stępień, 2022). The main revenue growth – in generation and distribution – will be achieved through the analysis of all available data, automation of business processes and local implementation of digital solutions at critical infrastructure facilities. It is important to note that digital transformation affects all industries of the fuel and energy complex from oil and gas and electricity to coal.

In oil and gas production, net profit growth is expected to be driven by lower data interpretation costs, increased production by predictive maintenance, and increased uptime for main and auxiliary equipment.

Today, oil companies are implementing projects that can be classified as "smart" production, for instance: "smart wells" - Schlumberger, "smart field" - Shell, "field of the future" - BP, "digital field" - Rosneft together with Bashneft(Digital Technologies in Arctic Oil and Gas Resources Extraction, 2022).

All these systems are similar to each other in their main goals and tasks that they solve. One the one hand, modelling various scenarios for the development of the situation in the oil and gas industry and choosing optimal solutions for the production, transportation, and processing of oil. On the other hand, the most promising smart oil and gas technologies include robotics for drilling, servicing, and monitoring wells, underwater oil production, and unmanned platforms.

The use of smart technologies in real-time allows digital oil and gas companies to achieve the following goals:

- expand the raw material base of the enterprise;
- increase recovery rates and oil production volumes;
- increase the productivity of enterprises;
- reduce the unit cost of oil production;
- reduce the number of accidents (including leaks and releases).

Economic efficiency from the use of "smart" oil and gas production is achieved primarily by reducing the number of downtimes of oil well stocks, reducing oil and gas losses during separation, and fully optimizing the oil production process. The research work would be based on one of the digital technologies called «digital twin» and gives a deep understanding of its implementation process and features.

2.2. Literature background

The master's thesis describes digital twin and before moving on to the details of its benefits, it is necessary to give a theoretical basis about what digital twins are.

Firstly, one of the sources mentions not only the definition of digital twins but also describes the difference between a digital twin and similar definitions of a shadow and a digital model, which speaks of full integration and automatic data flow from a real to a digital object (Fuller, Fan and Day, 2020). In addition, the article discusses the areas of application of digital twins with barriers. Digital twin can be applied in a variety of areas and have particular benefits, and each sector has specific challenges that need to be taken into consideration.

The key point of discussion in the next article is the enabling of digital technology within the gas and oil industry(Wanasinghe et al., 2020). The author highlighted that 22-26 percent are asset monitoring and support as the top 10 application areas. For publications in the Internet, there are 23 percent are 3D modelling and CAD, 12-19 percent are virtual systems and reality, about 9-10 percent are Internet of things, big data, and sensors. In addition, the article shows the most popular publications of scientific papers on the topic of "digital twins" and "manufacturing" and less as "the oil and gas industry".

In addition, despite of the relevant topics about equipment maintenance, it is worth noting that the key to applying digital twins is predictive maintenance which is described in this article (Aivaliotis, Georgoulias and Chryssolouris, 2019). The author finds the advantages of using sensors and data transmission according to the concept of digital twins to determine the remaining valuable life of the asset. This allows companies to monitor the status of the system and notify when it’s necessary to replace certain parts for preventing a complete shutdown.

Thus, the literature review allows to consider the topic in a general format, articles give general ideas about digital twins, their application, and separately consider areas with their complexities. The literature review is a kind of basis that helps to evaluate the definition, and components of digital twins and adapt to the specific area of the oil and gas sector, and focus on equipment maintenance.

2.3. The concept of digital twin

Digital twins as a technology are mature and will be in demand within five years(Gartner Hype Cycle Research Methodology, 2021). By 2021, half of all large industrial companies, according to Gartner's forecast will deploy digital twins, and it will increase the company's productivity by 10%.

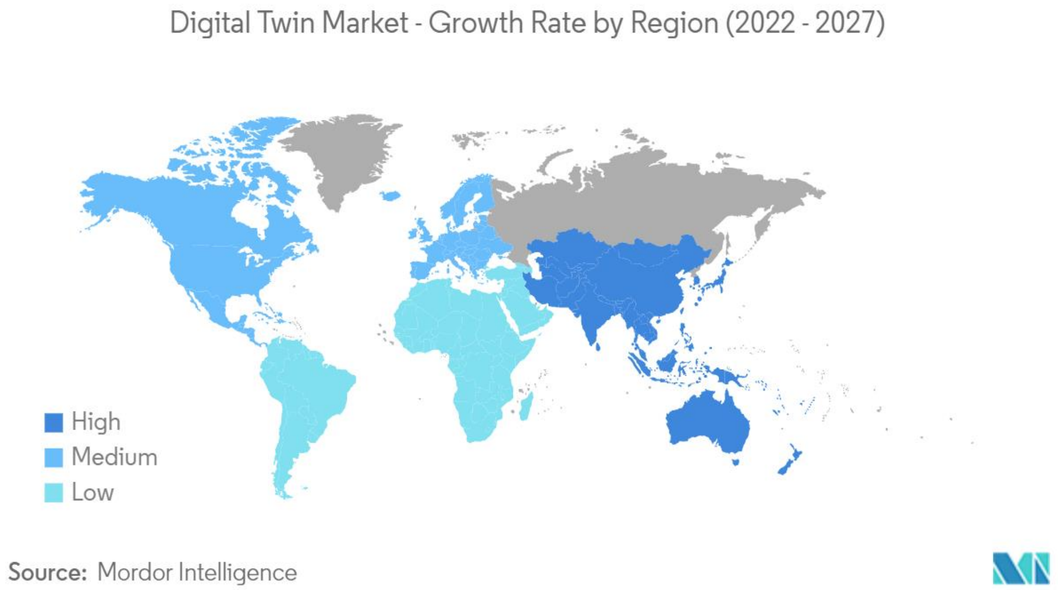

Figure 2. Digital twin Market(Cameron, Waaler and Komulainen, 2018)

The amount of contribution from digital twins is estimated at 10.27 billion US dollars for the period of 2021,according to experts, in 2027 it will increase to 61.45 billion US dollars, so the average annual growth rate will reach 34.48% for the period from 2022 to 2027 (Cameron, Waaler and Komulainen, 2018).

For more detailed research the necessary part is to consider definitions from different sources that characterize digital twins(Fuller, Fan and Day, 2020). To sum up these definitions, digital twins are virtual copies of individual components, systems or entire industrial enterprises or infrastructures that track and collect data in real-time using sensors. They display operational activity and help to control it and manage assets in the real world, optimizing decision-making processes. Typically, such smart technologies can be divided into several parts: a physical product and a digital one, and the connection between them (Figure 3).

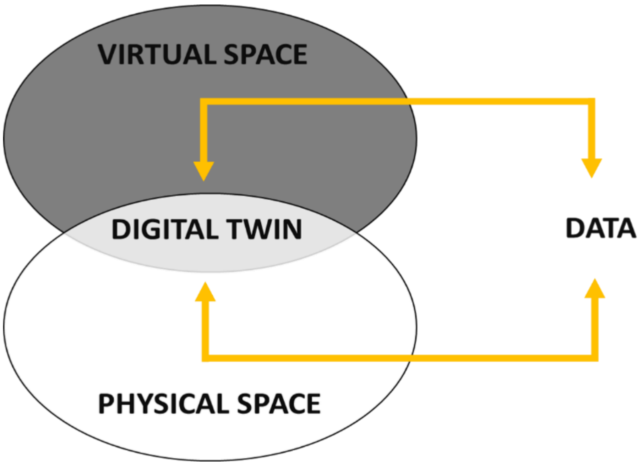

Figure 3.Digital twin concept *(Adapted from* Digital Twins and Cyber–Physical Systems toward Smart Manufacturing and Industry 4.0*, 2019)*

The digital twin is a collective technology, where data is stored in cloud storage by cybersecurity protocols. This software collects and analyzes data directly on the object. Utilizing comparing own situations with the templates of situations uploaded to the cloud storage and transfers the data to the operator. The principle of the digital twin consists of three steps: see, think, and do (Digital twin-driven product design framework, 2018).

The first step is «see». It is the collection of data from the object, which can be divided into operational data (temperature, pressure, depth, volume, and any other internal data), and data from the environment (external factors affecting the object).

The second step is «think» which is the analysis of the received data following the specified technical and economic parameters and protocols established by the security system. The algorithm compares with the data already available in the cloud storage from existing objects with the most similar parameters and works out several options, but the final choice when choosing leaves the operator to the person.

The third step of «do» is to get a report on the work, analyze the viability of the production chain and identify problems and the possibility of visualizing them in 3D and quickly being able to localize them. Artificial intelligence within the digital twin makes an appropriate decision on self-neutralization of a malfunction or the need for human intervention. The output of information for the employee is carried out through a simple programming interface.

The technology can be applied in a wide variety of areas, but today it is most widely used in industry - which is not surprising, since digital twins make it possible to radically optimize all processes in the value chain.

Usually, a digital twin of a product is created at the stage of defining its concept and design. This allows engineers to model and evaluate product features based on specified requirements, such as whether the proposed body shape will provide the lowest possible drag coefficient or what is the likelihood of electronics failing under given conditions(Ilin et al., 2021). With the digital twin, any component of the solution can be pre-tested and optimized: mechanical, electronic, software, or system performance.

The same is for the digital twin of manufacturing. The technology allows simulating virtually anything in a virtual environment, from machine tools and controllers to entire production lines, as well as launching preliminary production optimization, including creating programs for programmable logic controllers and virtual commissioning. Due to this, even before actual use, the source of failures and errors can be identified and eliminated(Levina, Borremans and Burmistrov, 2018). On the scale of mass production, there is a significant time saving due to the rapid programming of all routes and situations with a minimum of effort and cost.

In addition, products or production plants continuously feed their performance data into a digital performance model, which continuously monitors equipment health and the energy consumption of production systems. This greatly facilitates preventive maintenance, reduces downtime and energy consumption.

To sum up, the deployment of digital twins is relevance for enterprises whose core business technologies involve specific technological equipment and complex technological infrastructure (engineering networks, auxiliary production, transport, and logistics infrastructure, etc.) (Ilin, Levina and Iliashenko, 2018).

Concerning enterprises, there is the term "infrastructure-intensive enterprises". Figures 4 and 5 show the difference between a "digital" approach to process control and an "intelligent" approach using twins that add intelligent analysis, computer simulation of processes and their optimization, as well as control of the stable state of objects based on the collected data.

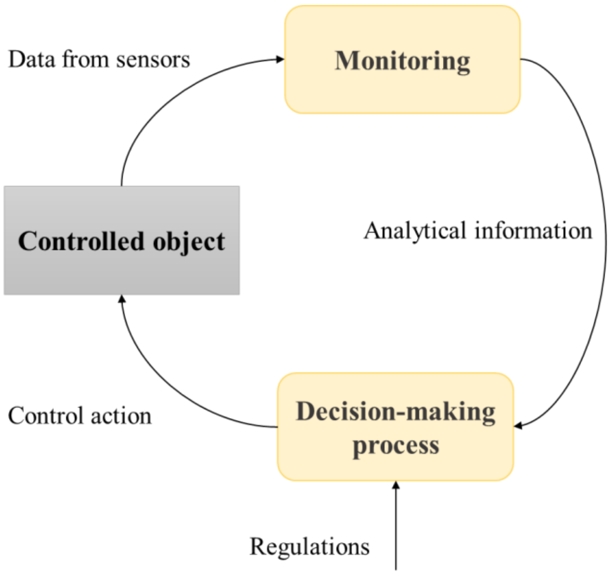

Figure 4. «Digital» approach to process control

The deployment of a block of digital twins gives a fundamental advantage to the "Intellectual" pro-active approach both in terms of efficiency, operation parameters, and the level of safety of the facility.

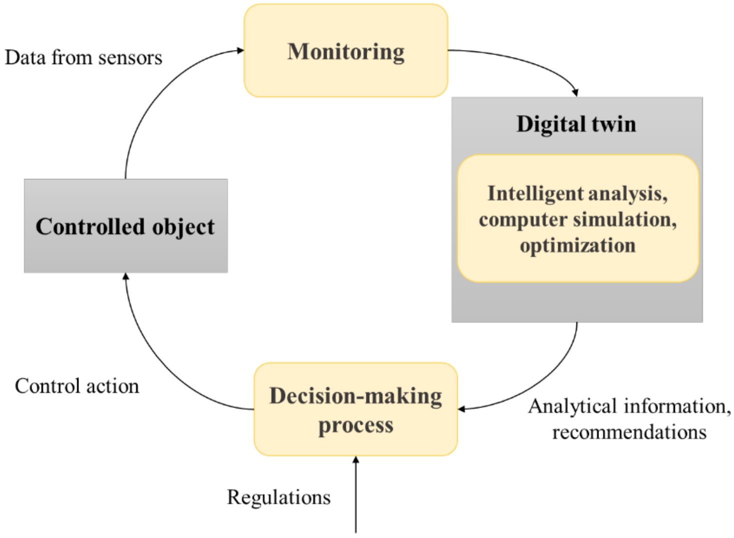

Figure 5. «Intelligent» approach to process control

For such enterprises, the functions of process management (including their monitoring, control, forecasting) as well as asset management play a key role. Digital twins allow simulating the behavior of such complex automated technical systems as infrastructure-intensive enterprises, in short, they are considered as the main-stream in the automation of such enterprises (Ilin et al., 2019).

Oil and gas companies are a typical example of infrastructure-intensive enterprises. The oil and gas sector was among the first to show interest in IT - this industry has always introduced advanced technologies, and in addition, it was stimulated by growing competition from other energy sources and current oil prices.

The research task of developing a model for an integrated architectural solution for the Digital Twin is considered as relevant. Considering all the features of the introduction of modern technology in the oil and gas industry, it is necessary to pay attention to the implementation process and evaluate the effectiveness of its implementation. This work is aimed at describing the functions of the digital twin of an oil-producing enterprise, developing a model of the architecture of the digital twin, and calculating the economic effects of its application.

2.4. Digital twin structure

Digital twin can be realized at different levels which are presented in Figure 6: component, asset, system, and process levels(IOPscience, 2020).

Figure 6. Types of digital twin *(Plank, 2019)*

Not only in the oil and gas industry but also in other industries there are differences in the types of digital twins. This variety of types depends on the sphere of product application which can lead to optimization in the whole process or just its component or asset like bulb or pump.

Component twins/Parts twins

Component twin represents particular asset part or component. It allows to control the main components that directly affect the performance of the system.

Asset twins

Asset consists of two or more components working together. Asset twin gives information to investigate the system while determining the potential for improvement parts that work together. For example, digital twin of the pump or engine.

System or Unit twins

This type of DT covers one system block of the production chain and includes several assets. It helps to monitor and improve the whole functional system.

Process twins

Process twins can create an entire manufacturing plant. Such twins can help identify system integrations that affect overall performance.

In this research work much attention is paid to asset twins. In many ways, the implementation and management of digital twins refer to the assets of companies (BI Capabilities in a Digital Enterprise Business Process Management System, 2019). For example, Oil and gas equipment helps to explore the landscape, extract minerals that are highly valued all over the world. The type of the equipment depends on the production method, for example, oil and gas equipment is divided into: pumping, fountain and gas lift production. Such equipment allows performing huge amounts of work in a day that is impossible to do manually. The key role is played by the mechanization and automation of production processes, the improvement of technologies, the applying advanced materials, and the optimal use of existing assets. The cost of purchasing and operating special equipment makes up a significant share of the main product cost, thus, reducing the cost of this subsystem is an urgent problem and a huge economic reserve.

Building a holistic model of the operation of industrial equipment without information about the facility involves combining various categories of data (Uhlemann, Lehmann and Steinhilper, 2017):

1. Design-estimated, design, operational documentation, that is all documentation developed during the creation of an asset. It is capital construction, repair / reconstruction of operation;
2. Visual representation and its components (2D and 3D models, flow diagrams, cartographic models, etc.). It requires a high level of detail of the component, for example, in addition to the main technological equipment, models of cable wiring, electrical equipment, instrumentation, control systems, process control systems, engineering systems are required;
3. Engineering data - characteristics that determine the properties of an object (passport data, diagnostic examinations data, boundary parameters of work, etc.);
4. Online data - data received in the mode, near real-time mainly from automated process control systems, instrumentation.

An obligatory and key component is also the mathematical models of the asset. The results of the model considering engineering and online data are used to predict the technical condition of equipment and control technological processes. In some cases, not only the physical but also the economic model of the equipment is formed (Digital Twin Through the Life of a Field, 2018).

Data is an important value in the management and design-making process. Due to the information received from sensors located on wells, pipes, and equipment, full information transmits about production indicators in real-time, and signals in advance about possible problems or breakdowns. The data goes through several transformations and uses in certain processes of an oil and gas facility in real time. A description of how the data can be performed is given in Table 1.

Table 1. Basic methods of data processing in the digital twin

Collection	Collection of raw and estimated transactional data, e.g. using sensors
Registration	Registration of data in digital format, e.g. in databases real time
Processing	The process of converting data into information for exchange and analysis, such as compatible formats
Storage	Storing data from different sources in one storage, e.g. in databases
Transmission	Transmission of data to multiple consumers for processing and non-processing, e.g. using communication technology
Visualization	Representation of data in graphical formats from multiple sources, such as real-time widgets
Reporting	Data processing for specific business reports, such as daily
Analytics	Generate insights such as trends
Availability	Open access to data from anywhere, such as global mobility
Manual action	Manual action taken from software information, e.g. in real time (advisory systems)
Automatic action	Automatic action performed by the software, such as an artificial intelligence system, and automation

Manufacturing assets generate millions of data points whose value can be analyzed, transformed, and used to make decisions.

2.5. Digital Twin architecture

Since data enters the systems in large volumes and comes from different segments that are not interconnected: different databases, formats, data structures, and methodologies for obtaining them(Wanasinghe et al., 2020). Formally, there is a lot of information, but it is practically impossible to use it effectively without a properly designed digital twin architecture. The digital twin combines data on all systems at the facility and contains only up-to-date information. Determining the architecture for the digital twin is difficult because there is potential diversity relying on the use case.

The 4.0 industrial revolution is driven by the use of cyber-physical systems that lead to digital twins (A Review of the Roles of Digital Twin in CPS-based Production Systems, 2017). The key meaning of CPS is the formation of a two-sided channel with the reverse direction and the establishment of the connection between physical and cyber. Physical objects with the help of various sensors, mechanisms, and controllers transmit feedback, it is worth noting that in real-time and for processing data in a virtual form. As the core technology of CPS, Digital Twin gives a clear and workable approach to implementing CPS functionality. Artificial intelligence empowers asset and process management mechanisms and simplifies the development of a response strategy and process optimization.

Typically, the concept of a digital twin includes (AltexSoft, 2021):

Hardware components. The key technology driving DT is IoT sensors that share collected information from assets to software and vice versa. This part includes sensors that convert digital signals into mechanical algorithms, network devices, hubs, routers, servers and others.

Middleware data management. Its basic element is centralized storage for the accumulation of data from different sources. Such software performs the tasks of data connectivity, integration, modelling, quality control, and visualization.

Software components. An integral part of the DT is an analytics engine that transforms raw data into business values. It also includes dashboards, real-time simulation tools, and software, as well as asset lifecycle management and product lifecycle management programs.

The simple of architecture components is presented in Figure 7.

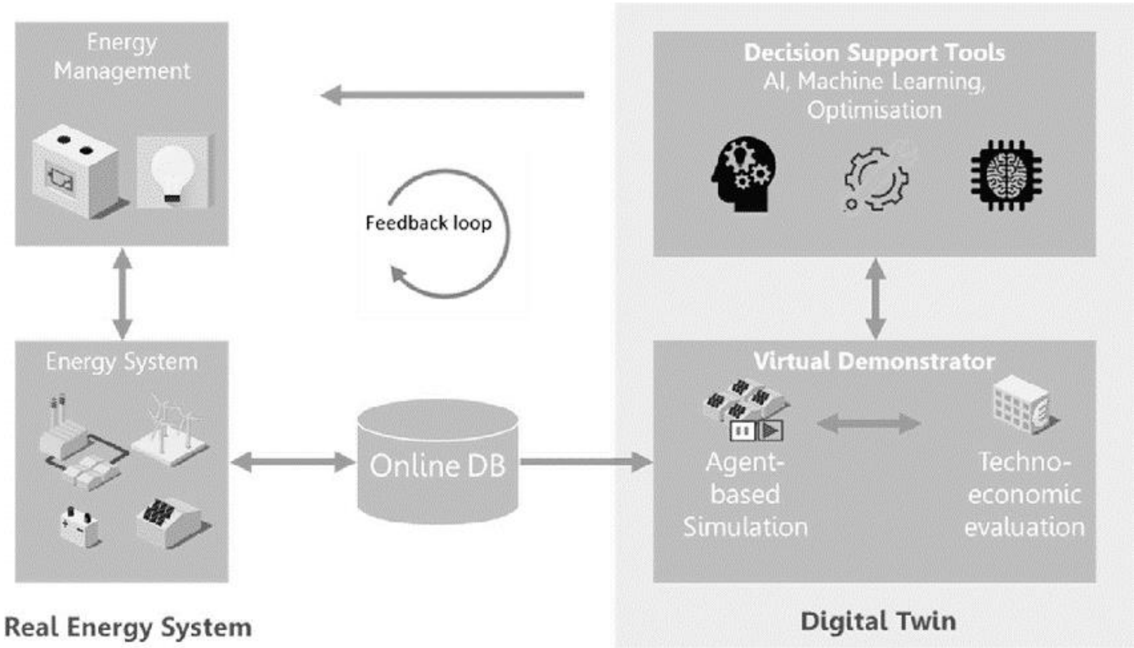

Figure 7.Key architecture components(Adapted from *Khajavi* et al., *2019*)

In this picture, the hardware components like sensors are located in the elements of the energy system, which transmit data through hubs to the middleware presented as an online data base and management system. Further, the received information enters to the digital twin and, with the help of simulations and comparisons of economic and technical parameters, is converted into visualization and, based on the intellectual tools, conducts analytics of the system condition and sends feedback to the decision-making system.

The structure of the digital twin allows displaying reliable information about real remote objects, which is especially important in the oil and gas industry where wells are located in hard-to-reach places(The Industrial IoT in Oil & Gas, 2020).

In addition, there is a classification of digital twins that separates representations into layers, as shown in Figure 8. (Atalay et al., 2022).

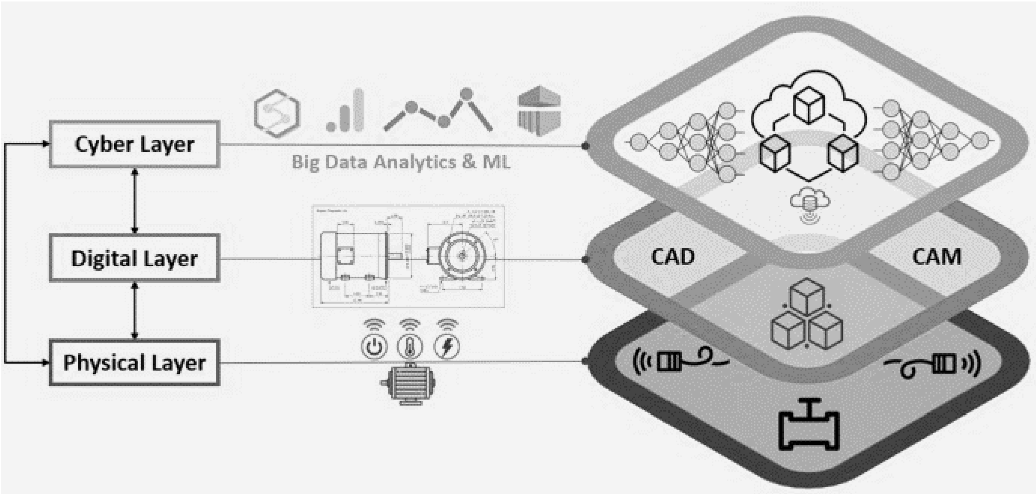

Figure 8. Digital twin layers*(Adapted from A Six-Layer Digital Twin Architecture for a Manufacturing Cell, 2018)*

Physical Layer. The level of primary data processing and mathematical calculations of asset indicators is carried out through the transfer of a higher cyber-physical level through the infrastructure IoT hubs, gateways, and servers.

Twin Layer. The level of models, visualization and user interface. Creates twin models from online data and various services. Data storage is carried out using a cloud service.

Application Layer. Level of algorithms for the development of various scenarios, performance monitoring, predictive maintenance, scheduling optimization and others.

As architectural aspect, it is important to mention that the digital twin should be integrated with enterprise-designed architecture, perhaps many elements are already in place and only need to be changed and revised (Evans, 2019).

Digital twins, integrating into existing corporate solutions of the organization (for example, Figure 9), make it possible to support the expected business results and increase them.

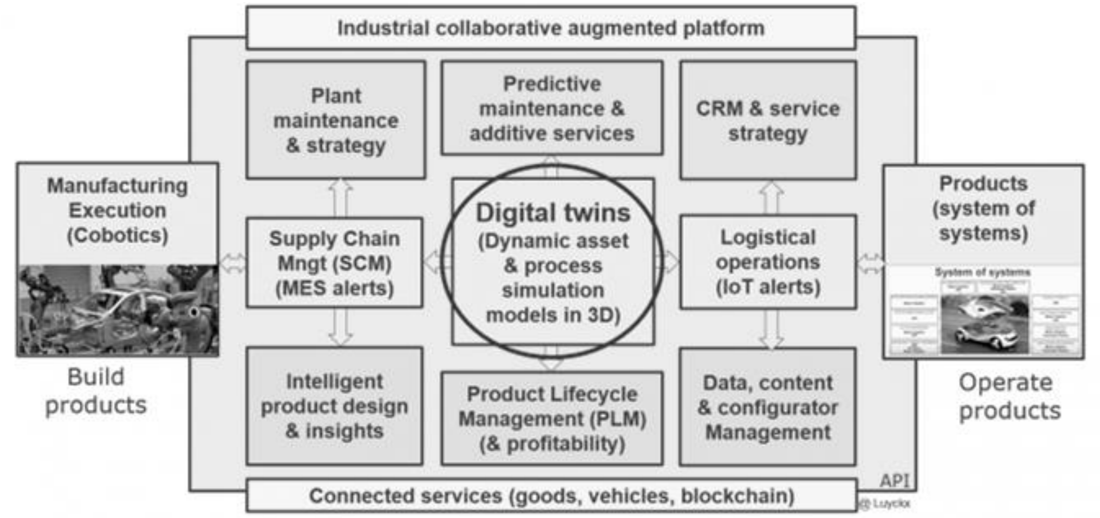

Figure 9.The digital twin in the corporate structure *(*Impact of the digital twin on the enterprise architecture, *2018)*

Modeling of the digital twin takes place in a single information environment (with shared access for employees) and all data is interconnected. For example, company processes are associated with organizational structure, processes and the IT architecture (since most of the processes are performed using existing information systems). The information management systems give current information for analysis and receive the proceed data from digital twins. Based on a bunch of organizational structure and business processes, the system understands in which processes the employee is involved, what functions are assigned to him. The average manufacturing execution time of functions, downtime and probabilities of forks, help system to calculate the cost of the process. The combination of the company's management systems makes it possible to automate the updating information for whole process and create collaborative augmented platform. Any changes in the company and its digital copy allow to follow all the regulatory documentation of the organization and adopt to company strategy changes. Linking the IT architecture with other digital entities gives the opportunity to exchange information between the software products used in the company and connective services.

2.6. Applying Digital twin in maintenance

The technology considered in this work can be applied during product development, production, operation and maintenance, that is, throughout the entire life cycle. It helps companies to be aware, interested in modelling optimization scenarios, evaluating input data and transforming them into models for decision making and further system sustainability (Figure 10).

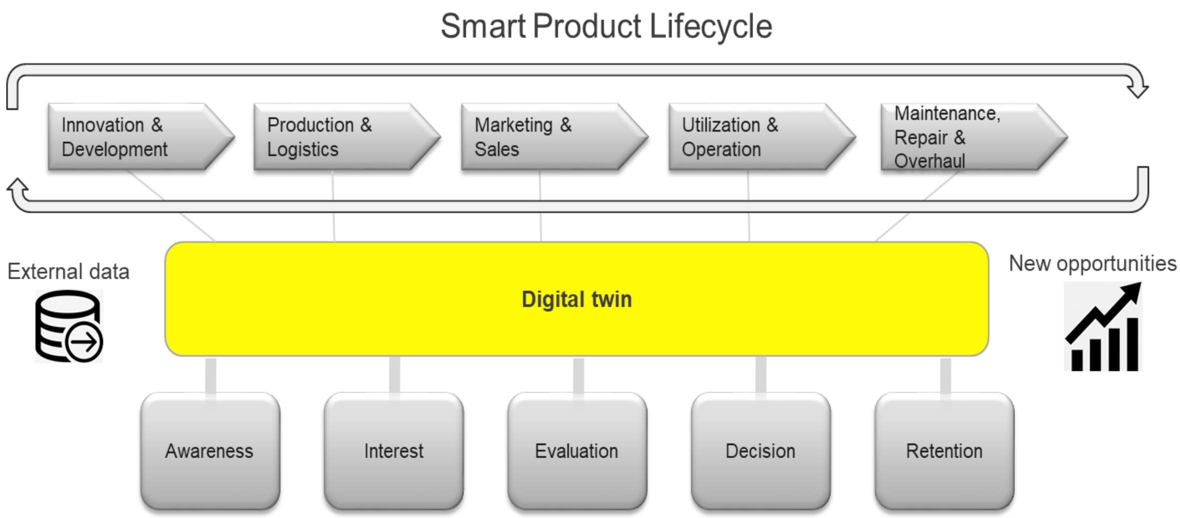

Figure 10. Digital twin lifecycle (Digital twin-driven product lifecycle management,2018)

The digital twin gives better understanding how well the production process organize on the factory level before the actual production begins. By modelling processes through digitalization and analyzing information flows, companies can create their production strategy that will increase efficiency in a variety of conditions.

As for the oil and gas industry twins are especially important for two reasons. Firstly, many production facilities (oil platforms and rigs) are remote from the main and head office of the company and are located in hard-to-reach places. Therefore, virtual twins monitor their work from any point of view, taking trips only in case of emergency. Secondly, the extraction and processing of oil cover high risk, and natural disasters at the facility lead to huge costs and environmental disasters. Double cases occur in patients, and therefore cases of consequences, equipment downtime and victims.

To optimize production gas and oil companies create digital twins of products for all production equipment. By using product data and the production of digital twins, companies can save on long downtime by predicting the need for maintenance. The constant flow of collected information allows us to speed up operations, make them more reliable and sustainable.

The operation of equipment has certain strategies for managing its maintenance(Patidar, Soni, 2017).

1. Preventive (planned) maintenance. With this strategy, equipment maintenance work is scheduled and adheres to a strict schedule, which sometimes wastes time and money to avoid breakdowns and shutdowns on production lines.
2. Emergency maintenance. In this case, the maintenance of the equipment is a reaction to its failure.
3. Predictive maintenance. The service is based on specific information about the equipment, which is a reliable prediction for imminent failure. To carry out such service, it is necessary to spend money either on the purchase of analytical equipment and user training, or on the involvement of contractors to perform the analysis.
4. Condition-based maintenance (CBM). In the case of state-of-the-art maintenance, the system identifies emergency conditions by verifying information about the state of equipment in real-time. Thus, the sensors transmit data, and the indicators are compared with the reference parameters, warning of an imminent possible breakdown.

Predictive and condition-based maintenance are the most used in gas and oil sphere. The difference between the two key types is described in Table 2.

Table 2. Characteristics of strategies for managing maintenance

Condition-Based Maintenance	Predictive Maintenance
Condition-based diagnostics (such as vibrations, pressure, speed) are used to determine when maintenance is required.	The current analysis is combined with complicated prediction algorithms to determine when maintenance may be required.

The decision-making process is based on the condition of the equipment.	Sensor devices provide real-time data which is utilized to predict and avoid asset failure. The decision-making process is based on dynamic rules.
Noise input is quite sensitive.	Noise input is less sensitive.
Continuous detection, diagnostic, and prognostic algorithms are used to inform upkeep.	Maintenance is based on technologically improved algorithmic pattern recognition of objects.
Alerts about the problem at the exact moment.	Predicts future failures.

Thus, the most advanced types of maintenance are condition-based and predictive maintenance. It involves the elimination of asset failures through determining the technical condition of the equipment based on the evaluation of statistical data coming from the sensors, in addition, develops optimal scenarios for the operation of individual parts and the entire system. This modern digital technology can be called one of the tools for modelling the consequences of failures, the influence of the environment on the device, operating modes, as well as the criticality of parts wear.

The description of the maintenance process is shown in the Figure 11.

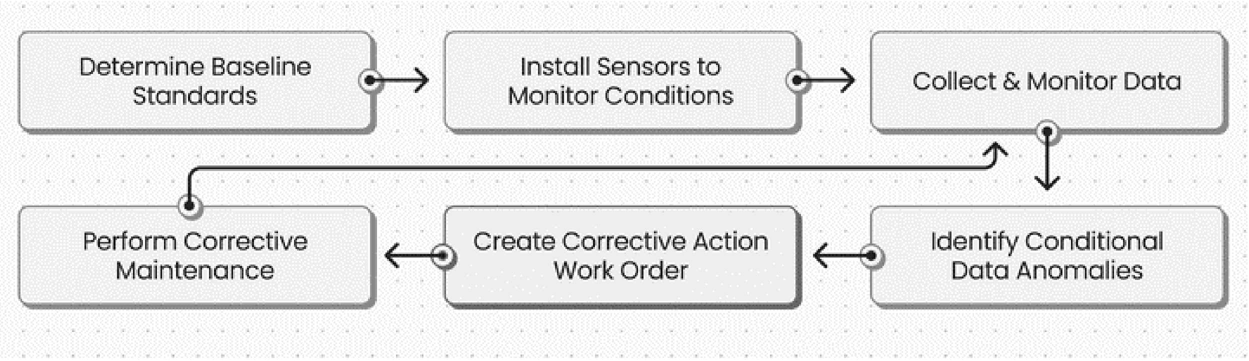

Figure 11. Maintenance process

Equipment maintenance with digital twins according to regulatory documentation and standards, starts from installing and receiving information from sensors, and then determining the status of the equipment and monitoring it. During the process twins identify data anomalies and suggest corrective actions and strategy for different scenarios. This corrective maintenance supports with specialists which can fix some moments remotely or the system make changes automatically by human control.

2.7. Positive effects of the digital twin implementation

The description of digital twin allows to draw conclusions about it usefulness in the subject area. The advantages of using virtual models with the characteristics of real objects can be described as (*Digital twin simulation: benefits, use cases and predictions*, 2018):

- Assessment of risks in production. Even before the start of the mass production, product can be tested and even predict the demand in the market, and most importantly, prevent the occurrence of defects. The intensity of testing increases several times. Also, engineers get the opportunity to test in the most unusual conditions.
- Saving time for design. Moreover, it is possible to reduce not only time but also labor resources. The period for creating a project and making changes to it is significantly reduced, which allows to: reduce salaries for employees, reduce their staff, reduce the likelihood of a human factors, and quickly bring the finished product into mass production.
- Timely service. Twin calculates the degree of equipment wear in advance. It indicates critical periods of operation and allows maintenance to be carried out before the equipment fails. This will save money on repairs and extend the life of the equipment.
- Remote access to technology. Digital twins provide real-time equipment monitoring. And not only diagnostics of the state, but also the possibility of interaction. For example, switching modes of operation. The technology is used for automated equipment and units in hard-to-reach places, for example, in gas or oil wells.
- Combining systems. The use of digital twins ensures the integration of systems linked to it, thereby allowing access to data and parameters of synchronizing systems.
- Optimization of decision-making process. Virtual simulation helps to calculate the cost of processes, products and assess financial risks when introducing new technologies, for example, assembly lines, conveyors. Without a digital model, all company work must be stopped to test new equipment. Not the fact that it will bring the expected profit. Virtualization helps to decide about the need of updating technical processes even before purchasing equipment.

Thus, digital twins help in predictive analysis with the possibility of modelling processes in the future. In addition, this technology makes it possible to project certain situations onto the equipment or system, embodying "what-if" scenarios. In the oil and gas sector, it also improves operational efficiency by helping to remotely find anomalies that have occurred and take corrective actions, visualize problem areas, real-time equipment state condition and make strategic important decisions.

2.8. The Challenges of the digital twin implementation

Although digital twins have a number of possible cases, some issues need to be compensated for achieving the goals and deploying considered technology. There are several challenges to be overcome(Singh *et al.*, 2018):

- Data correctness. Details of machine failures are required. To predict failures, it is necessary to saturate the digital twin with data on equipment failure modes. Such data should be collected over a long period (for example, a year) to observe the process of degradation of machines;
- Flexibility. Each time the configuration of the equipment or the state of its elements changes, it is necessary to re-create the digital twin. Any modification that affects the operation of the equipment requires changes in its model and the algorithms underlying it. Such modifications at the machine level (replacement of original parts with custom-made ones) or plant level (changes in operating policy) are not always reflected in factory specifications and therefore cannot be modeled accurately, increasing the risk of errors.
- Qualification of specialists. To work with modern technologies, there should be employees with good knowledge of systems modelling and analysts who can make proper analyses. Moreover, a valid model must accurately reflect all properties of the physical object, including parameters of pressure, temperature as well as electrical characteristics (capacitance, conductivity, etc.). This requires the participation of plant managers, process engineers, electrical engineers, equipment manufacturers, etc., which complicates deployment

- Security. The oil and gas sector is one of the economically important resources for countries, that’s why data leakage is a great danger for companies. It is essential that cybersecurity provides protection against scammers and hackers.

Despite the problems with the operation of sensor networks, and processing large amounts of data, other important aspects should be mentioned and will be described below.

2.9. Asset management standard ISO 55000

The ISO 55000 series standards in world practice streamline knowledge in the field of asset management, systematize and bring together existing developments, experience and ideas in asset management into a single document(Asset Management Standards, 2018).

Regarding these standards, asset management ensures the availability of information on asset management, reduces the cost of their acquisition and distribution, presents the knowledge base for asset management in the form of a commodity which facilitates the dissemination, reduces uncertainty and misallocation of information and accelerates the process of change in the field of asset management of organizations.

Therefore, one more feature of the introduction of digital warriors that can be distinguished is the standardization of business processes through world practice, which allows optimization operations, planning the correct use of assets, making strategically important decisions, and maintaining assets within the organization.

An "asset" in this standard is an identifiable object with potential value for the organization. Thus, the scope of the standards includes both tangible (physical) and intangible assets. For example, physical assets could be company equipment or inventory. Tangible assets are described as leases, rights, and licenses.

The complex ISO55000-55002 includes an overview, methodology of implementation, requirements, and guidelines. One of the standards describes the structure of the main asset management documents which is shown in the Figure 12.(Digital Twin of a Research Organization, 2020) :

Figure 12. The ISO55000 standard components

The requirement of the standard specifies that an organization has a set of assets that it owns and manages based on a corporate plan which is documented and described in detail actions to deliver value. Each asset performs certain tasks by verified rules to achieve business value or objectives. Thus, a unified management strategy is created by combining part of those objectives and describing the main company goal. An emerging connection between actions objects and goals, there are rules for managing assets leading to business benefits. The emerging relationship between actions and goals provides the basis for asset management rules leading to business benefits through the creation of a top-level management set of rules and methodology called policy.

The benefits of asset management may include(Bierwirth, Kirschstein and Sackmann, 2019):

- improving financial results: reduce payback period and cost savings;
- investment decision making: easier investment decisions and evaluating risks, prospects and performance;
- manageable risk: reducing financial losses, improving safety, minimizing negative impacts on the environment;

- improving service and performance: confidence that asset performance can lead to improved service or product quality, which in turn meets or exceeds customer and stakeholder expectations;
- social responsibility: reducing polluting emissions, conserving resources shows responsibility in society;
- demonstrable compliance: transparent compliance with laws, rules and regulations by applying asset management standards demonstrate compliance with quality;
- sustainability: effective short- and long-term management plans improve the sustainability of the part and whole company.
- improving efficiency: standardizing processes, procedures and asset performance make business more effective in achieving organization objectives.

For example, one of the main material assets of the gas and oil company is an electrically driven centrifugal pump and this asset management standard makes sense to maximize performance benefits.

2.10. Digital maturity model essence

In addition, the process of implementing digital companies depends on the digital maturity of companies. Thus, in this paper the general approach is described. There are different models of process maturity: Project Management Maturity Model, Capability Maturity Model for Software that defines the level of maturity in the direction of project management.

Based on the process maturity methodologies with five-grade models, a digital maturity model of companies is provided which also includes 5 levels (Khan, 2019):

Level 1. Initial: Basic infrastructure and technologies that do not provide business values. there is no certain structure, systematic knowledge.

Level 2. Conceptual: Consideration of pilot projects and the preparation for digital transformation but the strategy for the implementation of digital products is under development. Mostly, data is entered manually.

Level 3 Defined. Processes are defined and separable for management throughout the company. Awareness of digital transformation, the company is prepared for implementation and a methodological framework is developed. The processes are automated by some IT system.

Level 4. Managed: Processes are measurable, controllable, and digitized as well as services and products. Digitalization is implemented and integrated into business models to manage company strategies.

Level 5. Optimized: Focus on process improvement. Implemented systems have a remedial impact on hardware autonomously and maximize the productivity of the corporate framework. Corporate culture is changing dramatically, new approaches to digitalization, and processes are emerging.

Levels are assessed by measuring the following blocks:

1. Digital culture. The company organizational level for supporting processes, system development and change management.
2. Staff. Compliance with technical background of personnel competencies.
3. Processes. The level of management methods for optimization, analyzing, decision-making processes.
4. Digital products. Analysis of the digital company products to carry out the future value.
5. Models. Evaluating constant updating of models, validity, existing process models.
6. Data. The measurement of data security, completeness and quality level.
7. Infrastructure. Analyzing how digital infrastructure works and what tools are used.

Most companies by expert opinion are between the second and fourth levels, therefore they are not yet fully ready for the digital transformation which also applies to the digital twin implementation(Brodny and Tutak, 2021). To sum up, for the transition to a strategy of adaptable maintenance of equipment, the use of the wide functionality of the IOT, Machine Learning, the company needs to have a methodological base and a suitable IT architecture.

2.11. Digital twin implementation process steps

Thus, summarizing the information described above, the research work draws attention to carefully study the application area(ScienceDirect, 2022).

To properly implement the digital twin the following steps should be done:

1. Assessment of the company characteristics: description of the activities and processes, regulations and standards, readiness for digital transformation, implementation risks.
2. Data collection: analysis of the automatic systems existing in the company, data architecture and interconnection of corporate management systems.
3. Creating a product: data transformation into the necessary form (cleaning data for anomalous/incomplete data), IT architecture development, setting up simulation models, selecting optimal operating strategy, introducing restrictions based on settings, technological instructions, and enterprise features.
4. Product development and service: transformation to business values by the required form for the user, product testing/debugging, creating corrective actions, and visualizing. Possibility of system configuration and support by other modern technologies.

Regarding to the theoretical basis research paper gives the opportunity to make clear understanding of principles of digital twin work, its features and components. This approach accordance with the research methodology moves from general statements to specific examples and confirmations of the prior theory. The business case in the oil and gas industry as a certain situation will be described in the next paragraph.

3. The practical part. Digital twin implementation in the equipment maintenance in a real gas and oil company

This section gives a specific case study of a real company in the oil and gas industry. Describing a certain case following the methodology the problem and its solution using a digital twin will be considered. In addition, this part presents the economic benefits of implementing smart technology as well as other business benefits, and architecture will be proposed.

3.1. Case description

Asset management is based on the ISO55000 standard and includes the optimization of processes related to assets in an organization such as development, planning, application, and maintenance.

In gas and oil companies one of the main material assets is an electrically driven centrifugal pump (ESP) that is used in wells. Shell companies and joint ventures operate in the Russian Federation, including Sakhalin Energy Investment Company Ltd. and Salym Petroleum Development. All wells of the Salym fields are equipped with ESP pumps. The amount of oil produced from a well directly depends on the correct operation of the pump (Shell Global, 2021). Since ESPs are the main lift tool in the Salym oil field, Salym Petroleum Development pays great attention to the layout and maintenance of these pumps.

During the operation of the ESP, it is necessary to systematically monitor the condition of all electrical appliances and ground equipment. Control over the state of the electrical equipment of the ESP as well as the performance of the ESP is carried out by a specialist in the maintenance of such installations. In the overhaul period of the installation, a preventive inspection is carried out at least every three months(ESP Maintenance, 2022). In the company, the production of maintenance work, firstly, starts from checking the equipment functionality. Daily inspection of the ESP unit performance is carried out by the oil and gas production operator.

In this case, the mining operator should:

- Make an external inspection of the ESP for the integrity of all its equipment. Instrument readings are taken on the control panel. All changes in parameters for these control instruments are transmitted to the ESP maintenance specialist and the dispatcher. Timely adoption of appropriate measures to eliminate these faults allows to increase the overhaul life of the ESP.
- Control over the operation of the installation by deliberately raising the pressure. When the ESP works properly depending on the type of installation with the correct phasing the pressure rise to a certain pressure is carried out for a certain period. By changing the load, one can judge a decrease in pump efficiency due to sand entering through the strainer, a decrease in load is the first sign of leaks in the pipes or the passage of part of the liquid through the bypass valve.

An integrated approach to the analysis of load changes, flow rate instability, tracking of dynamic and static levels allows to plan the type of repair work in a timely manner. However, monthly scheduled equipment maintenance is sometimes useless, as the system is in good condition and does not need to be repaired. In addition, this type of manual inspection takes a lot of time to inspect the object, moreover, it is often located in hard-to-reach places, and it is not always possible to find the place of breakdown.

In contrast, condition-based maintenance by applying digital twin reduces the number of repairs performed, thereby reducing labor costs for their implementation. And predictive maintenance helps to plan scenarios to avoid further breakdowns and accidents. This opens up the possibility to reduce the number of workers to repair breakdowns and reduce overall costs.

The problem of unplanned pump stops can be happened for various reasons which entailed large financial and temporary losses. Pumping unit malfunctions include: hydraulic protection fails, rubber diaphragm rupture; motors failure, body corrosion; clogging with mechanical impurities, and the pump shaft quickly wearing out. For example, almost 40% of pump failure cases are associated with salt deposition on their working surfaces(SpringerLink, 2021). Other breakdowns can be connected to motor and cable failure, overloading, connection severance and other operating and mechanical problems.

Depending on the operating conditions, various elements fail, the replacement of which can restore not only its basic performance but also raise it to the level of standard performance (Evans, 2019). The design of the submersible unit twin allows it to be repaired by nodes, for instance, separate electric motor, pump and hydraulic protection. The components of the pump are presented in Figure 13.

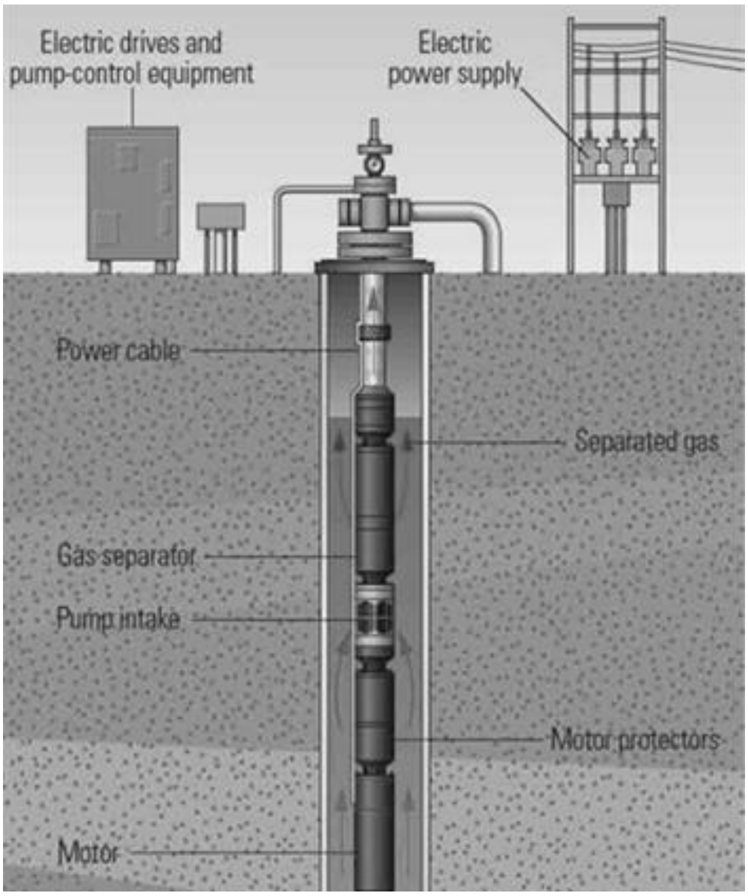

Figure 13. ESP pump

Digital twin which simulates different scenarios of operation failures including pump modes, impacts on the environment and varying degrees of the part wear. The maintenance process becomes much easier with the help of digital twins (Fig.14). Firstly, the remote control is possible. Often wells with pumps for oil and gas production are located in special areas that are difficult to get to. Thus, time is saved on the way to the objects and on the specialists who will do it. Secondly, digital technologies after collecting data help to prepare models in various forms not only to see the equipment in real-time and its condition but also to simulate different situations and offer preventive plans.

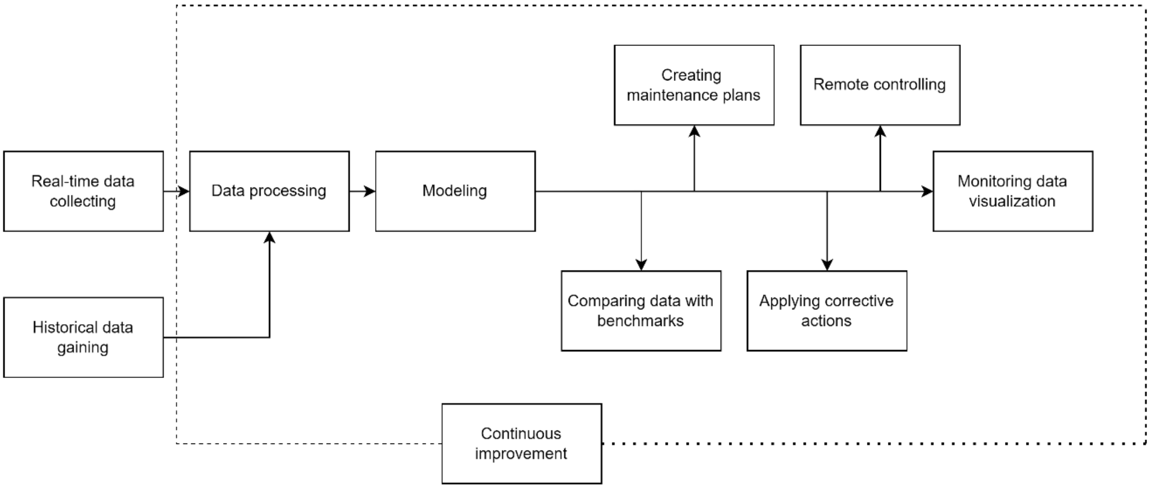

Figure 14. Data process after applying Digital Twin

In addition, digital twins optimize the maintenance process, reducing downtime and equipment repairs. The pump algorithm needs parameters and data from sensors to determine which components or combinations of components may fail. After obtaining the necessary information, various analytical models will be created that will signal anomalies and corrective actions that need to be taken. Despite these advantages of the proposed solution, it is necessary to calculate the quantitative efficiency indicators to let the company receives economic benefits from it.

3.2. The economic parameters of implementing a digital twin of ESP pump

As the economic parameters of the digital twin in this work the indicator that stakeholders are guided for planning to take part in investing process is described. Before making a decision on the direction of investment in a particular project, the investor wants to know how long he will be able to return the funds and make a profit. Following this, an indicator such as the payback period is used, which is calculated by Formula 1.

$$\text{Payback period} = \frac{\text{Initial Investment or Original Cost of the Asset}}{\text{Cash Inflows}} \quad (1)$$

The case study has external data from considered company. The example used average oil prices and the dollar exchange rate. One of the fields in the Salym group includes 24 wells. All of them are equipped with ESP. Calculations are made for one well and shows the overall picture of the implementation of modern technology. This part will only show by example what benefits can be obtained in this case, and this result is not guaranteed in all cases for other companies. For an accurate assessment of investments, it is necessary to conduct a detailed study of the certain company and the market situation.

Table 3. Economic parameters and calculations

Parameter	**Digital twin**	**ESP**	
Implementation costs	374 000 $	-	
Service	10%	-	Service fee from digital twin cost
Total cost of asset	**411 000 $**	-	
Repair period	2 days	7 days	71% less downtime with DT
Breakdown days of ESP failures per year	-	36 days	10% downtime per year from statistic data of the company
Number of ESP breakdown days per year		5 times	
Breakdown days per year (Repair work with DT)	10 days	-	According to CBM, 5 times per year
Advantage difference of breakdown period	26 days		
Price per barrel of oil	75$		Average statistic data
Production of barrels of oil per day	35 barrels		Statistic data of the company
Cash flow	**68 250$**		Profit from reduced downtime for 26 days
$\mathbf{T_{payback}}$	**6 year**		

Since the company is quite large, it purchases equipment, rather than leasing it. Based on the average repair process, pump malfunction takes about 7 days to fix a failure, which brings some losses per the daily profits from oil production. Using a digital twin based on the actual state of the well saves time for troubleshooting, and in case of any problems, it can solve the problem without an engineer visiting the well. Thus, the average downtime is reduced to 2 days. The difference between shutdowns due to malfunction and scheduled maintenance is equal to the benefit that the company gets from reducing the well shut-in time by 71% through the implementation of the digital twin.

From statistical data, pump stops are about 10% per year (~36 days) of all work from the beginning of the installation (SpringerLink, 2021). It means 5 times of complete shutdown due to the need for repairs. Regarding the application of the digital twin, repairs could be carried out before the accident occurred and will take only 10 days a year. It should be noted that the advantage is 26 days for which oil can be produced and bring benefits for company.

To calculate the payback, it is necessary to compare the costs of implementing a DT with the positive effects. In addition, it is worth noting that the cost of the digital twin includes maintenance and a specialist responsible for managing the software. The service cost is 10% of the DT price. According to mathematical formulas, the payback period can be calculated. Following this case for 1 well of the Salym fields, the calculations shows that digital twin will bring positive effects within 6 years.

This example implies a simplified version of a specialized calculation indicator that describes the period required to fully recover the initial investment costs made, based on the planned target level of feasibility of the selected undertaking. But here it is important to consider the presence of three assumptions: it is planned to achieve the required profitability indicator, inflation growth and its current level are not considered, additional expenses are not taken into account and are not calculated.

One of the challenges in evaluating the benefits of the Digital Twin is that the main benefit comes from «hidden» cost savings such as reduced time needed to find and verify information at the manufacturing site, fewer errors and returns when purchasing spare parts, reducing equipment downtime.

Salym Petroleum Development with digital twin technology gets the optimal operation of the ESP and increases the operation time in the well. This contributes to production growth, ensures a consistently high operating ratio, increases the turnaround time of downhole equipment, reduces operating costs and, ultimately, improves oil production efficiency(Zhang et al., 2017). This innovation allows technicians to better identify and prevent anomalies and failures, as well as deviations from operating ranges, in the early stages.

The digital twin will also impact on return-on-investment parameter (ROI). To calculate this ratio, more data on the performance of the organization is needed and this may be a further research question. The purpose of these calculations is to show not only a qualitative reduction in downtime and an or increase in efficiency, but also quantitative calculations of the economic parameter for investors.

3.3. Proposed architecture for digital twin of pump

As mentioned earlier in theory, the digital twin is embedded in the corporate structure and is a supporting system for decision making. This technology is closely connected with various management systems and provides support as a service. The proposed architecture of the digital twin at the top level represents in Figure 15.

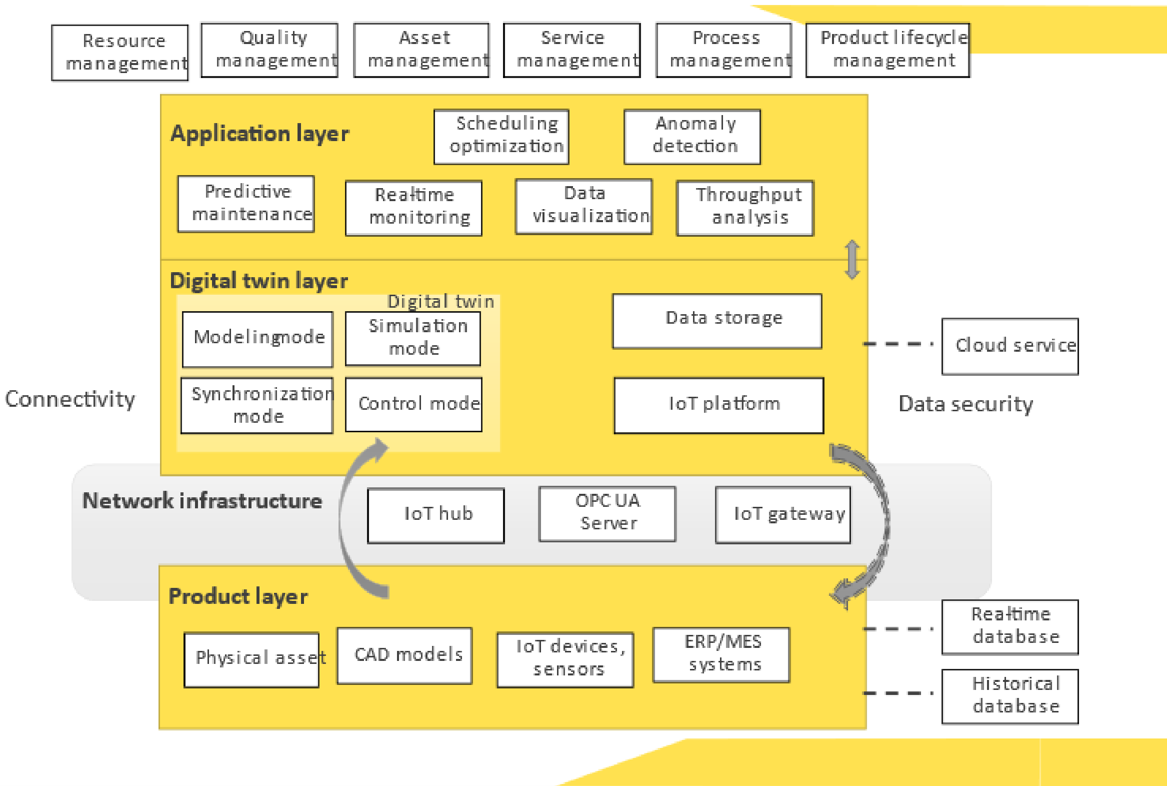

Figure 15.Architecture of DT

The general algorithm of the digital twin is as follows. The readings of physical sensors installed on the equipment are transmitted through a standard process control system to a digital twin, implemented as an industrial server or an industrial controller(Siemens Energy Global, 2022). The mathematical model receives this data and continuously calculates the rest of the process parameters that are not physically measured. It provides the operator with this data in the form of virtual sensors and uses it to calculate technical and economic indicators, as well as to diagnose certain defects and predict.

The mathematical model is regularly calibrated to match the current state of the equipment. It also allows deviations to be determined at an early stage since it can be used as a reference for comparing physical measurement data. The forecast is based on the extrapolation of the growth of deviations by the diagnostic criteria and rules.

During the operation of the energy block, many interrelated complex continuous physical processes take place. For individual complex nonlinear processes, three-dimensional models are created, then converted into reduced-order models and then integrated into a single system model that reproduces the actual operation of the power unit.

The example of a DT implementation is proposed as a platform in partnership with Bentley using Bentley's iTwin open platform jointly with [Microsoft] Azure, a cloud-based platform that enables interoperability between owner systems and supply chains. The iTwin platform implements APIs and services for developers to create, visualize and analyse a digital twin of a pump. In addition, the platform provides security points, data integration with infrastructure features. iTwin services in the cloud are simply synchronized with Azure, thereby allowing engineers to access data from any remote device. Azure IoT Hub connects virtual and physical object. Thus, this synergy makes it possible to model, simulate various use cases and carry out planning. In turn, the relationship is built with the business components of quality, assets management, resource and service management to make strategic decisions.

3.4. Case study results

As a result of monitoring the technical pump condition and its maintenance according to the actual state is considered following advantages:

- Prediction of failure of components, assemblies and assemblies of equipment (reduces equipment downtime by 71%, typical repair costs in case of equipment emergency failures are, on average, 10 times higher than the cost of repairs with a timely detected defect);
- Identification of cases of improper operation of equipment;
- Establishment of optimal modes of equipment operation (enables remote monitoring of the installation);

- Investment attractiveness (costs are reduced by 5-10% by minimizing unnecessary repairs, payback period is about 5-7 years);
- Increasing productivity of oil production (increases by 30%, thereby increasing the profitability of the well and the entire field).

The business case considered the CBM management scenario. An event or a marked time interval allows machine learning to be applied with so-called supervised data. Working with controlled data, machine learning algorithms can make predictions and determine the main indicators of the occurrence of a predicted event (Abukova, Dmitrievsky and Eremin, 2017). The ability to analyse thousands of sensors and data over decades allows to identify patterns associated with specific events, as well as predict the time of occurrence of an event. The technology helps realize these capabilities with machine learning analytics: increase throughput, reduce downtime, or prevent dangerous events.

To achieve such advantages of the digital twin of equipment, there must first be several aspects:

1. Inspection of the digitalization object
2. Development of a mathematical model using numerical multiphysics and system modelling tools, machine learning
3. Integration of a mathematical model with a physical object by connecting to sensors and / or a control system
4. Accumulation of statistics, verification and additional training of models
5. Development of user interfaces and augmented reality
6. User training, support for the industrial operation of the digital twin

Nowadays, in almost all companies such a transition is impossible for several reasons: the lack of methodological training and necessary IT infrastructure.

To move to a more optimal scenario companies must have a satisfactory level of technological maturity. To summarize, the research work shows that the predictive maintenance scenario can be viewed as a perspective. However, the company must be at a certain level of technological maturity, has a suitable IT architecture and methodological basis for the transition.

Thus, using the example of the considered particular case of using digital twins in an oil and gas company, specifically, ESP pump, a general conclusion could be done which confirms the prior theory. It is obvious that digital twins, despite their expensive cost, pay off quite quickly, while optimizing processes and helping businesses save costs. In addition, by debugging all processes, integrating systems and customizing the methodology, companies will be able to move to the required level of digital maturity to use the digital twin not only to control the current state but to predict future failures. Hence, using predictive algorithms and the symbiosis between Industry 4.0 technologies, it is possible to consider "what-if" scenarios and calculate the benefits received from a particular outcome.

4. Discussions & Concluding remarks

One of the indispensable attributes of the digitalization of industrial facilities and production processes is digital twins. By accumulating data from sensors and measuring devices, specialists model the behavior of an object or process, identifying risks and deviations in operation and suggesting the best ways for the system to function. The final section includes information on key findings, contributions for further research, and perspectives.

4.1. Key findings

The oil and gas industry is currently one of the leaders in the use of digital twins to improve production efficiency. This is facilitated by such factors as the diversity of production processes (development of fields, construction of wells, artificial lift, transport and treatment of oil, processing of hydrocarbon raw materials), the presence of a large amount of industrial information and a high level of automation. In addition, digitalization gives high return on investment (due to increased production and reduced operating costs and capital investments).

Digital twin is a quite mature technology that can be applied in different areas of companies. Even though this type of digitalization has been studied from various aspects that were considered in the work, such as types of twins, structure, architectural components, interactions with business management systems levels, as well as integration schemes, implementation is complicated. The research work highlights aspects that need attention. For example, it is necessary to work out not only the features of digital twins but also change the entire role and process model of the organization.

Many companies, realizing the benefits of technology should transform the business and digitize it, the data entering the digital twin is needed to be real, structured and systems should be integrated in such a way that the databases existing in companies can be synchronized with it. The reason why digital twins are rarely used and not at the highest advanced level is that nowadays many organizations have processes that are not automated and therefore not at the proper level of digital maturity. The training of specialists in various modern technologies is quite long, the processes are constantly being improved, the qualifications of employees also sometimes do not meet the needs for the introduction of twins. Also, some companies are not ready for implementation due to the lack of formal regulations and standards that are necessary for the correct and high-quality operation of systems.

Thus, digital twins as one of the directions of Industry 4.0 in the reviewed and analysed scientific articles from an empirical point of view is a potentially relevant technology that is being developed. By overcoming the engineering ignorance, organizational and economic barriers described in this paper, companies will be able to obtain certain benefits from the use of digital twins. Potential customers due to the implementation digital twins get the opportunity of optimised decision-making support, the ability to work with the highest speeds of various models and modifications of equipment and providing personnel with information about the state of the equipment in real time, moreover, reducing costs and increasing productivity.

Future research can be based on the case of the company and considered from the side of digital twin integration methods, programming, and model simulating methods using timed experiments. Achieving such a goal will provide a deeper understanding of the operation and implementation of digital twins, as well as quantitative advantages.

4.2. Contributions

At the beginning of the work the following questions were identified to achieve the main goal of the study:

Q1. What are the key opportunities/ challenges of the digital twin implementation in the gas and oil industry?

Q2. How are digital twins deployed? What are the infrastructural features?

Q3. What are the areas of application of digital twins in the service industry? How does digital twin help in condition-based maintenance?

Q4. What is the economic efficiency from the introduction of digital twins for servicing an electric submersible pump?

In answering these questions, the research work reviewed scientific articles, collected data from various sources and considered a specific case of applying a digital twin in the oil and gas sector to support equipment maintenance. Based on the research methodology, the main concepts of digital twins, areas of application, barriers to implementation, architecture and components were considered. The collected data provided the theoretical basis of the study which helps to delve into the field of equipment maintenance, identifying advantages and disadvantages, describing the standards applied to asset management, and the current situation of the digital maturity model of companies.

Based on the statistical data of a certain company which were obtained through a request and contain only part of the information that is not a commercial secret, an analysis was carried out and cost-effectiveness calculations were made. In addition, an architectural model for Salym Petroleum was proposed which is not mandatory for implementation but can be used as an example for implementation. Short payback period, optimization of the company's processes provides relevance to attract the attention of investors or for companies that have not yet had time to implement this technology. Reflections on digital transformation give impetus to a detailed study of the interested group of individuals and applications in various fields. According to the results of the work received, digital twins are ready for use and can be interpreted according to the needs of companies. The considered case and prior theory emphasize aspects that need to be taken into account and do not limit further research.

4.3. The prospects of digital twins

Further development of digital twins as a complex system integrating several technologies is determined by their degree of change and improvement. The expansion of the use of such technology in new industries and applications follows the development of mathematical models which are improved in describing physical processes, as well as in reflecting complex economic and social phenomena. An important role in the new possibilities of digital twins is played by the growth of available computing resources for mathematical modelling. Today, many problems based on numerical simulation with the necessary accuracy and available computing resources require a very long computational time(A Look Inside the Potential of Digital Twins, 2022). These, in particular, include the problems of multi-parameter optimization in the design of modern industrial facilities, as noted in this book. In most cases, the solution to such problems requires time much longer than is acceptable for process control. Several experts predict a qualitative leap in the speed of hardware systems in the next decade with the transition to quantum computing, which will allow performing numerical analysis based on the same (and more complex) models in a time acceptable for the operational interaction of a physical object and its digital copy.

Nowadays, companies are working on the development and use of quantum algorithms for modelling complex physical processes. These projects include modelling of airflow around an aircraft wing, turbulent fluid flow in hydro monitoring problems, and molecular interaction in applications for medicine and biology. These allow us to hope that in the next few years digital twins based on radically faster calculations will appear, which is not possible today. Moreover, it will be possible to increase the speed of signal transmission between the physical and digital twins, and a qualitative leap here should be expected with the transition to 5G technology(Digital Twin for 5G and Beyond, 2021).

New possibilities of artificial intelligence will the creation of digital twins which able to make decisions autonomously, coordinate with others, perform self-diagnosis and troubleshoot problems on their own. Decision-making systems based on digital twins will eventually save a person from the need to be in dangerous and aggressive areas. Industrial manned objects will appear, where many processes will be controlled autonomously by digital twins - platforms in the field of mining, energy, and agriculture.

Being embedded in highly critical products (such as, for example, nuclear power plants), "smart" digital twins will be highly vulnerable and will require the development of intelligent self-defense tools aimed at neutralizing malicious actions during external attacks and unauthorized access, as well as protecting against incorrect or unauthorized use. In the event of massive attacks, smart digital twins will take automated responses using environmental knowledge.

Smart twins will be able to collect historical data and generate real-time forecasts. They will find suitable sources, use various methods of collecting and processing data, structure it, enrich and transform it into useful information and also choose suitable methods of intellectual analysis and forecasting. Twins with common tasks will be able to provide services to each other and unite in the so-called "digital swarms" ("digital swarms"), find and identify such communities, join them and perform complex collective tasks(Datta, 2017). Over time, any product (product, object) will be associated with a digital twin that has information sufficient to reproduce it, thus, digital world would be created. For the design of new objects, it can be noted that in the digital world it is possible to create a whole range of prototypes of a future material object with different characteristics.

When designing a product, dozens of twin options may appear in different price categories, designed for different technological capabilities, including those that cannot be implemented today, for example, for structural materials that exist only in the form of digital prototypes. Most of these digital solutions will wait in the wings when they can be embodied in this or that material. Digital twins, which have not yet received their physical embodiment for economic reasons, will wait for the moment when the market model shows that the hour for such a twin to acquire its material essence has come, and only then the material object will be created.

In the future, people will also receive digital twins that will collect information about the owners and offer individualized, effective treatment and the accumulated experience will be passed on to the next generations(Schwartz et al., 2020). Recently, a lot of fears have appeared regarding digitalization in its various manifestations. People are afraid that new digital technologies carry the threat of ousting a person from his usual world, where he performs a well-established set of production and social functions. However, research work shares an optimistic point of view, according to which humanity is progressively developing both technologically and socially. Following this logic, digital technologies are a new effective tool, which, like any new technology that has not yet been tested, is fraught with certain threats that can be studied and overcome to achieve human progress.

Mankind has already become accustomed to many and cannot imagine its existence without them, even though they carry a certain amount of danger (the same aircraft, for example, or cars). People need time to realize not only all the advantages of innovation but also its threats and develop rules (including those prescribed legally) to neutralize these threats. It is supposed that humanity will have enough intelligence and goodwill to turn for good those amazing opportunities that digital technologies and the digital twin as their embodiment carry.

4.4. Conclusion

Digital twins allow companies to remain competitive in the global market and manage changes at all subsequent stages of the life cycle. Most examples of digital twins are virtual models of individual elements of production: products, equipment, systems, lines, and processes. This master thesis examines the impact of transforming the operation of an oil pump and generating benefits using a digital twin. It can be noted that in the future, companies will increasingly approach this issue in an integrated way, using technologies at all stages of the value chain, from design, collection and analysing of the information until the commission of the products and maintenance.

Combining all the equipment into a network and creating a communication channel with higher-level systems, which exactly implies an integrated approach allows to centrally manage resources and production data. Accordingly, the purchase and operating costs of equipment are reduced, and the company becomes able to develop an optimal well operation strategy. In addition, the author says, that a visual representation of the equipment characteristics and processes helps to quickly assess the current situation and effectively coordinate activities.

The paper described the value of an integrated approach to the management of the equipment. The work illustrates the architecture of digital twin and economical effects as an example in the real object. In the future, it can become not a twin of the tool or part of equipment but also a complex system. First of all, digital twin will improve procedures for documenting production procedures and visualize parameters, components that are installed in it, what features they have and how system works, in generally. To summarize, companies purposefully identify potential problems with the help of digital twins. In addition, the information regularly received from the IoT sensors can help to adjust and optimize processes with high efficiency.

In conclusion, the use of a comprehensive data model that contains all the information about production at all stages of the life cycle reduces the time to market, while increasing the flexibility and efficiency of the enterprise. As a result, companies applying this approach successfully adapt to the variability and diversity of global markets, achieve higher productivity and more efficient use of energy and resources, thereby ensuring long-term competitiveness.

In the era of digitalization, an important task for industrial enterprises is to ensure efficient operation when implementing modern information tools for industry 4.0. In this scientific work, special attention is paid to the concept of introducing digital twins. Despite the difficulties of introducing digital twins, the master's thesis highlights the problem of assessing the increase in the efficiency of industrial enterprises. The prior theory and the research work describe the development and implementation of digital twins and also the advantages and architectural part of a digital twin using the example of creating an ESP to support maintenance.

Future research may consider the following aspects:

- Data analytics between other areas of application and building relationships
- Some verification of the findings of the study and consideration of another real case and comparison of the results, since such work has not been carried out in the discussion before
- Comparative characteristics with other digital technologies
- Assessing the interest of stakeholders and ways to involve them
- Conducting empirical experiments, creating conditions for the operation of a digital twin
- Carrying out research in the field of predictive analytics and using technology synergy
- Ensuring technical awareness of existing architectural components and platforms to implement the digital twin
- Calculation of other economic indicators for a more detailed comparison of the economic efficiency of implementation
- Development of a digital twin using the regulatory framework in various countries.

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Appendix 1. Scopus search results