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战略决策和风险管理

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CONTENTS / 目录

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Unemployment level as a trigger for threats to the national security of countries (On the example of Russia and European countries)

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Abstract

The phenomenon of unemployment is characteristic of almost all developed countries, and the issues of unemployment regulation remain the most important at the macro and micro levels of public policy. Unemployment is one of the most important indicators of the general state of a country's economy. The authors of the article drew a connection between the unemployment rate in Russia and European countries and the state of economic and national security of the states. Pyramids of the security levels of Russia and the EU countries are proposed. The characteristics of the labour market of the European countries and the Russian Federation are considered with an emphasis on the diversity of the regions. It has been established that the unemployment rate in the developed countries is connected with the processes of globalisation and digitalisation, with the geopolitical situation, and can be an economic trigger that has provoked fundamental changes in the modern labour market, the state of human capital and social tensions in the world countries. A number of universal measures are proposed to strengthen the national and economic security of countries.

Keywords: general unemployment rate, economic security, national security, triggers in the economy, unemployment in Russia, unemployment in European countries, measures to prevent unemployment.

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失业率是威胁国家安全的导火索（以俄罗斯和欧洲国家为例）

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简介

失业现象是大多数发达国家普遍面临的问题，对其进行调节仍然是公共政策宏观和微观层面的重点。失业率是衡量任何国家经济总体健康的关键指标之一。本文章作者确定了俄罗斯和欧洲国家的失业率与国家经济和国家安全状况之间的依赖关系。作者提出了俄罗斯和欧盟国家的安全等级金字塔，考虑了欧洲国家和俄罗斯联邦劳动力市场的特殊性，重点是地区的多样性。作者确定了，发达国家的失业率与全球化和数字化进程、地缘政治局势相互关联，并可能成为引发现代劳动力市场、人力资本状况和世界各国社会紧张局势发生根本性变化的经济导火索。为加强各国的国家安全和经济安全，作者提出了一系列普遍性措施。

关键词: 总体失业率、经济安全、国家安全、经济领域中的导火索、俄罗斯的失业情况、欧洲国家的失业情况、防止失业的措施。

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Introduction

Today, high unemployment is a problem in the global economy, which leads to the dispersion of labour potential and is one of the economic triggers for the reduction of gross domestic product and the poverty of the population.

In Russian legislation, the definition of national security is presented as 'a state of protection of the individual, society and the state against internal and external threats, which ensures the implementation of constitutional rights and freedoms of citizens of the Russian Federation, an adequate quality and standard of living, sovereignty, independence, state and territorial integrity, sustainable socio-economic development of the Russian Federation'[1]. The consequences of unemployment are traditionally expressed in a fall in consumer demand, a reduction in household savings, a slowdown in the investment process, a fall in GDP and a fall in the level of national security.

The unemployment rate in Russia over the last thirty years of statistical observation has ranged from 5.2% in 1990 to 5.4% in 2020, with peaks during the economic crises of 1998 and 2008.[2] (Fig. 1). Some Russian researchers believe that unemployment of 4-5% is considered natural for a developed country, and low - at 2-4%[3] and does not affect inflation. According to Rosstat, the unemployment rate in Russia fell to 3.1% in June 2023[4] and created the problem of personnel shortage.

The unemployment situation in the European Union is different. The high unemployment rate in some European countries is explained by many geopolitical factors, as well as the peculiarities of European labour law, where there are more rules and restrictions that hinder the hiring of employees. The unemployment rate in the European Union in August 2023 was 5.9%, while the youth unemployment rate remained traditionally high at 14%[5].

It can be said that unemployment is one of the forms of macroeconomic instability and is a social problem.

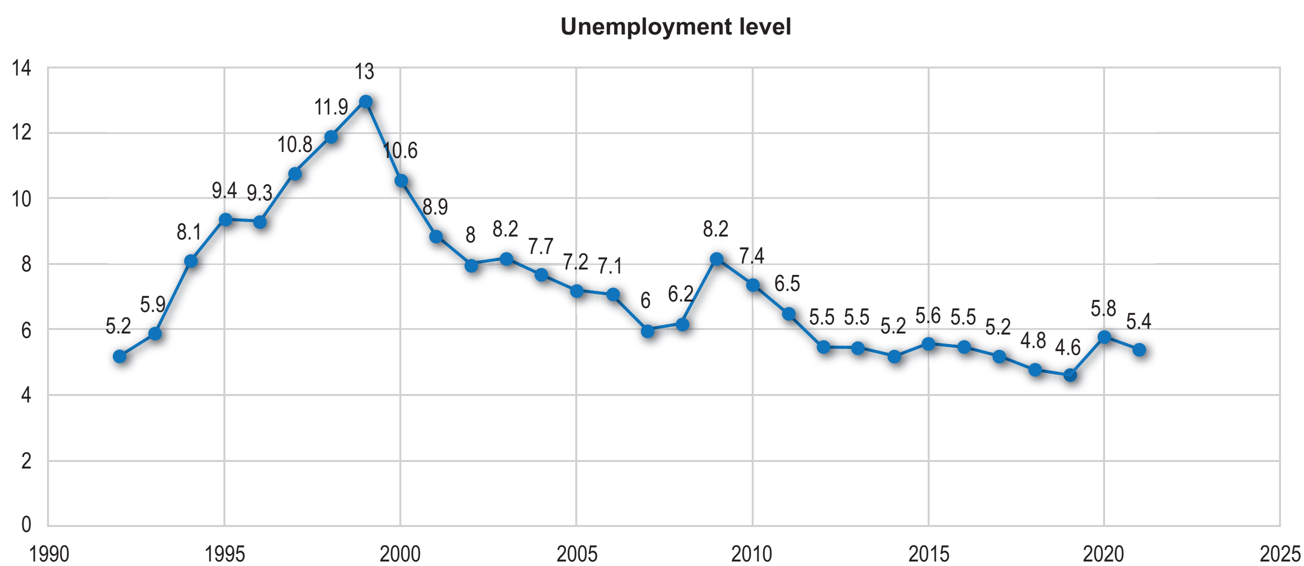
The study was based on methods of integrating theory and practice, factor analysis of statistical data, objective processes and trends in the global labour market. The work used methods for identifying cause-and-effect relationships, expert and predictive assessments.

1. Generalised portrait of unemployment in the 21st century in Russia and Europe

The need to work is characteristic of modern man. If we refer to the pyramid of needs of the American psychologist A. Maslow (Fig. 2), we can identify several levels of human needs that imply the need for work: security, a place in society, the need for respect and creative fulfilment. As a rule, the ladder from the level of social needs to the upper level of self-realisation and recognition of a person is more closely associated with his or her success in professional activities.

In 2022, the lowest unemployment rate is in the Czech Republic (2.3%) and the highest in Spain (12.9%), followed by Greece and Italy. A long-term gradual downward trend in

Fig. 1. Unemployment dynamics in Russia for 1990–2020 (%)



Source: https://ratenger.com/economics/bezraboticza-v-rossii/.

[1] Decree of the President of the Russian Federation dated 11 March 2019 No. 97 'On the Fundamentals of the State Policy of the Russian Federation in the Field of Ensuring Chemical and Biological Security for the Period to 2025 and Beyond' https://mvd.consultant.ru/documents/1056690.

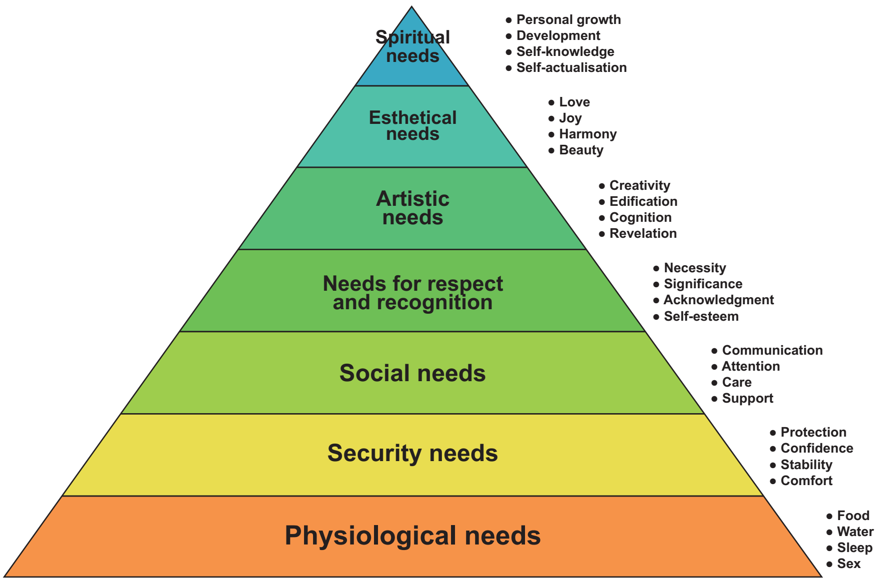
[2] Unemployment in Russia: statistics 2021-2022, causes and forecast. https://ratenger.com/economics/bezraboticza-v-rossii/.

[3] The concept of natural unemployment. https://economy-ru.com/makroekonomika-rf-uchebnik/ponyatie-estestvennoy-bezrabotitsyi.html.

[4] Unemployment in Russia hit an all-time low of 3.1% in June. https://www.interfax.ru/russia/914527.

[5] https://take-profit.org/statistics/unemployment-rate/european-union/.

Fig. 2. Maslow's hierarchy of needs



Source: https://practicum.yandex.ru/blog/motivaciya-personala/.

unemployment is observed in Germany - from 6.8% in 2012 to 5.7% in 2022[6]. According to Eurostat, the unemployment rate in the EU remained stable at 5.9% in May 2023[7]. This was a record low in EU history (6.1% in 2022).

Russia ranks 10th with an indicator of 3.7%[8]. The stabilisation of unemployment rates in all countries was significantly influenced by the removal of anti-covidiation restrictions.

The level of youth unemployment in the European Union is particularly striking. Each country has its own specific causes of unemployment and its consequences. Young professionals with a good education and little experience find it difficult to get a job that meets their needs, and often not in their field. For example, youth unemployment peaked at 30% in Greece and 28.3% in Spain[9]. It is difficult for young people to find a job in Italy, Luxembourg and Cyprus, where they are unsuccessfully looking for any type of work. An increase in the number of unemployed people aged 15-24 is observed in countries with developing economies: Asia, Latin America. Countries with strong economies tend to have low levels of youth unemployment, facilitated by targeted government policies (Fig. 3).

According to some reports, the unemployment rate among Russian citizens aged 15-29 has fallen to 8.5% by 2022, thanks to a long-term government programme to boost youth employment[10]. According to other official sources, by the end of 2022 the youth unemployment rate will be 31.6% for teenagers aged 15-19 and 14.4% for young professionals aged 20-24[11] (Fig. 4). Why were there such large discrepancies? Among the main reasons, in addition to the inaccuracy of statistical observations, one can point to economic migration, conscription and mobilisation, as well as the consequences of the 2019 COVID pandemic. In addition, in Russia the level of youth unemployment (as well as the general level) depends on the specific region.

Geopolitical events have had a direct impact on the state of the labour market: since 2022, Russia has experienced a shortage of personnel not seen since the 1990s (Figure 5). It was partly provoked by human losses during the Cold War and the emigration of in-demand personnel under the conditions of the Northern Military District and sanctions, and was exacerbated by partial mobilisation in the spring of 2022. Thus, at the beginning of the third quarter of 2023, 42% of companies reported a shortage of workers[12]. Sociologists claim that this is the biggest staff shortage in the almost 30-year history of statistical monitoring.

Some EU countries are also facing labour shortages, most acutely in Germany, especially in the automotive sector. The reason for the shortage is geopolitical: artificial restraint in the development of Europe's largest companies and, as a result, inflation, a fall in consumer demand and wage levels.

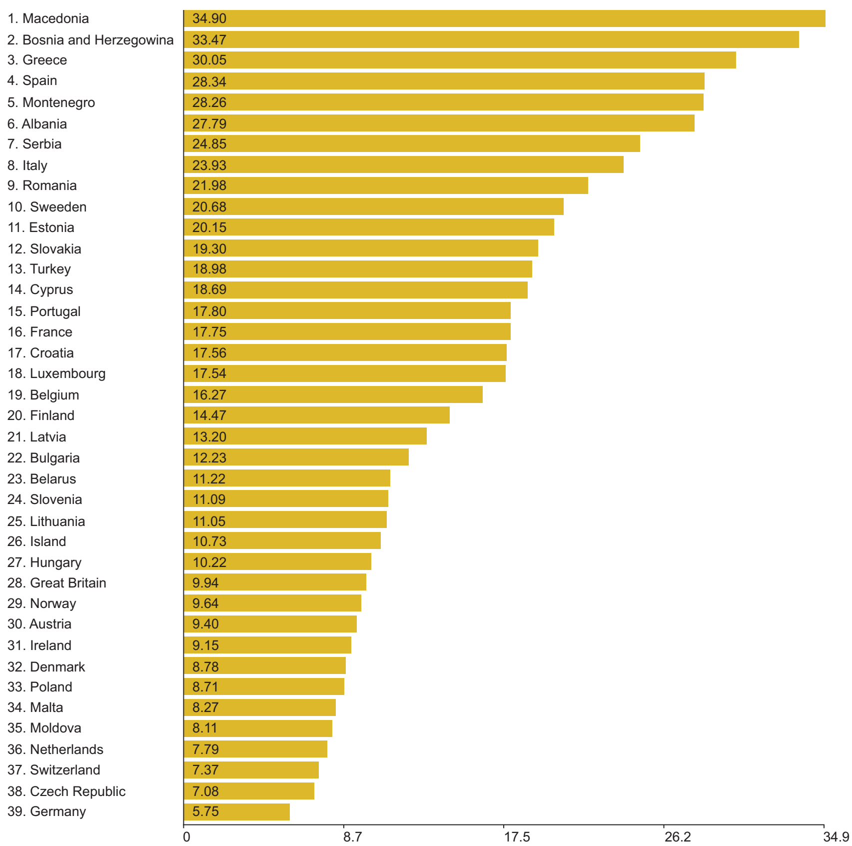
The development of new technologies and widespread informatisation have significantly changed the labour market around the world [Rimskaya et al., 2021]. Today, the professional potential of a significant part of the population of leading countries remains untapped. Labour migration is

[6] The rise in unemployment in Germany in August was higher than forecast. https://www.interfax.ru/world/.
[7] EU unemployment remains at record lows. https://www.kommersant.ru/doc/6136791.
[8] The European countries with the highest unemployment rates have been identified. https://ria.ru/20230220/bezrabotitsa-1853039560.html.
[9] Youth unemployment - classification of countries. https://ru.theglobaleconomy.com/rankings/Youth_unemployment/Europe/.
[10] In Russia, the unemployment rate for young people under 29 fell to 7% in the first quarter. https://www.interfax.ru/russia/914332.
[11] What is currently happening in the youth labour market. https://hh.ru/article/31218.
[12] No one to work for, nothing to pay: how the labour market started the process of impoverishment in Russia. https://newizv.ru/news/2023-08-03/rabotat-nekomu-platit-nechem-kak-rynok-truda-zapustil-protsess-oskudeniya-rossii-415386.

taking place, which in turn leads to the transformation of the economies of countries and the nature of the understanding of unemployment, which acquires a transnational character, creating social tensions.

The relevance of the research topic is due to the current state of unemployment as one of the factors influencing the economic and national security of countries.

Fig. 3. Youth unemployment by country worldwide, 1991–2022 (%)



Source: https://ru.theglobaleconomy.com/rankings/Youth_unemployment/Europe/.

2. Characteristics of the modern labour market

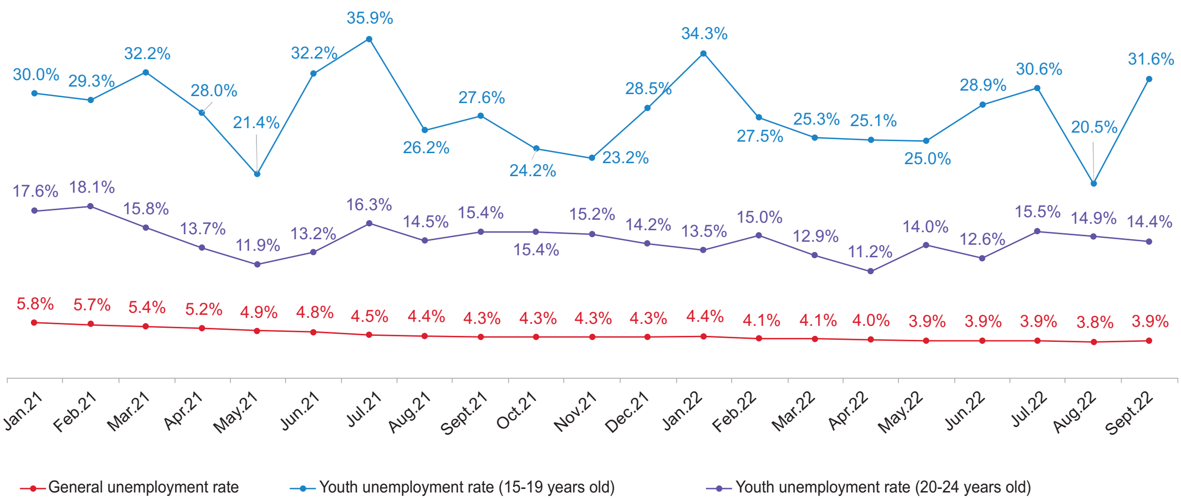
In conditions of rapid growth of scientific and technological progress and the modern digital economy, the labour market is dynamic. This is particularly noticeable in Russia's remote regions, which are attractive for investment. The Russian Federation occupies a vast territory made up of 91 regions; accordingly, the inter-regional differentiation of unemployment levels is large, which also poses a threat to the political stability and national security of the Federation.

Chronic unemployment has a negative impact on the quality of human capital, weakens the motivation to look for a job and also fails to fulfil the functions of anti-inflationary containment and coordination of supply and demand in the labour market. [Sharavina et al., 2018].

For the purposes of this article, human capital is understood as the accumulation and maintenance within an individual of skills, knowledge, abilities, competencies and motivation to work effectively.

It is quite obvious that human capital is part of the national security system of any country [Polyakov, 2012]. In the era of rapid growth of scientific and technological progress, intensified by the processes of digitalisation and globalisation, demographic imbalance, the structure and quality of human capital inevitably changes. Globally, the share of the working population in the total population will decrease from 62% in 1991 to 56.4% in 2022[13], however, there was a significant decline in 2008-2009.

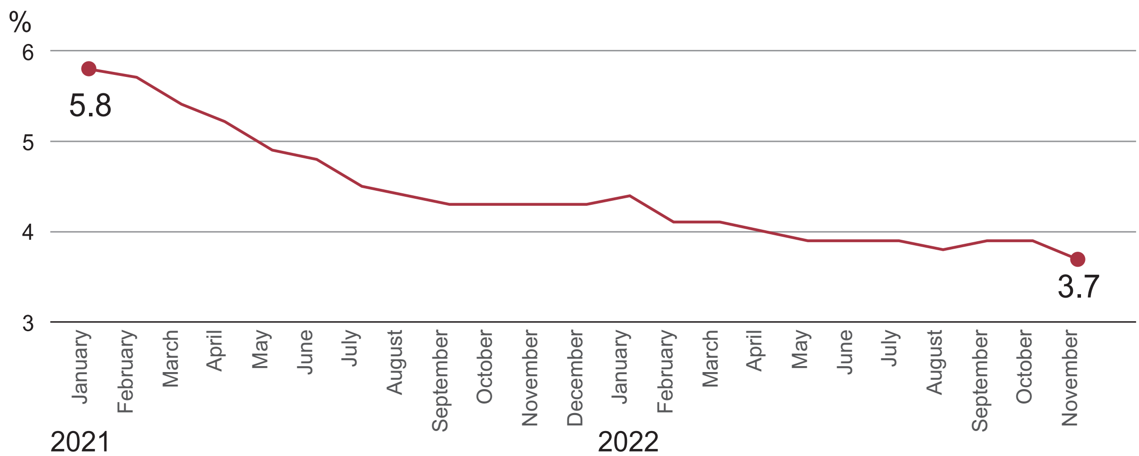
Fig. 4. Unemployment rates for young people and teenagers in September 2022 (%)



Source: Ministry of Economic Development, Rosstat. https://hh.ru/article/31218.

[13] Ratio of labour force to population. World Data Atlas. https://ru.knoema.com/atlas.

Fig. 5. Unemployment rate decline in Russia in the post-Covid period 2021–2022 (%)



Source: Росстат. https://www.vedomosti.ru/economics/articles/2023/01/18/959434-kadrovii-golod-i-lokalnaya-bezrabotitsa.

The basis of national security stability is economic security, which affects the political, military, technological, information, social and environmental systems. Therefore, it is important for any state to solve the problem of ensuring stability, first of all, its economic security, the ability of the country's economy to meet the needs of society with the prospect of developing productive forces at the national and international level.

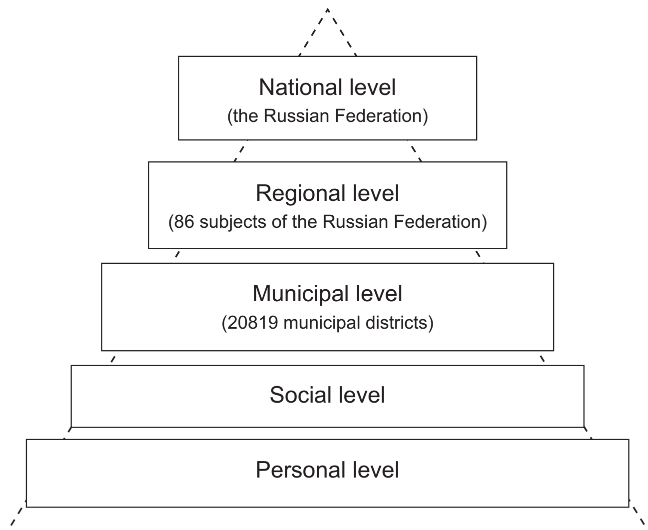
The elements of international economic security include: ensuring the sovereignty of states over their natural resources, production and economic potential; the absence of exclusive priority in the economic development of individual countries or a group of states; the responsibility of states to the world community for the consequences of their economic policies; focusing on solving global problems of humanity; free choice and implementation of a strategy of social and economic development by each state; mutually beneficial cooperation of all countries of the world community; peaceful settlement of economic problems [Kovalev, 2020]. It is obvious that the acceleration of globalisation processes has significantly undermined the world economic order.

In the 1960s, the American economist A. Okun concluded that an increase in the unemployment rate increases the gap between potential and real GDP, which is expressed in Okun's law: if the actual unemployment rate is 1% higher than the natural unemployment rate, the gap between actual and potential GDP is 2.5% (Okun's coefficient)[14]. The value of the Okun's coefficient in most developed countries of the world varies between 2 and 3, and its specific value depends on the importance of the labour factor in the production of the product.

In terms of GDP, Russia will be among the top five developed economies in the world by April 2023[15], ahead of Germany, France, Italy, Canada and the UK. Economists predict that China, the United States and India will maintain their leading positions until the end of 2030.

Thus, economic security is becoming a priority direction of government policy for most developed countries, including Russia. 'Economic security is understood as the state of protection of the national economy from external and internal threats, which ensures the sovereignty of the country, the unity of its economic space and the conditions for the implementation of the strategic priorities of the Russian Federation' [German, Bobrovskaya, 2019]. The peculiarity of Russia is that its national economic security consists of the economic security of the regions. The pyramid of security levels in Russia is shown in Fig. 6, and the security levels of the countries of the European Union are shown in Fig. 7.

Fig. 6. Russian security pyramid



Source: составлено авторами.

[14] Okun's Law - formula and content. https://nauka.club/ekonomika/zakon-oukena.html.

[15] Russia has entered the top five largest economies in the world, ahead of European countries. https://rg.ru/2023/08/04/rossiia-stala-piatoj-ekonomikoj-mira-po-paritetu-pokupatelskoj-sposobnosti.html.

At the present stage of development of the world economy, taking into account globalisation and the continuous growth of the technological process, a new approach to economic security as a criterion for the long-term national security of each state is needed.

The general level of unemployment, which is one of the indicators for assessing economic and national security, has a direct impact on the standard of living of the population, the state of mental health, the crime situation in society, the number of skilled workers, the quality of life of the population, as well as on the widespread modern phenomenon known as 'brain drain'. The policy of reducing unemployment is an integral part of the state policy in the field of ensuring economic security. It is primarily aimed at solving significant socio-economic problems.

The level of economic security is monitored using certain threshold indicators. Among the threshold values of economic security indicators proposed by the Institute of Economics of the Russian Academy of Sciences, the indicator 'Unemployment rate according to ILO methodology' was highlighted, the average value of which was determined at the level of 4%[16]. Unemployment is a negative phenomenon accompanying the market economy, the level of which cannot be reduced to zero.

3. Trends in changes in the structure of unemployment associated with global labour market changes

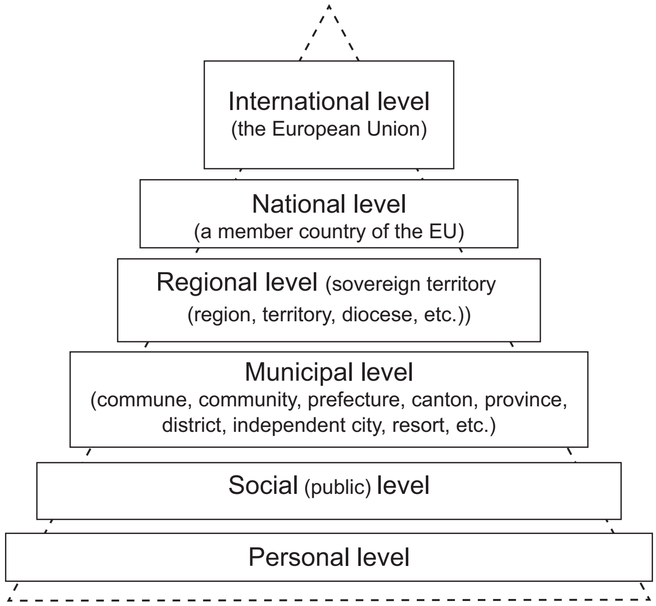
Globalisation processes contribute to the emergence of various crises at international, national and regional levels. The further development of integration processes leads to a convergence of national economic security with international economic security.

In the world view, the global risks to humanity are shown in Fig. 8. Among the types of economic crises (marked in blue), the largest share falls on the risk of rising unemployment, which in turn gives rise to social risks (marked in red): social instability and involuntary migration of population.

The sustainability of a country's economic security is influenced by the quality and development of its human capital. Human capital, as a stock of knowledge, skills, abilities and experience, can not only accumulate in the process of investing in its development, but also wear out physically and morally. This problem has now become global, as it is common to all developed countries of the world.

Unemployment thus affects the economic and, consequently, national security of the country as a whole, exacerbates negative social processes and increases the level of tension and anxiety among people. An unemployed person is deprived of the opportunity to use his knowledge, skills and experience, to receive income from their use in the

Fig.7. Security pyramid of the European Union



Source: составлено авторами.

labour process, and loses his personal status in the family and society.

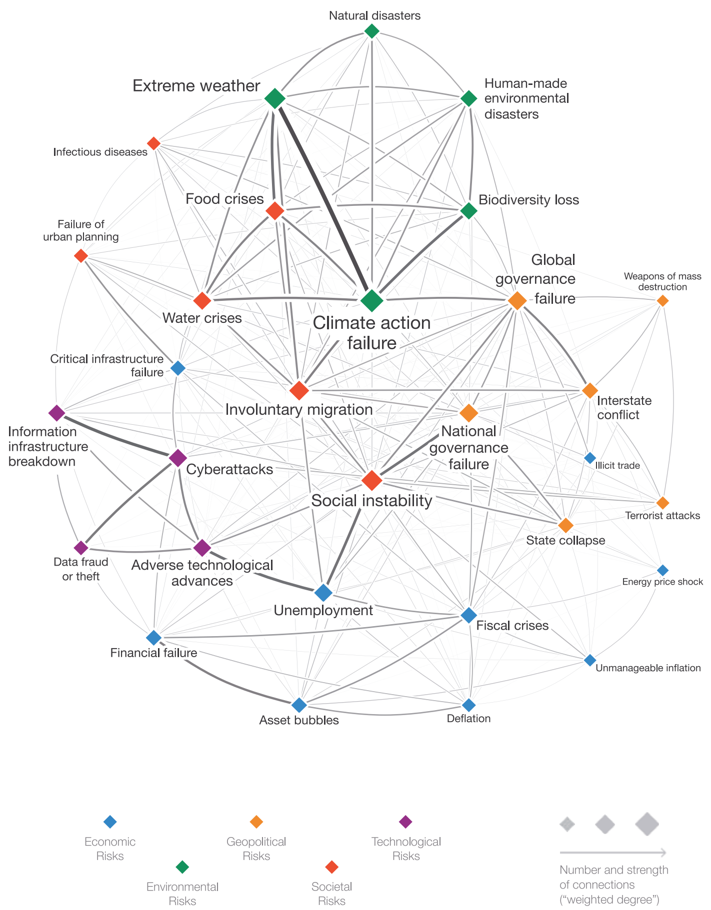
At the beginning of the 21st century, negative phenomena can be observed all over the world: local and international military conflicts, increased social inequality, low economic growth rates, imbalances in the labour market. Fig. 8 shows that the consequences of unemployment are associated with economic and social risks.

Economic losses due to unemployment are determined by the cost of goods, services and labour that are not produced or provided, as well as by a reduction in tax revenues, an increase in the cost of unemployment benefits and an increase in crime. Social losses are determined by the devaluation of scientific and cultural potential, a reduction in educational potential and a deterioration in the well-being of the population. The share of the economically active population decreases due to the negative dynamics of fertility, mortality and increased life expectancy and quality of life against this background.

Demographic change is also causing employers to rethink who they should be hiring. In many developed countries, the birth rate is below replacement level. In Greece, annual population growth in 2022 will be negative -0.4%, with a natural increase of 16,272 people and a migration increase of 25,496 people[17]. According to estimates by the French National Institute for Statistics and Economic Research, the country has experienced a stable average annual increase of 0.4-0.5% of the population from 2007 to the present. Population growth in France has been one of the fastest in Europe in recent decades and continued until 2022, with annual population growth of 0.45%[18]. France's fertility rate is 1.96 children per woman, a direct result of the influx of migrants: the vast majority of children are born into Muslim families,

[16] Unemployment rate (according to ILO methodology). Single interdepartmental information and statistics system. State statistics. https://www.fedstat.ru/indicator/43062.
[17] https://countrymeters.info/ru/Greece#population_2022.
[18] https://countrymeters.info/ru/France#population_2022.

Fig. 8. Map of global risk relationships, March 2020



Source: The global risks interconnections map 2020. https://www.improntaetica.org/wp-content/uploads/2020/01/Global-Risk-Report-2020.pdf

where women traditionally do not work. Germany reached a record population of 83.8 million in 2022, with population growth driven entirely by migration[19]. Half of female migrants are unlikely to ever enter the labour market, given Muslim traditions. Italy will experience a similar situation in 2022, with the number of migrants twice the natural population growth: 64,227 locals versus 107,247 arrivals[20].

The situation where the number of deaths exceeds the birth rate, and the ratio of these terms determines the natural increase, is observed both in Russia and in European countries.

The economic benefits of increasing human life expectancy through health science are questionable and premature if the economy and society are not ready to decide what kind of work, career or role workers should perform in a long life. Against this background, an ageing crisis has emerged, with an exponentially increasing burden on the pension systems and budgets of the countries of the European Union.

All these phenomena lead employers to create so-called social enterprises, which require the employee to have a clear definition of the civil position 'friend or foe' both in relation to the employer's policy and in relation to the citizenship and norms of the country of residence, the level of social tolerance, etc. It is obvious that the processes of professional adaptation for migrants and foreign workers are much more complicated. It is obvious that for migrants and foreign workers the processes of professional adaptation are much more complicated. This is a new factor that increases unemployment among intolerant workers.

The general social consequences of unemployment for most euro area countries are increased social tensions and stratification of society, a decline in labour activity due to a lack of motivation to work, and the emigration of skilled workers to more economically developed countries.

The delayed economic consequences of unemployment in European countries have also been predicted: a reduction in tax revenues, a decline in GDP, a fall in citizens' living standards, loss of skills among the long-term unemployed, reluctance to undertake training and retraining.

Unemployment undoubtedly has a positive impact on the labour market: it contributes to the creation of a labour reserve for structural restructuring of the labour market and to increased competition between workers. However, the negative consequences of unemployment far outweigh the positive ones and pose a threat to the country's national security and economic development.

4. Global reasons for changes in the structure of unemployment in Russia

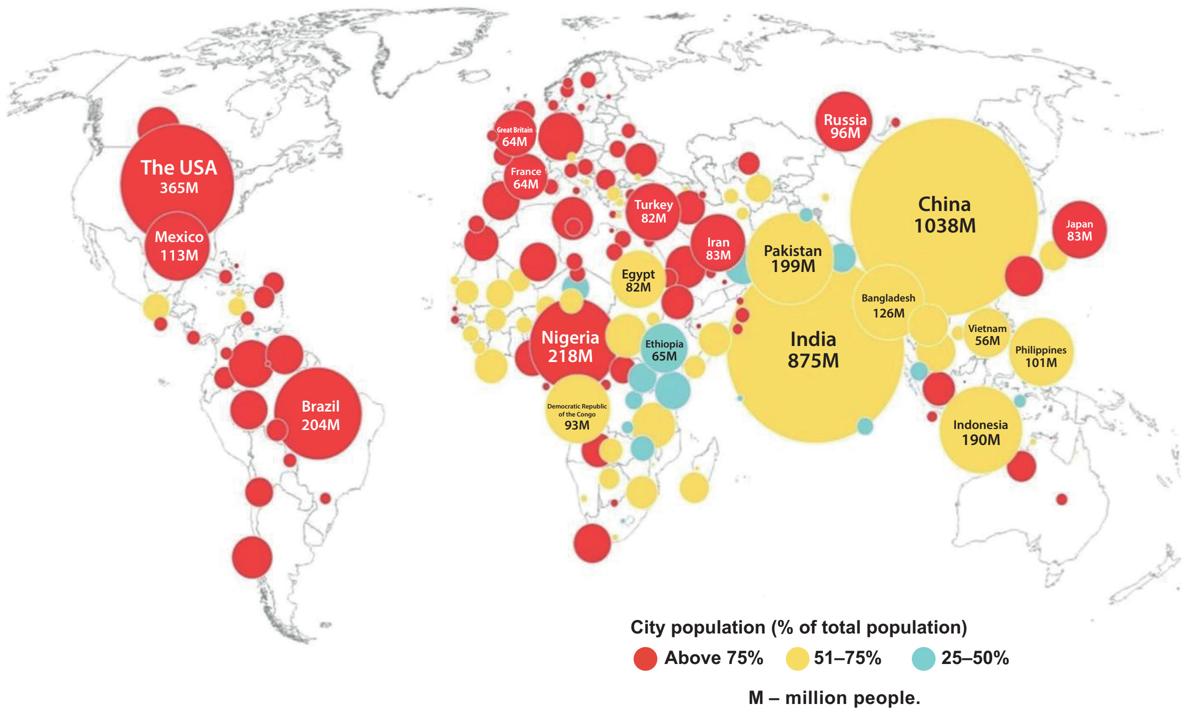
The transformation of the economy inevitably raises concerns about employment and the state of the labour market. The situation on the labour market in the Russian Federation varies by region. The preconditions for unemployment in Russia differ significantly from those in Western countries. The Russian scientist R.I. Kapelyushnikov proposed a model for the labour market, which highlights the interdependence of negative economic shocks not only with an increase in unemployment, but also with a reduction in working hours and a decrease in labour prices [Kapelyushnikov, 2023]. In recent decades, Russian enterprises have found a way to avoid mass layoffs by reducing labour time and pay. In developed countries, it is not possible to optimise the number of employees during a crisis.

Unemployment in Russia is a significant threat to both the state and public well-being. It leads to increased tension in the labour market and the development of forced part-time and informal employment, as well as illegal labour migration. These consequences have a negative impact on the economy and society as a whole.

In Russia, there is a significant issue with the decreasing share of wages in GDP and the resulting impoverishment of the population. This trend has been observed since 2016

[19] https://countrymeters.info/ru/Germany#population_2022.
[20] https://countrymeters.info/ru/Italy#population_2022.

Fig. 9. Population forecast and urban population share, 2050



Note. The figure highlights countries and regions where the urban population will exceed 100,000 by 2050. The size of the circles is proportional to the share of urban population.
Source: UNICEF – An urban world. https://www.unicef.org/sowc2012/urbanmap.

and is also present in some developed countries. To combat the effects of inflation, wages are gradually increasing in accordance with Art. 134, 421 of the Labor Code of the Russian Federation[21]. However, Russians are aware that an increase in wages often leads to a corresponding rise in prices, which can sometimes outpace the wage increase. Informal employment is also a significant issue in Russia, where work is not formalised by an employment contract, resulting in no payment of taxes or social contributions, and no accumulation of work experience.

In order to stabilise and regulate the relationship between income and prices, Russia needs to implement structural reforms to increase GDP per capita by 1.5 times[22]. Low wages lead to unemployment when workers spend long periods looking for a suitable job with a decent salary, and at the same time increase social tensions in society.

The analysis of the consequences of unemployment, taking into account the peculiarities of the development of the Russian labour market, is projected to 2050, when the global trends associated with the consequences of the demographic transition and the increase in healthy life expectancy in the leading countries, the acceleration of urbanisation processes and the move towards a smart city model, and the growth of international migration will become apparent. This will be accompanied by global trends related to the consequences of the demographic transition and the increase in healthy life expectancy in leading countries, the growth of urbanisation processes and the move towards a smart city model, the increase in international migration as well as social inequality and the emergence of new social classes, changes in public and individual values and lifestyles, the spread of social innovation and the digitalisation of society, and the transformation of the education system.

The growth of the world's population and the increase in the proportion of people living in cities, which is currently characteristic of the world as a whole, will lead to an overburdening of the environment and urban infrastructure, which can be alleviated by the introduction of smart technologies in cities (Fig. 9). In turn, the abundance of labour in megacities will create new forms of competition and unemployment.

The 21st century will see an increase in life expectancy and a decline in fertility rates, leading to an ageing world population that will reach 9.7 billion by 2050.[23] The world's population is growing, ageing and moving to cities - a trend that also characterises the Russian Federation with its vast territory.

Threats to Russia are determined by the projected decline in the country's working age population, migration from Asian countries, the increase in infectious diseases

[21] Labour Code of the Russian Federation dated 30 December 2001 No. 197-FZ (as amended on 16 December 2019). https://www.consultant.ru/document/cons_doc_LAW_34683/.
[22] How to achieve accelerated economic growth in Russia. https://finance.rambler.ru/economics/39399457/?utm_content=finance_media&utm_medium=read_more&utm_source=copylinkhttps://biznes-kanal.ru/idei-biznesa/nizkie-zarplaty-v-rossii-pochemu.html.
[23] UN: Rising life expectancy and falling birth rates are leading to an ageing global population. https://news.un.org/ru/story/2019/06/1357551.

(coronavirus, HIV, tuberculosis, AIDS, etc.) and the increase in crime in society.

Factors hampering socio-economic development include unequal access of regions and social groups to advanced technologies, including high-tech medical care, and low levels of citizen participation in lifelong learning.

Other ways for Russia to overcome the unemployment crisis include: realising the reserves of inclusive development by involving the elderly population and people with disabilities in labour activity; increasing the accessibility and quality of medical services for all population groups; developing remote regions through the digitalisation of the economy and education; improving migration policy in the direction of balancing the number and socio-cultural integration of migrant workers.

Conclusion

Theoretical approaches and the experience of effective public administration can develop principles for reducing unemployment. The diversity of unemployment makes this task extremely difficult. Since there is no single way to combat unemployment, each country has to combine various methods to solve this problem, especially in modern realities.

The economic consequences of unemployment, in particular the failure to reach the potential level of GDP, entail the problem of maintaining and strengthening national security at an appropriate level. The issue of employment regulation consists of measures to maintain the relationship between the demand for and supply of labour: a reasonable relationship should satisfy the economy's need for skilled labour and should not lead to an unreasonable increase in wages and a sharp decline in employment. Accordingly, employment regulation policies should aim at maintaining the natural level of unemployment.

To summarise the above, we can list a number of universal measures designed to strengthen the national and economic security of countries:

- creating favourable conditions for the development of small and medium-sized enterprises, thereby increasing the number of jobs and the number of self-employed;
- a tough fight against corruption at all levels and exemplary punishment of corrupt officials;
- investment in the uniform development of the country's regions (this measure is particularly relevant for countries with a large territory, such as Russia);
- government funding for continuing education and retraining programmes;
- rational and controlled labour migration;
- favourable foreign policy environment: the activities of foreign industrial companies, the presence of the defence industry and the absence of sanctions;
- identifying and tackling hidden unemployment, where employers do not dismiss workers but regularly underpay them and cut back on benefits;
- a sufficient level of unemployment benefit to meet basic human needs (in some EU countries, such as Germany and Switzerland, unemployment benefit[24] allows people to live safely on the edge of the lower classes, and for migrants this is simply a welcome gift. In Russia, you can barely survive on the maximum monthly unemployment benefit[25] for just two weeks);
- programmes to control the duration of unemployment (not limited to the end of the benefit period), after which the unemployed person has to take any job, even if it is not suitable for him/her in terms of his/her level of education, desired level of remuneration and existing skills.

The regulatory function of the state is to maximise the balance between the demand for hired labour (by employers) and the supply of the labour force at both micro and macro levels. The key point of the government's employment strategy should be the principle of preventing unemployment rather than fighting it.

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Development of risk assessment methods in the implementation of exploration projects

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Abstract

The peculiarity of oil and gas projects is their long implementation period, during which they are subject to the influence of a large number of different risk factors that complicate project implementation and result in failure to achieve the planned economic indicators set by investors. The effective operation of companies therefore depends on how reliably investors can predict the prospects for project development. The success of the subsequent functioning of the investment project depends to a large extent on the reliability of the assessment of the effectiveness of the investment project, based on the optimally chosen strategy of its development, and, above all, on the anticipation of possible risk factors and tools for their prevention. Therefore, at present, the competitive struggle in the oil and gas production industry is currently shifting to the area of pre-project preparation of investment projects and increasing the reliability (quality) of their economic efficiency assessment at the stage of making a decision to start their implementation.

Geological risks become important in the implementation of exploration projects, the first stage in the overall process of developing the Company's assets. It is necessary to find a balance between the cost of project implementation and the amount of accumulated hydrocarbons for the forecast period, which will ensure maximum profitability of the project. The challenge to optimize the financial outlay on the implementation of geological exploration works by focusing on the most promising and important projects for companies becomes relevant. In this regard, the article considers the methodological approaches proposed by the author to assess the risks of exploration with the aim of improving the efficiency of the planning process and reducing inefficient financial costs.

Keywords: risks, projects, financial efficiency, exploration works, dynamic risk assessment, statistical risk assessment, toolkit.

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实施地质勘探项目时评估风险的方法发展

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简介

石油天然气项目的一个显著特点是它们具有漫长的实施期，在此期间受到大量不同风险因素的影响，这些因素使项目实施变得复杂，并成为投资者未能达到其规划经济指标的原因。因此，企业的有效运作取决于投资者对项目发展前景的预见能力。基于选择的最佳发展策略以及尤为重要的是预见可能的风险因素和防范工具，对投资项目的效益进行可靠评估，在很大程度上决定了投资项目后续运作的成功。因此，当前石油天然气开采行业的竞争转移到了投资项目的前期准备和在投资决策阶段提高评估其经济效益可靠性（质量）的领域。

在地质勘探项目实施过程中，地质风险变得至关重要。需要在项目实施成本和预测期内累积的碳氢化合物数量之间寻求平衡，以确保项目的最大盈利能力。优化地质勘探工作的财务支出成为一项重要任务，通过将精力集中在对公司最具前景和重要的项目进行研究来实现。因此，本文讨论了评估地质勘探项目风险的方法论方法，以提高规划过程的效率并降低无效的财务支出。

关键词： 风险、项目、财务效益、地质勘探工作、动态风险评估、统计风险评估、工具。

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Introduction

A characteristic feature of oil and gas projects is the long implementation period, during which they are exposed to a large number of different risk factors: geological, production, financial and others, which complicate their implementation and cause the failure to achieve the planned economic indicators set by investors. Another important feature is that the volume of required investments is significant [Zubareva et al., 2005]. At the same time, the effective operation of companies depends not only on the size of the investment, but also on how reliable the investors themselves believe the project's development prospects to be. The success of the investment project's subsequent operation depends to a large extent on the reliability of the assessment of its effectiveness based on a correctly chosen strategy for its future development (planned volumes of hydrocarbon production, development technologies, etc.) and, above all, on the anticipation of possible negative (risk) factors and tools for their prevention. Therefore, competition in the oil industry is moving into the area of pre-project preparation of investment projects and increasing the reliability (quality) of assessing their economic efficiency at the stage of making a decision to start implementation.

When implementing geological exploration projects - at the initial stage of the overall process of developing the company's assets - geological risks become important [Imamov, 2014a]. Also at this stage it is necessary to find a balance (optimal strategy) between the costs of project implementation and the amount of accumulated hydrocarbons over the forecast period (planning horizon), which will ensure the maximum value of the financial indicator NPV (Net Present Value, net discounted flow). The task of optimising the financial costs of carrying out geological exploration works by concentrating efforts on studying the most promising and important projects for the companies becomes important.

There is no generally accepted methodology for the assessment and consideration of risk factors during the implementation of geological exploration projects that is accepted and shared by the majority of participants in the process (market) [Imamov, Yolokhova, 2015]. Oil and gas companies use their own corporate approaches and tools in their activities[1]. In this regard, the article discusses the proposed methodological approaches to quantitative risk assessment of geological exploration projects in order to improve the efficiency of the planning process and reduce ineffective financial costs.

1. Research methodology

Currently, oil and gas producing companies are paying increasing attention to assessing the economic risks associated with geological, technological and other uncertainties that may limit project realisation when making investment decisions in geological exploration (hereafter referred to as GE). At the same time, geological risks (hereinafter referred to as GR) play an important role in this process, as most exploration projects are implemented in an environment of geological uncertainty [Imamov, 2014a; 2014b].

Geological uncertainty affects the volumes of cumulative hydrocarbon production and therefore the value of the discounted net present value flow. Therefore, the expected monetary value (EMV) indicator is used to account for geological risks in investment planning [Bush, Johnston, 2003]. The expected monetary value of the project is calculated using the following formula:

$$EMV = NPV \times Rusp - Zrisk \times (1 - Rusp),$$

where EMV is the expected monetary value of the project (roubles), NPV is the net present value flow (roubles), $Rusp$ is the probability of geological success of the exploration (units), $Zrisk$ is the risky capital cost of the project (roubles).

The key indicator in the calculation of the EMV indicator, as follows from the formula, is the probability or chance of geological success. In international practice, the term ‘chance of geological success’ - gCoS (Geological Chance of Success). has become widely used. This indicator reflects the probability that the predicted reservoir or deposit will be discovered [Rose, 2001; Zagranovskaya, 2023].

Geological success is the main prerequisite for the financial success of geological exploration, and the success of the entire project ultimately depends on how accurately it is calculated. In this respect, methods for calculating the probability of geological success are becoming increasingly important in modern conditions. One of the ways to improve the accuracy of the calculation can be to use the results of conceptual geological modelling carried out in the region (district) of interest to the companies. The proposed methodological approach is described below.

In the practice of risk analysis of geological exploration (geological risk analysis), two approaches to the interpretation of geological data on an object (asset) have been formed - static and dynamic. In the first case, the information is analysed at a certain point in time (i.e. modern data). In this case, certain assumptions are taken into account to assess the sequence of geological processes over time. However, the static approach will not be able to take into account, in the formation and development of an oil and gas basin (its part), changes in various geological processes and parameters during its history from the perspective of a single hydrocarbon system. The use of a dynamic approach based on basin modelling tools provides a more reliable assessment of the geological risks associated with the implementation of exploration projects. In this case, a reconstruction of the geological history of the basin (its part) is carried out - from the moment of formation of the crystalline basement to the present stage - with modelling of all geological processes influencing the formation of its oil and gas potential [Tissot, Welte, 1981; Vassoevich, 1986].

Obviously, the dynamic approach is more accurate for assessing GR. However, the static approach also has a place: after all, when companies enter new areas, initial geological and geophysical information is not always available in sufficient quantity and quality to fully apply basin modelling technologies.

[1] See, for example: Methodology for evaluating new hydrocarbon exploration and production assets. St. Petersburg, Gazpromneft STC LLC, 2015.

2. Results from the analysis of evaluation methods

Static geological risk assessment. When conducting a static assessment of geological prospects, it is suggested that a risk matrix be constructed to calculate the ultimate probability of success of geological exploration. This is a quadratic diagram with the risk of the hydrocarbon system on the horizontal axis (from left to right, from larger to smaller) and the risk of finding oil and gas on the vertical axis (from bottom to top, from larger to smaller).

Hydrocarbon system risk assesses the likelihood that the processes necessary to form hydrocarbon reservoirs have occurred in the geological history of the region (basin or part of it) being assessed. The higher the hydrocarbon system risk, the lower the probability of deposit formation.

The risk of finding hydrocarbons in a prospective area evaluates the quality of predicting the results of the analysis of geological processes of formation of hydrocarbon deposits. The higher the risk, the lower the probability of finding a deposit (Fig. 1).

If all the points (system parameters) that characterise the main geological parameters are grouped in a triangular sector above the diagonal joining the upper left and lower right corners, the risk can be considered acceptable and the values along the axes allow the geologist to quantify the probability of a positive outcome for each system parameter. If at least one point is outside this zone, the risk is considered unacceptable.

The results of a risk assessment are highly dependent on the quality of the input data used in the analysis and the quality of the description and prediction of geological processes. At the same time, predicting the combination of various elements (parameters) of hydrocarbon systems and the geological processes that influence them is a very important step in improving the quality of the gCoS prediction.

It should be noted that the static method of assessing geological risks using a matrix is limited in situations where a number of important factors related to the history of the oil and gas formation need to be taken into account for the GCoS analysis. In this respect, it is advisable to apply this approach to new (to the company) exploration prospects (exploration assets) where there is insufficient geological and geophysical data to allow the application of dynamic analysis of hydrocarbon systems. As geological exploration is carried out and geological, geophysical, geochemical and other data are accumulated, companies have the opportunity to assess the geological risks of exploration in the analysed region (area) on the basis of a dynamic approach, if the spatiotemporal processes of hydrocarbon generation and formation of their accumulations are predicted.

Dynamic geological risk assessment. A dynamic approach to assessing the chances of geological success, as already mentioned, consists in the spatio-temporal modelling of the processes of changes in the main parameters of the hydrocarbon system. The system model is a dynamic model that allows us to reconstruct the processes of formation, migration, accumulation and loss of oil and gas in the hydrocarbon system during the geological history of the development of the sedimentary basin. During the modelling process, geological indicators can be presented in one-, two- or three-dimensional form for the studied zone (area). In addition, they can represent a model of both a single reservoir and an entire oil and gas basin (hereafter referred to as OGB).

The gCoS assessment process breaks down geological success as a complex concept into its component factors (dynamics), the implementation of which leads to the formation of hydrocarbon reservoirs. At the same time, the following key factors necessary for the formation of their deposits are examined (Fig. 2):

- the presence in the section of the sedimentary cover of the areas (zones) under consideration of oil and gas source strata (hereinafter referred to as OGSS), which,

Fig. 1. Geologic risk matrix

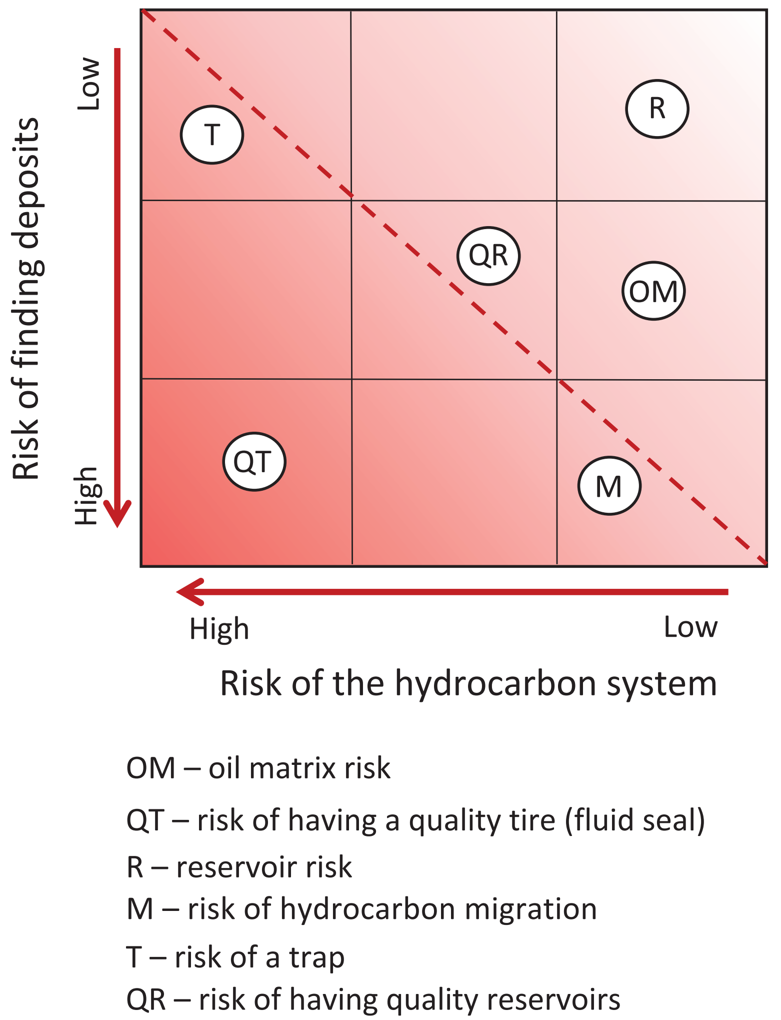
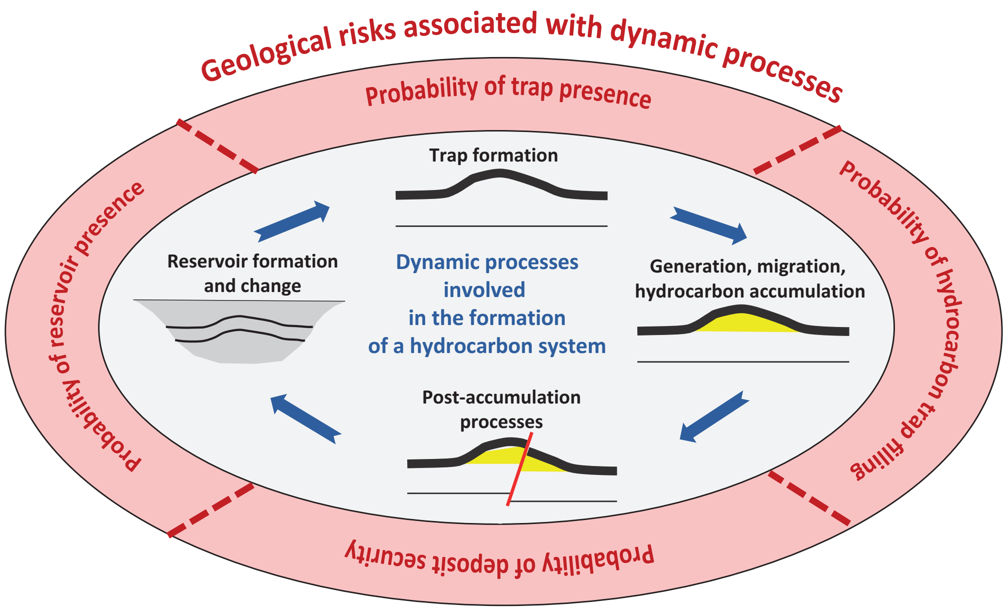


Fig. 2. Geological risks associated with the formation and maintenance of hydrocarbon reservoirs



depending on their composition and conditions of occurrence, may produce hydrocarbons;

- favourable migration-accumulation processes from the OGSS development zone (generation centre) to reservoir layers (reservoirs) in hydrocarbon accumulation zones;
- preservation of hydrocarbon reservoirs (deposits) formed during geological history.

In the process of analysing the dynamic factors obtained by modelling the hydrocarbon system, the probability of the existence of a reservoir, the existence of a hydrocarbon trap, the filling of the trap with hydrocarbons and the safety of the deposit after its formation are assessed. The final overall indicator of the predicted reservoir is calculated by multiplying the independent geological factors (Table 1). In addition, some factors have their own independent sub-factors, which are also multiplied to obtain a common value characterising the main factor. The proposed formula for calculating the final indicator is shown in the table.

Some of the dynamic success factors describe features that are characteristic of the entire oil and gas reservoir under consideration, while others may only characterise a local geological object within its boundaries. For example, the factor of the presence of oil and gas source strata is a regional feature, and the factor of the presence of a trap is a predominantly local feature. It should be noted that in recent years (for objective historical reasons) increasingly complex geological systems have been studied, which cannot always be integrated into simplified models. Almost all geological risk (success) factors, with the exception of OGSS, can be both regional and local. For example, when assessing the likelihood of the existence of hydrocarbon migration pathways, it is often necessary to consider not only regional conditions (the presence of persistent reservoir strata, tectonic faults, the distance from the source of hydrocarbon generation to the accumulation zone), but also the possibility of the existence of local barriers to a particular trap in its immediate vicinity.

The proposed dynamic risk assessment tools largely cover the process of formation of a hydrocarbon resrvoir (field). However, it does not include some external conditions and risks of a larger order that can affect the effectiveness of the implementation of an exploration asset (geological object/objects), for example, the likelihood of the implementation of the geological concept proposed by experts for the assessment of a poorly explored territory (zone, area, etc.). Often, without the necessary factual geological and geophysical information, geologists evaluate prospect areas on the basis of hypotheses about the structure of the area under consideration, the sedimentation conditions, the time of formation and migration of hydrocarbons, and so on. However, if the assumed hypothesis turns out to be incorrect, the geological risks may be significantly higher. This effect can be reduced by having companies' strategic exploration assets studied by separate expert groups and by organising their consideration by related specialist departments within companies.

Conclusion

Thus, as shown above, in the implementation of geological exploration projects, geological success is one of the main conditions for financial success, and the success of the whole project ultimately depends on how accurately it is calculated. In the practice of risk analysis in geological exploration, two approaches to the interpretation of geological data can be distinguished - static and dynamic. At the same time, the use of a dynamic approach based on catchment modelling tools allows for a more reliable assessment of the gCoS indicator.

Based on the results of consideration of the above-mentioned methodology for assessing risks during the

Table
Dynamic factors and conditions for geological exploration success

Dynamic success factor in geological exploration	Environment	Probability indicator	Calculation of the final indicator
Security of the deposit after its formation	Absence of deposit destruction processes caused by mechanical, physical, chemical or biochemical influences on the formed resrvoir (field)	*Рс*	
Existence of reservoir	Presence of reservoir strata in the section. Favourable areal distribution, effective thickness, filtration and capacity properties, facies variability, diagenetic processes	*Рпр*	*Рпр = Рф × Ри*
	Presence of facies with favourable reservoir characteristics	*Рф*	
	Favourable post-depositional changes in reservoir rocks	*Ри*	
Presence of a hydrocarbon trap	The presence of a geological body capable of trapping hydrocarbons. Reliable mapping of the trap based on actual data, accuracy of depth and area constructions, tightness and integrity of the seal and screens (tectonic, lithological) at the time of initial saturation and thereafter	*Рл*	*Рл = Рк × Рп*
	Presence of a closed circuit	*Рк*	
	Presence of fluid seal (tyre)	*Рп*	
Filling the trap with hydrocarbons	The existence of a source that ensures the supply of a promising area of hydrocarbons, depending on: the strength and areal distribution of the source rock; the content, type of organic matter and the degree of its catagenetic transformation. Filling of the hydrocarbon trap, taking into account its location in relation to the migration paths, the time of trap formation and migration time, the possibility of undersaturation (incomplete filling).	*Рз*	*Рз = РТ × Рм*
	Existence of oil and gas resources (sequences)	*РТ*	
	Time to realise oil and gas potential and hydrocarbon migration	*Рм*	
gCoS *= Рс × Рпр (Рф × Ри) × Рл (Рк × Рп) × Рз (РТ × Рм)*			

implementation of exploration projects, it can be argued that it is a serious tool for calculating the success rate of work. Confidence in this is based on the ability to reconstruct the main geological processes that determine the presence of hydrocarbon deposits within the area of the project being evaluated. The resulting gCoS indicator can have a significant impact on the financial efficiency of developing an exploration asset.

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Mapping the links between resource efficiency and the innovative capacity of national economies

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Abstract

The article examines studying the relationship between the level of innovation in different countries and the efficiency of their resource use, in order to better understand the potential impact of increased adoption of new technologies on the responsible use of resources in the future. Two country's samples were created for the study: the first includes 36 world economies, with calculations of energy and labour resource use efficiency, taking into account the size of the economy and the level of innovation achieved; the second sample includes data on the material footprint of 121 countries, along with levels of innovation and economic development. The empirical confirmation of the hypothesis that there is a relationship between the level of economic innovation achieved and the efficiency of resource use is a key finding. Furthermore, the results of the correlation analysis indicate a direct and close relationship between a country's economic innovativeness and its consumption volume of natural resources. This relationship can be described by a linear function. The analysis also confirms that as the population's welfare and economic innovativeness grow, the state's material footprint increases. The study is of theoretical and practical importance, encouraging the improvement of tools to ensure innovative development based on responsible production and consumption of resources. This approach aims to achieve better results at the same cost. Identifying the necessary factors related to innovative activity and efficient resource use by enterprises, as well as establishing functional dependencies between these variables, represent prospective areas for further research. In addition, a detailed examination of the experiences of Russian companies and their implications regional differentiation in terms of innovation and resource efficiency is a logical next step.

Keywords: resource efficiency, innovation, energy efficiency, labor productivity, material footprint, country, level of development, economy.

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绘制资源效率与国民经济创新之间的关系图

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简介
这篇文章研究了不同国家的创新发展水平与个人资源使用效率之间的关系，以进一步确定未来更多地引进新技术对负责任地处理资源的情况可能产生的影响。为了进行研究，我们形成了两个国家样本：第一个包括36个世界经济体，计算了它们利用能源和劳动力资源的效率指标，并考虑了经济规模和达到的创新水平；第二个样本包含121个国家的物质足迹数据，以及它们的创新和经济发展水平。 经验证实了一个假设，即国家经济的创新水平与资源利用效率之间存在关联。而且，相关分析的结果表明，国家经济的创新水平与自然资源消耗量之间存在着直接密切的关系，可以用线性函数描述，并且证实了随着人民福祉和经济创新水平的增长，政府留下的物质足迹也在增加。 研究的理论和实践意义在于促进基于负责任生产和消费原则的工具提供的创新发展程度的合理性，从而在相同成本下实现更好的结果。未来研究的潜在方向可能包括确定与企业创新活动和资源利用效率相关的必要和充分因素，以及建立所选变量之间的功能关系。对俄罗斯企业经验的详细研究及其对区域创新性和资源利用效率指标的差异化影响也是合乎逻辑的。
关键词： 资源效率、创新能力、能源效率、劳动生产率、物质足迹、国家、发展水平、经济。

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Introduction

The ever-increasing needs of humanity and the desire to improve the well-being of the economy in every way possible are leading to the rapid depletion of limited resources and their scarcity. This leads, on the one hand, to fierce competition and higher prices for resources and, on the other, to the problem of resource conservation, i.e. more rational consumption. The problem is further complicated by the fact that intensive production and consumption (sometimes driven by rapid technological development) not only drive the economy, but also have a destructive impact on the environment. In this context, the Sustainable Development Goals (SDGs) adopted by the UN General Assembly[1], call for countries to move towards rational consumption and production models (Goal 12) in order to ensure greater efficiency in the use of resources. The implementation of this goal is primarily aimed at breaking the link between economic growth and environmental degradation.

It should be noted that increasing the efficiency of resource use covers a wide range of interrelated aspects and is a boundless field of scientific research for many scientists (e.g. [Barrett, Scott, 2012; Bach et al., 2016; Hatfield-Dodds et al., 2017; Trofimova, 2022; Salmanov, 2023]). For example, [Barrett, Scott, 2012] examines the relationship between climate change mitigation and resource efficiency in the UK. The publication [Singh et al., 2024] examines the relationship between economic development and mineral rents in the BRICS countries. The models constructed in this paper, based on empirical data, confirm the existence of a relationship between the level of trade turnover, the volume of GDP, as well as foreign direct investment on the amount of mineral rent. Based on this, the authors recommend that when planning policies and measures aimed at ensuring inclusive and sustainable development, increasing GDP, facilitating trade and increasing GDP in the BRICS countries, issues of mining rent (including taxation of mineral rent, royalties on mining, conflicts between mining companies, etc.) should be taken into account.

Another equally important area of scientific research is the issue of ensuring the innovative character of the development of the economy, its industries and enterprises (for example, [Kravchenko, 2021; Trachuk, Linder, 2021; Kosolapova et al., 2023]). Thus, in the work of [Trachuk, Linder, 2021], based on the analysis of the activities of

[1] Transforming our world: The 2030 agenda for sustainable development (2015). United Nations. https://www.un.org/sustainabledevelopment/ru/sustainable-development-goals/.

more than a hundred manufacturing enterprises, the authors identify key indicators of the effectiveness of innovation activity depending on the innovation regime to which the enterprise belongs. The team of authors in [Kosolapova et al., 2023] makes an attempt to identify the drivers of the formation of a circular economy, among which scientists highlight the innovative activity of organisations, the digital technologies used, as well as the volume of investments in fixed capital.

In recent years, research on specific aspects of a combined topic - active implementation of innovations and efficient use of resources - has become increasingly popular (e.g. [Diaz Lopez et al., 2019; Sun et al., 2023; Tang et al., 2023; Fan, Wang , 2024; Rahmani et al., 2024]). For example, the work [Rahmani et al., 2024] examines the impact of digital innovations on increasing the efficiency of resource use and sustainable development in the metallurgical industry. The results showed that the ability to absorb technological innovations and the existing digital capabilities of the company have a positive and significant impact on the company's intentions to carry out digital transformations in the metallurgical sector. In addition, the authors propose a set of measures aimed at improving the state policy regulating the introduction of digital innovations in the activities of small and medium-sized enterprises in the metallurgical industry.

The publication [Tang et al., 2023] focuses on the importance of studying the impact of green innovations and resource use efficiency to achieve zero carbon emission targets. The authors conclude on the important role of the Green Economy Innovation Index and show that even a small increase of 1% results in a measurable increase of about 0.25-0.39% in the Net Zero Emissions Index, highlighting its significant environmental impact. The author concludes that the adoption of green innovations and technologies is crucial to move developed economies towards sustainable development.

However, despite significant scientific and practical developments in the field of increasing the efficiency of resource use and ensuring innovative development of the economy, the complexity and versatility of these problems determine their constant relevance. At the same time, one of the most promising areas of scientific research is the study of the links between the efficiency of resource use and the level of innovative development of the world's economies. In this context, it is proposed to empirically test the hypothesis that the most developed innovative economies are associated with the highest consumption of natural resources and a negative impact on the environment, using quantitative methods of data analysis.

The purpose of the work is to analyse the relationship between the level of innovative development achieved by different countries and the efficiency of their use of individual resources, in order to determine the consequences that the increased introduction of new technologies may have on the situation of responsible management of resources in the future.

1. Methodology and data

This was achieved in two stages: (1) analysis of the resource efficiency of the economies of different countries around the world, taking into account their size and level of innovation; (2) study of the relationship between a country's material footprint, determined by the ratio of global resource production to domestic final demand, and its level of innovation and economic development.

To carry out the first stage - comparing the resource efficiency of the economies of different countries - indicators such as gross value added, labour productivity and energy output of GDP were selected. In addition, the level of innovativeness of countries' economies (according to the Global Innovation Index 2023, GII-2023) was analysed as a factor associated with the extent of use of different types of innovation, including resource saving.

The indicators selected reflect the size or scale of the economy (gross value added in current US dollars) and the efficiency of the use of energy and labour resources. The energy efficiency of the economy was assessed by the ratio of GDP produced at purchasing power parity to the level of expenditure on energy resources. Although this indicator has certain shortcomings (such as the inability to take into account climatic, infrastructural, territorial and other characteristics), it is currently relatively universal and provides a means of comparing the energy efficiency of different economies.

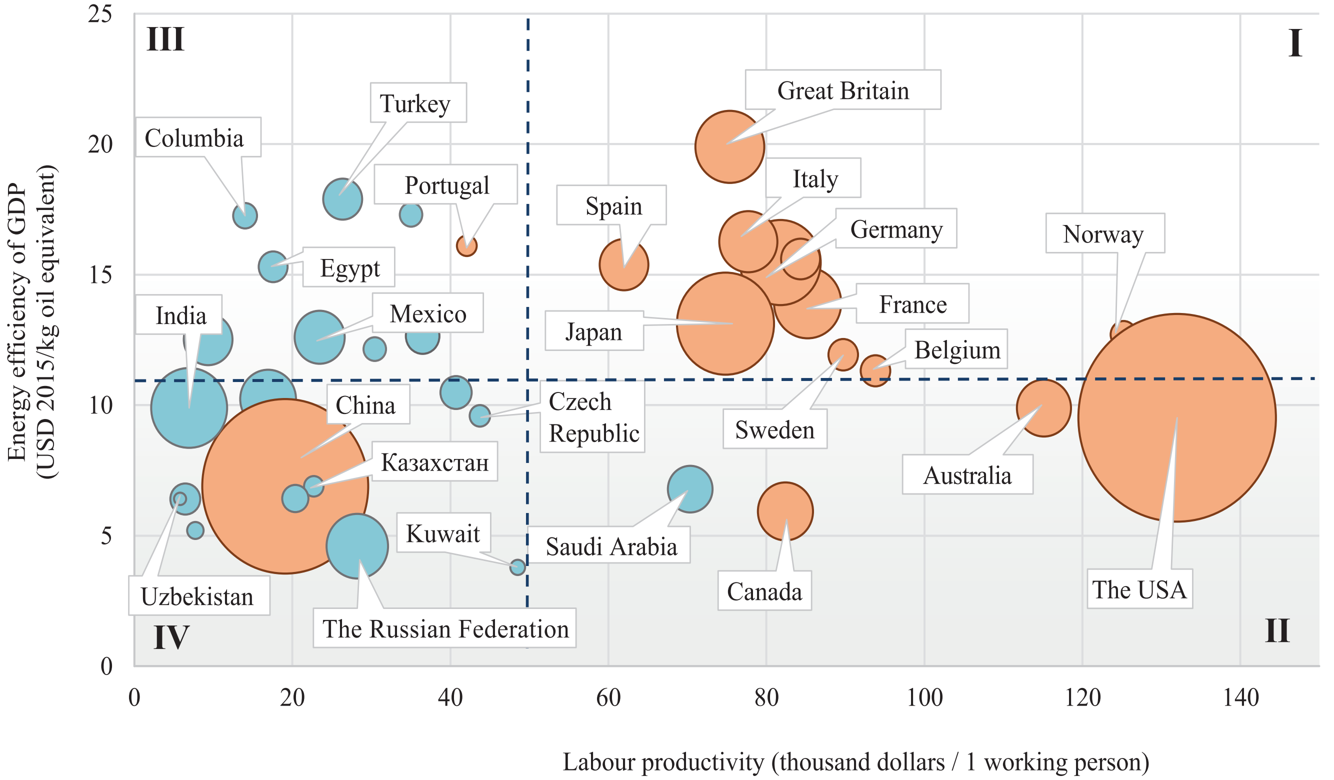
The efficiency of the use of labour resources is calculated using the labour productivity indicator as the ratio of GVA to the number of persons in employment (persons in employment include all persons of working age who, for a short period of time, were in one of the following categories: employees or self-employed).

These indicators have been calculated for 36 countries in the world, located on different continents, with different levels of development and resource endowment, and a matrix of the distribution of world economies by resource efficiency has been constructed. The limited size of the sample of countries is largely due to the availability of publicly available statistical information on the efficiency of energy resource use (namely the data published in the annual report of the Enerdata organisation[2]).

In the second stage, when studying the relationship between the material footprint of a state and its level of innovation as well as economic development, 121 countries were selected. For each country three indicators were collected from open sources of statistical information (including two quantitative ones: the rating score in points according to GII-2023, the value of the material footprint per capita - and one qualitative one: the distribution of countries' economies into groups according to their income level, proposed by the World Bank [Hamadeh et al., 2023]). Based on the quantitative data generated, the strength and direction of the correlation relationship was assessed by determining the linear Pearson correlation coefficient (r_{xy}):

[2] Global energy statistical yearbook (2023). Enerdata. https://yearbook.enerdata.net/total-energy/world-energy-intensity-gdp-data.html.

Fig. 1. Matrix of the distribution of world's economies by labour and energy efficiency



Note. The diameter of the bubbles characterises the value of GVA at basic prices; countries in the top 30 of the GII-2023 ranking are marked in lighter colours.
Source: Calculated and compiled by the author from data provided: Gross value added at basic prices (current US $). https://data.worldbank.org/indicator/NY.GDP.FCST.CD; Global energy statistical yearbook. https://yearbook.enerdata.net/total-energy/world-energy-intensity-gdp-data.html; Employment statistics. https://ilostat.ilo.org/topics/employment; [Dutta et al., 2023].

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \overline{x}) \times (y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2 \times \sum_{i=1}^{n}(y_i - \overline{y})^2}}, \quad (1)$$

where n – the number of observations, x_i, y_i – observation data, $\overline{x}$, $\overline{y}$ – Mean values of variables x and y.

The Pearson correlation coefficient varies from -1 to +1, with a value of -1 indicating a complete (functional) linear feedback, a value of +1 indicating a complete (functional) linear direct relationship, and a value of 0 indicating the absence of a linear correlation (but not necessarily a relationship).

The significance of the correlation coefficient for the relationship found was tested using Student's t-test where the null hypothesis is that the correlation coefficient is zero. To test the null hypothesis, the calculated value of the t-statistic (t_{calc}) is compared with the tabulated (critical) value (t_{table}) at a given significance level (α) and number of degrees of freedom. The calculated value of the Student's t-test is given by the formula

$$t_{calc} = \frac{r_{xy}}{\sqrt{1 - r_{xy}^2}}\sqrt{n-2}. \quad (2)$$

The null hypothesis is rejected if the calculated value, taken modulo, exceeds the critical value, and the probability of error is less than $\alpha \times 100\%$.

2. Research findings

The calculated characteristics of the efficiency of the use of labour and energy resources, as well as the resulting volume of GVA and the achieved level of innovativeness of the economies of the countries selected for further analysis are presented in Table.

The diagnosis of the sample of countries analysed in terms of the indicators of efficiency in the use of resources, which characterise the ability to achieve maximum results with minimum effort, made it possible to divide the economies into four groups (Fig. 1).

The visual distribution of countries between the sectors of the matrix (Fig. 1) shows that the developed European countries (Belgium, United Kingdom, Germany, Spain, Italy, the Netherlands, Norway, France, Sweden) and Japan have become representatives of the first quadrant. These economies are characterised by high labour productivity and high energy efficiency. All countries have relatively large volumes of gross value added (the maximum

Table
Resource efficiency and innovation characteristics of the world's economies in 2022–2023

Item number	Country	Labor productivity, (thousand dollars/ person)	Energy efficiency of GDP (2015 dollars/ kg oil equivalent)	Gross value added (billion $)	Rating according to GII-2023
1	Australia	115.12	9.89	1566.1	24
2	Algeria	17.00	7.86	184.0	119
3	Argentina	40.71	10.49	524.4	73
4	Belgium	93.80	11.31	468.1	23
5	Brasil	16.95	10.23	1659.4	49
6	Great Britain	75.38	19.89	2526.6	4
7	Germany	81.76	15.46	3477.3	8
8	Egypt	17.57	15.30	453.3	86
9	India	6.94	9.89	3074.4	40
10	Indonesia	9.33	12.51	1261.3	61
11	Spain	61.98	15.38	1263.9	29
12	Italy	77.72	16.26	1795.3	26
13	Kazakhstan	22.71	6.89	203.7	81
14	Canada	82.41	5.93	1622.9	15
15	China	19.10	6.89	14722.8	12
16	Columbia	14.02	17.26	309.0	66
17	Kuwait	48.52	3.78	112.4	64
18	Mexico	23.47	12.60	1344.2	58
19	Nigeria	6.44	6.40	470.2	109
20	Netherlands	84.33	15.60	808.4	7
21	Norway	125.21	12.70	358.0	19
22	Poland	36.49	12.65	611.0	41
23	Portugal	42.08	16.10	206.6	30
24	The Russian Federation	28.22	4.59	2031.4	51
25	Romania	35.02	17.30	273.4	47
26	Saudi Arabia	70.36	6.78	1052.0	48
27	The USA	132.00	9.51	20893.8	3
28	Turkey	26.38	17.89	811.1	39
29	Uzbekistan	5.78	6.40	74.9	82
30	Ukraine	7.71	5.19	141.6	55
31	France	85.21	13.91	2414.8	11
32	Czech Republic	43.73	9.59	226.3	31
33	Chili	30.44	12.15	270.2	52
34	Sweden	89.72	11.93	471.6	2
35	Republic of South Africa	20.37	6.42	363.8	59
36	Japan	74.81	13.12	5029.8	13

Source: рассчитано и составлено автором по данным: Gross value added at basic prices (current US $). https://data.worldbank.org/indicator/NY.GDP.FCST.CD; Global energy statistical yearbook. https://yearbook.enerdata.net/total-energy/world-energy-intensity-gdp-data.html; Employment statistics. https://ilostat.ilo.org/topics/employment; [Dutta et al., 2023].

value belongs to Japan - $5029.8 billion, the minimum value belongs to Norway - $358 billion) and are highly innovative economies as they belong to the top 30 of the GII-2023 rating. In terms of labour productivity, Norway is the leader - one person employed in the country's economy creates GVA in the amount of $125.21 thousand; in terms of energy efficiency - Great Britain, whose energy consumption is only 0.05 kg of oil equivalent to create 1 dollar of GDP.

The second quadrant includes the economies of countries such as Australia, Canada, Saudi Arabia and the US. This group is characterised by above-average labour productivity (for the sample of countries studied) and below-average efficiency in the use of energy resources. Among countries of this type, the highest GVA value belongs to the United States (more than USD 20 trillion). The highest labour productivity in this group of countries is found in the United States, where one person employed in the economy generates a GVA of $132.0 thousand; the highest energy efficiency value is found in Australia, where 0.101 kg of oil is consumed to generate $1 GDP. eq. of energy resources. The countries in this sector are in the top 30 according to the GII-2023 rating (the exception is Saudi Arabia - 48th).

The third quadrant is represented by Chile, Egypt, Indonesia, Colombia, Mexico, Poland, Portugal, Romania, Turkey. Countries of this type are characterised by labour productivity below the average level for the sample of countries analysed and above-average efficiency in the use of energy resources. Among these countries, Mexico has the highest gross value added - $1344.2 billion; the lowest value of labour productivity is in Indonesia, where one worker employed in the economy generates $9.33 thousand of GVA. Turkey is characterised by a high level of efficiency in the use of energy resources, where 0.056 kg of oil is used to generate $1 GDP. eq. The countries in this cluster are ranked from 30th to 66th in the GII-2023 ranking (with the exception of Egypt, which is ranked 86th).

The fourth quadrant included Algeria, Argentina, Brazil, China, India, Kazakhstan, Kuwait, Nigeria, the Russian Federation, Uzbekistan, Ukraine, the Czech Republic and South Africa. Economies of this type are characterised by energy efficiency and labour productivity levels below the average of the sample. In terms of labour productivity, the worst value among the countries in this group is Uzbekistan, where one person employed generates USD 5.78 thousand of GVA. Among the countries in this group, the Chinese economy is characterised by the highest volume of GVA (around USD 15 trillion) and the highest level of innovation, ranking 12th in the GII-2023 ranking. Other countries are much less innovative and do not appear in the GII-2023 top 30.

Separately, it should be noted that some countries with a relatively high level of innovation (e.g. industrial giants such as China and the US) are leaders in terms of gross value added, but in terms of efficiency in the use of labour and energy resources they are in the catching-up groups (e.g. the level of energy resource use in the US is below the average for the sample of countries analysed). For China, both resource use efficiency indicators analysed are below average.

The distribution of countries according to the efficiency of the use of labour and energy resources (Fig. 1) shows that countries with a high level of innovation, which usually generate higher volumes of GVA, are characterised by higher values of resource efficiency indicators. Thus, the existence of a relationship between the level of innovative development achieved by the country and the efficiency of resource use has been empirically documented, which is undoubtedly logical. Obviously, new technologies make it possible, ceteris paribus, to use fewer resources to produce a similar amount of goods as with outdated technologies. What is of particular scientific and practical interest, however, is the impact that the widespread diffusion and implementation of innovations by developed and developing countries may have in the future on the situation with regard to the responsible use of resources.

The Intelligence Study also analysed the relationship between a country's Material Footprint (MF) and the innovativeness of its economy. The total Material Footprint is the sum of the Material Footprints of biomass, fossil fuels, metallic and non-metallic ores and is calculated as the resource equivalent of imports plus domestic production minus the resource equivalent of exports. In turn, the per capita MF describes the average material use for final demand [Giljum et al., 2015; Wiedmann et al., 2015; Matuštík, Kočí, 2021]. It should be noted that the material footprint is an indicator for the achievement of sustainable development goals, which include the desire to gradually increase the global efficiency of resource use in consumption and production systems and to ensure that economic growth is not accompanied by environmental degradation[3].

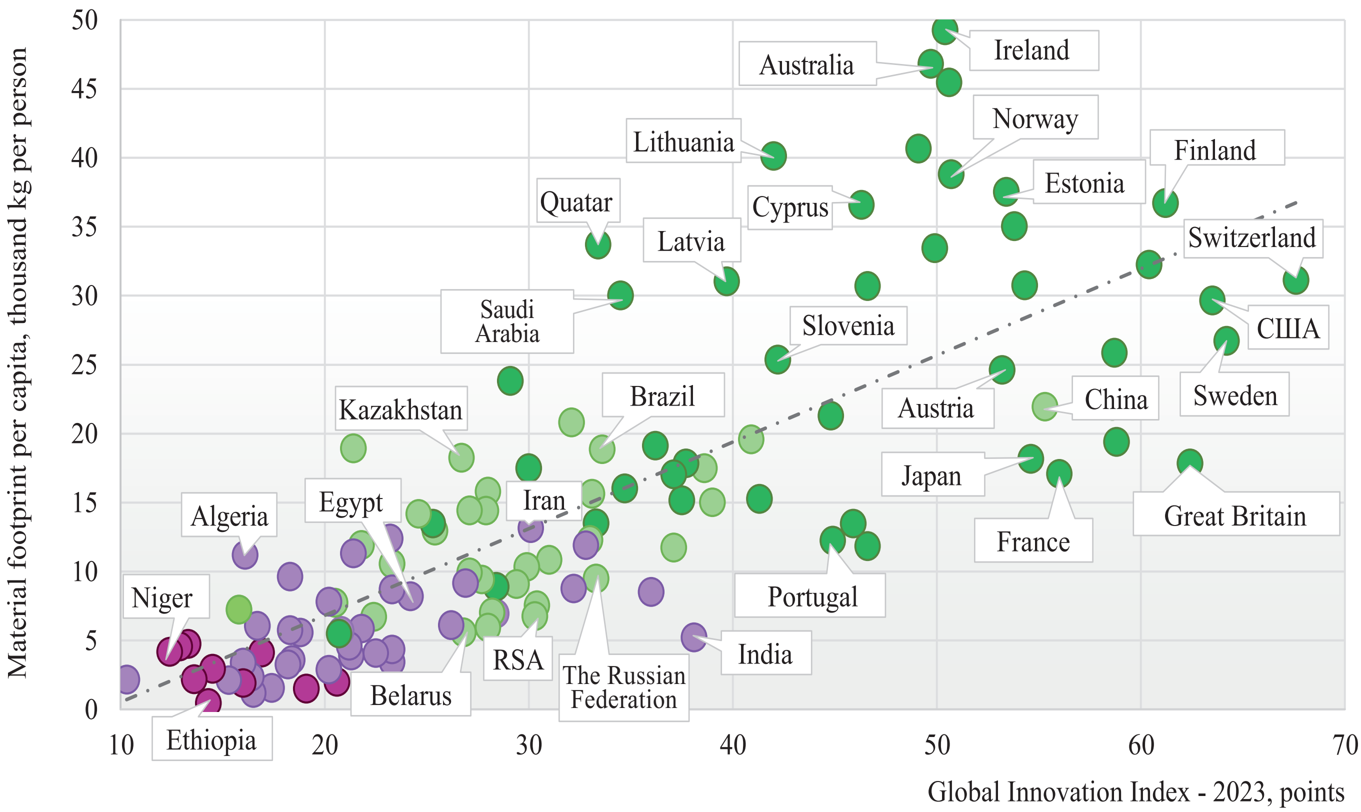
In order to establish the existence of a relationship between these indicators, a correlation matrix was provided covering 121 economies in the world (Fig. 2). The construction of this field has also taken into account the classification of economies into groups (according to income level) proposed by the World Bank, namely:

- high-income countries (GNI per capita greater than $13,845);
- upper middle-income countries (GNI per capita between $4,465 and $13,845);
- lower middle-income countries (GNI per capita between $1,136 and $4,465);
- low-income countries (GNI per capita less than $1,135).

Based on the visual analysis of the correlation field, it is possible to assume the existence of a relationship, its form and its closeness. Thus, according to Fig. 2, it can be argued that the relationship between the variables under

[3] Transforming our world… (2015). United Nations. https://www.un.org/sustainabledevelopment/ru/sustainable-development-goals/.

Fig. 2. Correlation field of the interdependence between the material footprint and the level of innovative development of the world's economies



Note. Dark green indicates high-income countries, light green indicates upper-middle-income countries, light purple indicates lower-middle-income countries and dark purple indicates low-income countries.
Source: constructed by the author from data: Material resources. Material footprint per capita. https://stats.oecd.org/Index.aspx?DataSetCode=MATERIAL_RESOURCES; [Dutta et al., 2023; Hamadeh et al., 2023].

study can be linear, direct and close, i.e. an increase in one indicator is characterised by an increase in another. A more detailed analysis was carried out by calculating correlation indicators based on statistical data.

Based on the calculated data, the close relationship between the volume of the material footprint of countries' economies and their level of innovation was determined according to formula (1):

$$r_{xy} = \frac{15061.35}{\sqrt{15623.77 \times 23964.7}} = 0.778.$$

Pearson's linear correlation coefficient is positive, i.e. the relationship between the variables studied is direct, and when the coefficient is close to 1, it indicates the presence of a linear correlation. The interpretation of the tightness (strength) of the relationship based on the rxy value obtained is carried out using the Chaddock scale, which makes it possible to convert a numerical indicator or quantitative value into a qualitative parameter. Thus, the strength of the relationship between the volume of the material footprint of a country's economy and the level of its innovativeness can be characterised as high.

Using formula (2) and the previously determined value of the correlation coefficient, the calculated value of the t-criterion was obtained:

$$t_{calc} = \frac{0.778}{\sqrt{1-0.778^2}}\sqrt{121-2} = 72.71.$$

The critical value (t_{table}) at $\alpha = 0.001$ is 3.373, i.e. the null hypothesis of no relationship between the variables is rejected, since $t_{\text{calc}} > t_{\text{table.}}$ The correlation coefficient is therefore statistically significant.

In summary, several points should be noted: firstly, the results of the correlation analysis indicate the existence of a direct close relationship between the level of innovation of the economy of a country and the volume of consumption of natural resources, which can be described by a linear function. Secondly, in accordance with Fig. 2, we can conclude that, moving from the origin along the trend line, there is a gradual transition from developing countries to developed countries. Thirdly, a high level of resource consumption, as well as a higher value of the GII index, is characteristic of developed countries. This confirms that the most developed innovative countries consume more resources. Consequently, further research should be conducted on the assumption that the widespread diffusion of innovative technologies (in both developed and developing countries), aimed at ensuring economic growth without taking into account the resource consequences, may in the future lead to a reduction in resource reserves and increased competition among buyers for the right to own them, with consequent rising prices on commodity markets and negative environmental consequences for humanity.

3. Conclusions and limitations

The study confirms that countries that have achieved a high level of innovation in their development are characterised by higher indicators of efficiency in the use of resources (i.e. there is a direct relationship between these parameters), which creates their competitive advantage, allowing them to produce more goods by attracting new technologies, other things being equal.

At the same time, the results obtained indicate that the widespread dissemination and implementation of innovations by developed and developing countries can contribute both to their economic growth and to an increase in their material footprint, thus leading to the depletion of natural resources in the future. In such conditions, the economic development of all economic entities should be based on the principles of lean production and its intensification, which will help to increase the return on the use of available factors of production with a constant volume of resources consumed or their reduction.

This empirical study is based on quantitative methods of data analysis, but it did not include the identification of functional dependencies between the parameters studied, which is its main limitation. The economies of the countries are characterised by various features (e.g. geographical and climatic conditions affecting the level of energy consumption by households for final consumption and by business entities for the maintenance of production and other premises; the presence of natural resource reserves in the country and the possibility of their extraction, etc.), but such factors have not been taken into account in the analysis.), but these factors were not taken into account in the analysis. In addition, the analysis was carried out in the context of country samples whose representativeness was not statistically verified.

Thus, promising areas for further research may be the identification of the necessary and sufficient number of factors associated with the innovative activity of enterprises and the efficiency of their use of resources, as well as the establishment of functional dependencies between selected variables. It also seems logical to conduct a detailed study of the experience of Russian enterprises and its impact on the differentiation of regions in terms of innovation and resource efficiency.

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Aims to digitalise the circulation of precious metals, precious stones and their products

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Abstract

The need to digitalise economic sectors in today's world is perceived as an objective reality. In the circulation of precious metals, precious stones and their products, the digitalisation process is at a fairly high level, with continuous improvement. The article analyses the progress made in achieving the goals of the implementation of the State Integrated Information System in the Sphere of Control over the Circulation of Precious Metals and Precious Stones at all stages (GIIS DMDK), which is the main project of digitalisation of the industry.

Keywords: GIIS DMDK, precious metals, precious stones, digitilisation of the sphere, digitalisation goals, physical marking, jewelry.

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贵金属、宝石和贵金属制品交易的数字化目标

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简介

当今世界，经济部门的数字化需求已成为客观现实。　在贵金属、宝石和贵金属制品、宝石和宝石制品的交易领域，数字化进程处于相当高的水平，并在不断改进。　文章分析了监管贵金属、宝石和贵金属制品交易各个环节中采用国家综合信息系统的达成目标进程，该系统是贵金属、宝石贵金属制品行业数字化的主要项目。

关键语: 贵金属、宝石和贵金属制品交易的国家综合信息系统；　贵金属, 宝石、领域数字化、数字化的目标、物理学标志、珠宝制品。

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Digitalisation in the Russian Federation is progressing at a fairly rapid pace, including through the National Digital Economy Project[1], which helps to generate a fairly large number of technical ideas and economic proposals. In this regard, scientific analysis and justification of the key points of digitalisation of the described sphere is an urgent issue of practical implementation of the State Integrated Information System in the field of control over the turnover of precious metals, precious stones and products made from them (hereinafter - GIIS DMDK).

Digitalisation is not just the use of software products, which have become an integral part of the working environment of people in almost every field of activity. At the current stage of development, it is an integral process that accelerates any economic activity, enables the exchange of data in digital form at various levels of communication and characterises the competitiveness of the participants.

This is one of the main reasons why digitalisation has become a subject of study for economists. The field of precious metals, precious stones and products from them, which, in addition to the economy, covers the interests of the state and citizens - consumers of jewellery products, is no exception. The creation of the GIIS DMDK digital platform, operated by Goznak[2], is aimed at achieving the development goals of a specific sector of the country's economy that works with strategically important mineral raw materials: gold, silver, platinum group metals and diamonds[3].

DMDK's sphere of influence encompasses completely different but interdependent areas: mining, refining, processing, acceptance of DMDK scrap, jewellery production and sales. The degree of digitalisation of each of the listed sectors is different, but at the moment this factor is not an obstacle to unification on a single platform of the GIIS DMDK. With the exception of companies engaged in the extraction of precious metals and stones, refining and manufacturing companies, manufacturers and importers of jewellery, workshops, pawnshops, purchase, retail, consignment and online shops are registered in GIIS DMDK, i.e. all companies subject to the Federal Law 'On Precious Metals and Precious Stones'[4] which provides for special accounting.

All legal entities subject to special accounting are interconnected according to the tolling principle, which makes it possible to create a system of traceability of the movement of strategic raw materials, to which the legislation of the Russian Federation includes precious metals, precious stones and products from them[5]. 'Digital technologies in modern conditions are the main tool determining the functioning of the value chain. Currently, production networks unite independent economic entities of the market, taking into account the high level of coordination of interests and interdependence of participants based on the common goal of production' [Bogachev, Trifonov, 2022].

In addition to legal entities subject to special registration, the GIIS DMDK programme is used by all ministries and departments whose functions include the control and supervision of the turnover of the sphere. Thus, the composition and scope of users of the GIIS DMDK system make it possible to solve two of the five declared objectives at the same time[6]: ensuring traceability and effective control. Let us take a closer look at the results of achieving the other objectives of the integrated system.

Ensuring the transition to electronic document management – a goal that was stated since the beginning of the mass use of computers, both in government control and accounting and in business. Unfortunately, the need to store documentation in two formats - electronic and paper - remains a guarantee of the authenticity and security of information. In addition, not all business partners use electronic document management, document formats are different, not all primary documents are subject to digitisation, etc. Experienced users therefore note that electronic document management has not ensured the transition to digital accounting, but has made it easier to maintain.

In the case of GIIS DMDK, the situation is somewhat different: the information entered into the system, along with the general capabilities of continuous improvement of digitalisation, can be easily restored and compared across previous and subsequent transmission links of the counterparts. 'Modern principles for the construction of such systems are aimed at the creation of multi-level software that makes the interaction through the communication environment transparent. For interaction, high-level mechanisms are used, many of which have already been adopted as standards for information processing systems' [Belyakov, 2004].

The digitalisation of the sector related to precious metals, precious stones and products from them has

[1] Passport of the national programme 'Digital Economy of the Russian Federation' (approved by the Presidium of the Council under the President of the Russian Federation for Strategic Development and National Projects on 24 December 2018, No. 16). https://base.garant.ru/72190282/.

[2] You don't change horses at the crossing: The Government of the Russian Federation has extended the functions of Goznak as the operator of GIIS DMDK.07.10.2023. https://www.jewelry-club.ru/novosti/2023/konej-na-pereprave-ne-menyayut-pravitelstvo-rf-prodlilo-funkcii-goznaka-v-kachestve-operatora-giis-dmdk.html?ysclid=lo038pvhl0261866628.

[3] Decision of the Government of the Russian Federation dated 30 August 2022 N 2473-r 'On Approval of the List of Main Types of Strategic Mineral Resources' «Об утверждении перечня основных видов стратегического минерального сырья». https: //www.garant.ru/products/ipo/prime/doc/405118925/.

[4] Federal Law No. 41-FZ of 26 March 1998 'On Precious Metals and Precious Stones'. http://www.kremlin.ru/acts/bank/12117.

[5] Id.

Decree of the Government of the Russian Federation dated 30 August 2022 No. 2473-r 'On Approval of the List of Main Types of Strategic Mineral Raw Materials'. https://www.garant.ru/products/ipo/prime/doc/405118925/?ysclid=lnyyq02lmb423093813.

[6] About GIIS DMDK. https://dmdk.ru/about/.

led to the abandonment of the practice of providing reports to market participants in non-electronic form and to working with electronic data as the main source of information. The specificity of the sector, its diversity and remoteness, and the wide range of related industries required a single platform. GIIS DMDK manages the structure of the turnover, taking into account the basic parameters, rules and methods of interaction of the different areas and modules.

The interaction mechanism within the system is constantly being improved, taking into account the wishes of both the companies operating in the area, and therefore the programme, and the authorities controlling it. In each module, taking into account its functional features, mechanisms of interaction with suppliers, buyers, supervisory authorities are formed, as well as with other information and integration systems of a similar type operating in the Russian Federation, which help to track the movement of products. Other systems best known to the mass user include USAIS - alcoholic product sales control, USAIS - timber accounting and transactions, FSIS ‘Mercury’ - sales accounting for products subject to veterinary control. ‘All of the listed integrated information systems have the same principle - accounting for the promotion of labelled goods in order to exclude illegal trade, tax evasion, payment of duties and fees, and protection of consumers from counterfeit products’ [Ivanova, Umgaeva, 2023].

Increasing the efficiency of consumer protection procedures is the fourth of the stated objectives of the implementation of the GIIS DMDK. As a means of achieving this, a decision was taken to physically mark gold and platinum jewellery (hereafter referred to as jewellery). According to the decree of the Government of the Russian Federation[7] as of 1 March 2024, all jewellery sent to the Federal Assay Office of the Russian Federation (hereinafter referred to as the FAO) for examination, as well as all imported products that have passed through customs, will be subject to mandatory marking. From 1 September 2024, all products subject to marking and offered for sale must have a DM code applied directly to the jewellery. The gradual implementation of the stated goal is explained by the strategy of the Ministry of Finance of the Russian Federation ‘to ensure a smooth transition without affecting legally operating businesses’. At the same time, the main message we want to convey to the industry is that labelling is a benefit. The sooner the system is up and running, the sooner the end user will appreciate the result of our work together[8]. Marking of jewellery made from precious metals, precious stones and products from them is in accordance with the Concept of the creation and operation in the Russian Federation of a system for marking goods by means of identification and traceability of the movement of goods, approved by the Order of the Government of the Russian Federation[9]. The concept aims to protect consumer rights against counterfeit, uncertified products.

However, the implementation of the product labelling process itself does not yet allow to guarantee the success of the implementation within the set timeframe, which is not planned to be postponed. Specialists calculate a fairly large number of parameters to make the codes on products absolutely readable. In addition, if the depth of application of the DM code is determined by the participants during testing in conjunction with the FAO, further implementation of the project will be left to those who plan to, if not increase, then at least maintain sales volumes.

It should be noted that, according to a number of experts, the labelling of jewellery is rather difficult to promote because of the additional costs involved. ‘It would be possible for a company to at least make it easier - to enter not the UIN (Unique Identification Number - author’s note) but the IBN - the individual batch number - in the DM code applied directly to the piece of jewellery. Yes, theoretically, without reading the UIN directly from the products coming from the FAO after they have been branded and marked, the manufacturing plant could make a mistake. They’ll find out. There will be no need to spend on everything associated with reading marks off metal products’[10].

To comply with the law, many sellers, mainly small businesses, will need to purchase readers, provide lighting, train staff and collect and label all unsold, unlabelled products. According to Jeweler Soft, the developer of the GIIS DMDK system, ‘taking into account the time needed to collect a batch and the subsequent processing/sorting of the products arriving from the FAO, we come to the conclusion that it was necessary to start marking balances at retail outlets yesterday. All new jewellery entering the retail chain must already be physically marked. Failure to do so will result in all new products received being sent to the FAO at your expense for labelling as surplus. This has both financial and time costs. The time taken to physically mark a product at the FAO may be a key factor, as no additional staff are foreseen at the FAO for the residue marking period’[11]. For example, the introduction of labelling for jewellery products was complicated by

[7] Resolution of the Government of the Russian Federation dated 02/26/2021 No. 270 "On certain issues of control over the turnover of precious metals, precious stones and products made from them at all stages of this turnover and Amendments to Certain Acts of the Government of the Russian Federation" (with amendments and additions). https://base.garant.ru/400380713/?ysclid=lo1pheup44671954577.

[8] Trukhanova E. Jewellers hope for the abolition of physical markings on jewellery. 20.09.2022. https://rg.ru/2022/09/20/reg-cfo/vse-ravno-ne-razgliadet.html?ysclid=lnq68ck2v3444770594.

[9] By order of the Government of the Russian Federation dated 28 December 2018 No. 2963-r. http://static.government.ru/media/files/xZ2pPl6khqfC8tCkRXf3z7VQ8JgeZbk3.pdf.

[10] Zboykov V. We create problems for ourselves so that we have something to overcome. 24 September 2023. https://uvelir.info/news/vladimir-zbojkov-myi-sami-sozdaem-sebe-problemyi-chtobyi-byilo-chto-preodolevat/.

[11] How to prepare for the physical marking of jewellery? Jeweller Soft. 17 July 2023. https://uvelirsoft.ru/blog/giis-dmdk-chto-ostalos-k-chemu-gotovitsya/?ysclid=lnq654inuo626900211.

the additional costs involved, which were prohibitive for a certain part of the business.

The best confirmation of this comes from the Russian Federal Tax Service. ‘According to the Federal Tax Service, the number of small jewellery businesses has decreased by 35 per cent since the beginning of 2023. Some seven thousand small industries have closed or gone into hiding, and many of those that remain have reduced production volumes and the number of employees. Industry representatives and experts attribute this to the abolition of the Simplified Tax System (STS) for jewellery. They also believe that the introduction of the GIIS DMDK - a system for monitoring the circulation of precious metals, stones and products - has had an impact’[12].

Indirectly, the difficulties of physical marking of products have been confirmed by the Chamber of Commerce and Industry of the Russian Federation, which supports the abolition of compulsory marking of jewellery exported from the EAEU. According to the President of the Chamber of Commerce and Industry, S. Katyrin, ‘the Russian hallmark is not recognised in countries outside the EAEU, which significantly reduces the competitiveness of Russian jewellery on the world market. At the same time, jewellery buyers in these countries may perceive the imprint of the Russian hallmark as a damage during processing that violates the aesthetic perception of the product’[13].

If this proposal is implemented, Russian manufacturers will mark products only for domestic consumption and for sale in the EAEU countries. Physical marking on jewellery in the coming years will be applied only to products for the domestic market of Russia, since none of the EAEU countries, despite the signed agreement in the sphere of circulation of DMDK[14], has started it, with the exception of the Republic of Belarus, and then as an experiment . The analysis of the analytical information from the GIIS DMDK system will show how this will affect the competitiveness of Russian manufacturers, the quality of control over DMDK sales and the protection of consumer rights.

The generation of analytical information on the state of the precious metals and jewellery industry is an objective which, among other things, opens up the possibility of scientific analysis of the effectiveness of the system. To date, the GIIS DMDK does not provide summary information for analysis by third parties. Information for buyers is available both on the website and in the DMDK mobile application: you can get information about a standard or measured Russian ingot, jewellery and its characteristics using a unique identification number. Coming back to the question of the physical marking of jewellery, it is logical to check the information at the time of purchase. For this purpose, the information and the digital code on the label are sufficient for the buyer.

The digitalisation of the circulation process of DMDK and products made from it is a definite plus, and labelling is a mandatory tool for its implementation. Thanks to the inclusion of DMDK in the GIIS system, the information will be available to all the government departments involved in controlling sales, as well as to buyers, producers and distributors. The first is the FAO, which is the authorised body for state control of the circulation of precious stones, metals and products made from them. At the same time, on the FAO website, all the proposed list options (market participants who comply with the legislation of the Russian Federation and violate it; market participants who do not reflect information in the GIIS DMDK; market participants who submit their products for physical labelling etc. are available.[15]) are not numbered and do not include a total. The analyst must generate the necessary information independently.

On the website of this department, in the ‘Open Data’ section, more analytical information is presented. For example, the Register of Special Accounts of Legal Entities and Individual Entrepreneurs Dealing in Precious Metals and Precious Stones is numbered. There are 21,968 of these on 27 October 2023; there is no information in the open data on how many were specifically registered with the FAO before the introduction of the GIIS DMDK. The FAO website also provides information on the number of licences issued by the territorial bodies of the Federal Assay Chamber, information on the composition of the Public Council. This information is not sufficient to assess the effectiveness of the system and of digitisation efforts in general.

The GIIS DMDK system allows you to create a compilation of open data on all government agencies involved in the process of regulating and controlling the circulation of DMDK and products made from it. This mechanism will primarily help control structures to benefit from the digitalisation of the sales process and to analyse each other’s data when making decisions. The stated aim of the GIIS DMDK is to achieve a complete transition to an electronic document management system. It implies the completeness of analytical information.

An attempt to find information on the websites of GIIS DMDK, FAO, Goznak on how many people downloaded the mobile version of ‘DMDK’, how many

[12] Ledyaeva M. Why the small jewellery business decreased by a third. 17 October 2023. https://rg.ru/2023/10/17/reg-szfo/serebro-uhodit-v-podval.html.

[13] The Chamber of Commerce and Industry supports the abolition of compulsory hallmarking of jewellery exported from the EAEU. 11 August 2023. https://ap-dm.ru/news/tpp-podderzhala-otmenu-obyazatelnogo-klejmeniya-yuvelirnyh-izdelij-pri-vyvoze-iz-eaes.

[14] Agreement on the Specifics of Transactions with Precious Metals and Precious Stones within the Eurasian Economic Union of 22 November 2019. http://publication.pravo.gov.ru/Document/View/0001202105280015?ysclid=lnta5ize7t351504704.)

[15] https://probpalata.gov.ru/spisok-uchastnikov-rynka-sovershayushhix-oborot-s-narusheniem-zakonodatelstva-rossijskoj-federacii/.

used it, how many fakes were detected was not successful. All departments only provide a link to download the information resource on their websites and do not make any marketing efforts to promote it. Promoting such an important source of information will also help to achieve the main goals of digitising the sphere - transparency of sales, increased competitiveness of products and increased revenues for the industry.

The objectives of the implementation of the GIIS DMDK, which is a key mechanism for the digitisation of the circulation area of the DMDK and its products, are gradually being achieved. Thanks to the implementation of the system, production processes in jewellery manufacturing and sales, in the management system of industrial enterprises in the sphere, refineries, pawnshops and recycling of precious metals scrap have changed significantly; logistics have been simplified, additional jobs have been created, the mechanism of interaction between business and regulatory structures has been accelerated and clarified.

At the same time, the level of readiness (financial, human, technical) of each participant registered in the DMDK sales system determines the potential for the development of the digital space not only in his company, firm, but also in the entire sphere. The level of readiness of companies varies greatly. However, it must be stressed that the digitalisation of the sphere is necessary to create the conditions for its development, and not vice versa. From an economic point of view, it is illogical to develop the sphere in a way that it considers unprofitable when introducing digitalisation. This principle is conclusively formulated for the purpose of the implementation of the GIIS DMDK, and provided that they are fully achieved, the area under study will contribute to the digitisation and development of the Russian economy as a whole.

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The impact of product and process innovations on financial results: An empirical study of Russian companies

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Abstract

The relationship between product and process innovation and financial performance remains largely unexplored, especially for Russian firms. An analysis of publications on this topic shows both a positive and a negative relationship. At the same time, there are no empirical studies based on Russian companies. This study was conducted on the basis of empirical data from 137 Russian companies. The study shows that investment in R&D has a positive effect on the financial results of the company; and the financial results of the companies depend on the type of innovation (product or process) that the companies carry out.

Conducting R&D and scientific research related to product and process innovations can increase the profitability of sales, which characterises the financial results of Russian companies. In addition, it was concluded that the relationship between process innovations and financial results is stronger than the relationship between product innovations and financial results, which means that it is more profitable to develop and implement process innovations.

Keywords: process innovations, product innovations, R&D, financial results, profitability.

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产品和流程创新对财务业绩的影响：对俄罗斯公司的实证研究

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简介

俄罗斯公司的产品和流程创新与财务结果之间的关系在很大程度上仍未被充分研究，特别是对于俄罗斯公司而言。对该主题的出版物进行的分析显示了正面和负面的关联。然而，基于俄罗斯公司的实证研究却很少。本研究基于对137家俄罗斯公司的实证数据进行了研究。结果表明，对研发的投资对公司的财务业绩产生了积极影响，而这些业绩则取决于公司所进行的创新类型（产品或流程）。

通过进行与产品和流程创新相关的实验设计和科学研究，能够提高俄罗斯公司的销售利润率，从而改善其财务业绩。此外，得出结论：流程创新与财务结果之间的关系比产品创新与财务结果之间的关系更为密切，因此，开发和实施流程创新更为有利。

关键词： 流程创新、 产品创新、科学研究和试验设计、 财务业绩、 盈利能力。

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Introduction

There are many studies devoted to the impact of innovation on different aspects of business activity: entry into international markets and efficiency of export activities [Peters et al., 2018; Fayazova, 2020]; efficiency and competitiveness [Garipova, 2011; Alvarez et al., 2015; Kozlov, Kadyrova, 2019]; productivity [Baumann, Kritikos, 2016; Trachuk, Linder, 2020; Domnich, 2022]. For example, the introduction of process innovations helps reduce costs and often leads to the introduction of product innovations. At the same time, many authors emphasise the relationship and mutual influence of product and process innovation and also confirm with empirical data that the most effective companies are those that manage to ensure synergy between product and process innovation [Homburg et al., 2019; Ehls et al., 2020; Malek et al., 2020; Linder, 2021].

At the same time, the relationship between innovation activity and financial performance remains under-researched, as the results of such studies tend to be contradictory. Thus, the authors of some works conclude that there is a positive relationship between innovative activity and the financial capabilities of companies [Criscuolo, 2009; Cassoni, Ramada-Sarasola, 2012; Acosta et al., 2015; Santi, Santoleri, 2017; Crowley, McCann, 2018; Edeh, Acedo, 2021], while others conclude that there is a negative relationship between them [De Loecker, 2011; Doran, 2012; Goedhuys, Veugelers, 2012]. There are no Russian empirical studies on this issue.

The purpose of this article is to empirically examine the impact of process and product innovation on the financial performance of Russian firms.

1. Research on the relationship between innovation and firm financial performance

The impact of innovation on financial performance can be both positive and negative. In the study [Pantagakis et al., 2012], the authors attempted to establish a relationship between the intensity of investment in R&D, calculated as the ratio of R&D expenditure to net sales, and the financial performance of companies involved in the development of software and hardware. To determine the results of the study, the company's return on investment and market capitalisation were measured. A study based on data from 39 companies in the European Union found a negative correlation between return on investment and R&D investment intensity. The authors explain this by saying that investments in R&D do not pay off immediately and do not always pay off in the current year due to the high uncertainty of the results.

As additional regressors in the model, the authors used the sales growth rate and the ratio of debt to assets as a feature of the capital structure [Pantagakis et al., 2012]. The researchers found a positive correlation between return on assets and sales growth, but a negative correlation between return on assets and the debt ratio. The researchers found a positive correlation between return on assets and sales growth, but a negative correlation between return on assets and leverage. The study found that to achieve maximum market value growth, a company must invest approximately 41% of annual revenues in research and development.

[Hall, 2011; Crespi, Zuniga, 2012] show that innovation helps to increase the efficiency of resource use, to introduce new technologies and to overcome the technological gap of weaker firms, thereby achieving better financial results.

The study [Ku et al., 2010] also confirmed the hypothesis that there is a non-linear relationship between R&D investment and company financial performance, which was measured in the study using Tobin's coefficient and return on assets. The study [Ku et al., 2010] also confirmed the hypothesis that there is a non-linear relationship between R&D investment and company financial performance, which was measured in the study using Tobin's Q and return on assets. The authors of the article [Vithessonthi, Racela, 2016] conducted a study based on data from non-financial companies traded on the US stock exchange. They found a negative relationship between the intensity of R&D investment and the financial performance of companies and concluded that R&D investment has a negative impact on the financial performance of economic entities in the short term. At the same time, a positive relationship was found between the intensity of investment in research and development and the value of the company, suggesting that innovation has a positive impact on long-term performance.

In the study [Chen et al., 2019], the authors assessed the correlation between the intensity of investment in R&D and the profitability of assets, which characterises the financial performance of the company. The study is based on information from 96 companies listed on the Taiwan Stock Exchange. In addition to the R&D intensity indicator, the explanatory variables included the natural logarithm of the value of assets as a measure of the size of the firm, the growth rate of the firm's assets, and the coefficient of financial dependence (the ratio of the value of liabilities to the value of assets) as a measure of the firm's capital structure. As a result of estimating the coefficients of the model, the researchers found a negative relationship between the intensity of R&D investment and the return on assets in the current period, but the relationship between the return on assets and the intensity of R&D investment with a lag of one and two years was positive. These results suggest a positive effect of R&D investment with a time lag.

Regarding the relationship between return on assets and other explanatory variables in the model, the authors of [Chen et al., 2019] found a positive correlation between current return on assets and return on assets with a one-year lag, firm size expressed as the natural logarithm of the value of its assets, and the growth rate of firm assets. The relationship between return on assets and the ratio of a company's liabilities to its assets is negative, i.e. companies with higher levels of debt have lower returns on assets than companies with lower levels of debt.

There are other papers that assess the relationship between different indicators of firms' financial capacity and their innovative activity. The results of these studies may vary depending on national characteristics, the choice of different dependent and explanatory variables, and the degree of innovation capacity of industries.

The analysis of the scientific literature allowed us to formulate the following hypotheses:

1) investment in R&D has a positive impact on the company's financial results;
2) companies' financial performance depends on the type of innovation (product or process) they undertake.

2. Research methodology

In order to examine the relationship between the innovative activity of Russian companies and their financial results, the authors of this article first conducted a survey and then an empirical study.

The purpose of the survey was to determine the main characteristics of the innovative activities of Russian companies for further research: types of innovations carried out, types of expenditures on innovations, methods of developing and implementing innovations, etc.

The participants in the survey were employees of Russian companies whose professional activities are directly related to the development and implementation of innovations.

The survey was a Google form that could be completed online by clicking on a link and consisted of 8 multiple choice questions. At the same time, participants were not limited in the number of answers to the question and had the opportunity to offer their own options if they were not satisfied with the ones suggested.

After conducting the survey and processing the results, the authors of the study were faced with a new goal - to identify the relationship between process and product innovation of Russian companies and their impact on financial results. To achieve this, a sample of 335 large Russian companies was selected and 137 companies responded (response rate of around 40%).

An important condition for a company to be included in the sample was that it had expenditure on research and development, provided that this work was completed by the end of 2022.

For each enterprise, information was collected on the R&D costs incurred in 2022 and the financial results achieved. The sources of information used were the annual accounts for 2022, namely form 2 'Report on the financial results', the notes to the annual accounts and statistical form 4 'Information on the innovative activities of the organisation'.

Once all the necessary information had been obtained, indicators for further research were calculated for each company, namely:

- the share of R&D costs related to product innovation in the turnover of the enterprise as a characteristic of the innovative activity of the enterprise;
- the share of R&D costs related to process innovations in the turnover of the enterprise as a characteristic of the innovative activity of the enterprise;
- return on sales as the ratio of net profit to company sales as an indicator characterising the financial results of the company.

The data obtained were summarised in two tables: the first and third indicators - in one table to confirm the first hypothesis; the second and third - to confirm the second hypothesis. Thus, at this stage, the study was conditionally divided into two sub-stages, but the algorithm of action for each of them was similar, except for the data used for analysis.

The analysis was carried out using the Excel programme: the = CORREL function was used to determine the correlation between the data studied (the share of R&D costs related to product or process innovation in the company's turnover and sales profitability) at each stage.

The authors of the study then carried out a regression analysis. As a result, two linear equations were obtained, the analysis of which makes it possible to assess the presence or absence of a relationship between the innovative activity of Russian companies and their financial results:

$$ROS = 1.8227 Iprod + 0.1921, \qquad (1)$$

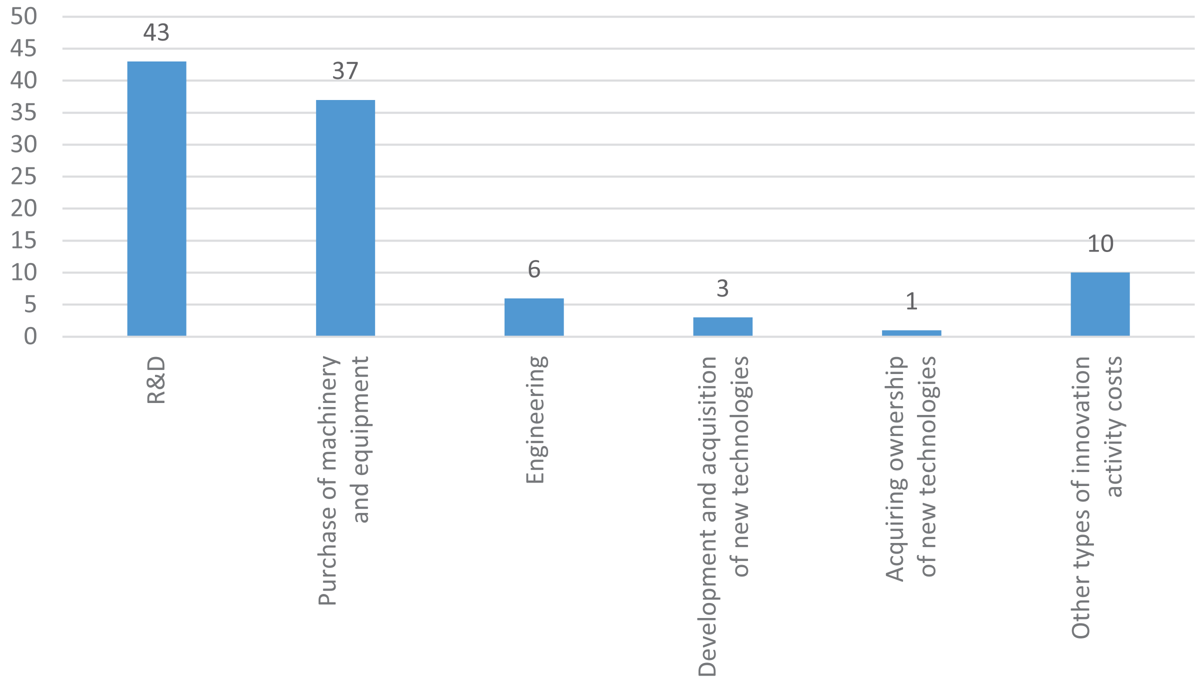
$$ROS = 1.8235 Iproc + 0.116, \qquad (2)$$

where *ROS* – company sales profitability, *Iprod* – R&D costs related to product innovation as a percentage of company sales, *Iproc* – R&D costs related to process innovation as a percentage of company sales.

3. Research results: the impact of product innovation on the financial results of Russian companies

One of the questions that interested the authors of this study was related to the costs that companies incur in the innovation process: 'What types of innovation costs predominate in your company?' (Fig. 1).

Fig. 1. Distribution of answers to the question ‘What types of innovation costs are prevalent in your company?’ (% of respondents)



Source: compiled by the authors.

According to the survey results, research and development of new products, services and methods of their production, new production processes, account for the largest share of costs (43% of respondents). A large share of innovation expenditure is also related to the purchase of machinery, equipment and other fixed assets used in innovation activities (37 %). 10% of respondents chose other costs associated with carrying out innovation activities (other costs in this case include marketing and branding, design, staff training, etc.).

Respondents were then asked to select the priority type of cost incurred by their company (product or process innovation costs). The study found that 59% of respondents incur product innovation costs and 41% incur process innovation costs. This is due to the nature of the business, its current needs and other factors. It should also be added that product innovation is often more expensive to create and implement than process innovation, and therefore costs more.

According to Rosstat, only 4.5% of domestic organisations spent on product innovation in 2022[1].

With regard to product innovation, respondents were asked the following question: ‘Who develops product innovations for your organisation?’ (Fig. 2).

From Fig. 2 we can see that 44% of companies develop innovations on their own, 26% use the help of third party organisations to develop product innovations, 23% prefer to collaborate with other companies and only 7% create innovations by transforming products created in another organisation. The next question asked of respondents related to factors that have a negative impact on innovation activity (Fig. 3).

According to the majority of respondents, the most common factor slowing down the innovative activity of Russian companies is the high cost of innovation (76% of respondents), followed by the delayed impact of research and development (43%). These factors are real and many foreign studies have been devoted to them. It is worth noting that the high cost of innovation, if successful, pays off and has a positive impact on the company’s financial results.

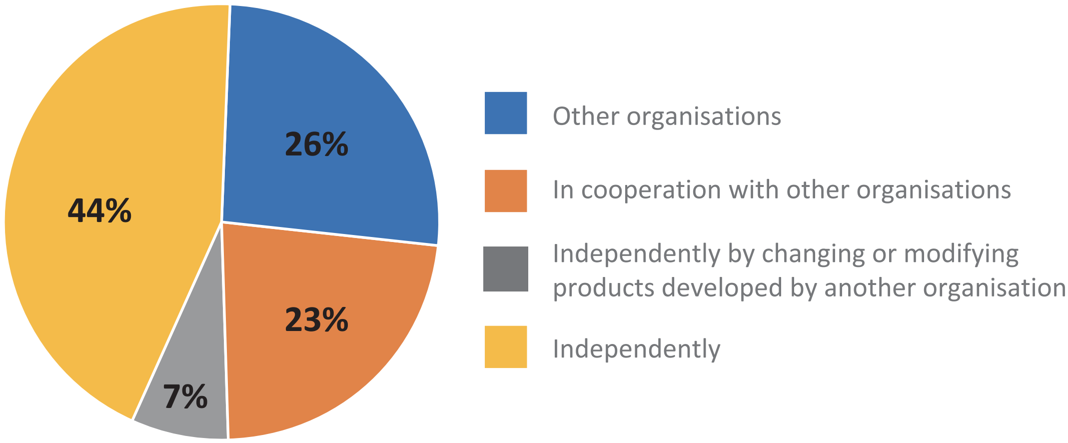
Respondents were also asked to answer a question on the impact of innovation activity on the performance of their enterprise (Fig. 4).

As a result of the analysis of the answers to this question we can conclude that innovative activity has an impact on various spheres of activity of Russian enterprises. In particular, according to 78% of the respondents it allows to maintain traditional sales markets, according to 67% of the respondents - to improve the quality of goods, works, services, according to 60% of the respondents - to reduce the time of interaction with consumers or suppliers, etc.

To explore the relationship between product innovation and financial performance, it was decided to examine the relationship between R&D costs related to product innovation as a percentage of sales and sales profitability.

[1] https://rosstat.gov.ru/statistics/science.

Fig. 2. Distribution of answers to the question 'Who develops product innovations for your organisation?' (% of respondents)



Source: compiled by the authors.

This was done by calculating the average of the company indicators by industry. On the basis of the data from the 2022 annual accounts, the estimated indicators for each company were determined: aggregated results of research and development (line 1120 of the balance sheet and notes), turnover (line 2110 of the profit and loss account), net profit (line 2110 of the profit and loss account).

Table 1 presents aggregated information on Russian companies' spending on product innovation in 2022 by industry.

In 2022, spending on product innovation ranges from 450,605,431 to 6,346 thousand rubles. The largest expenditures on product innovation were made by gas extraction enterprises (450,605,431 thousand rubles), oil extraction and refining enterprises (300,006,727 thousand rubles), and ferrous and non-ferrous metallurgy enterprises (101,156,735 thousand rubles).

Table 2 provides information on the average financial results of Russian companies in 2022.

After collecting all the necessary information from each company's annual accounts, the R&D costs related to product innovation were calculated as a percentage of the company's turnover and the return on turnover. The initial data are presented in Table 3.

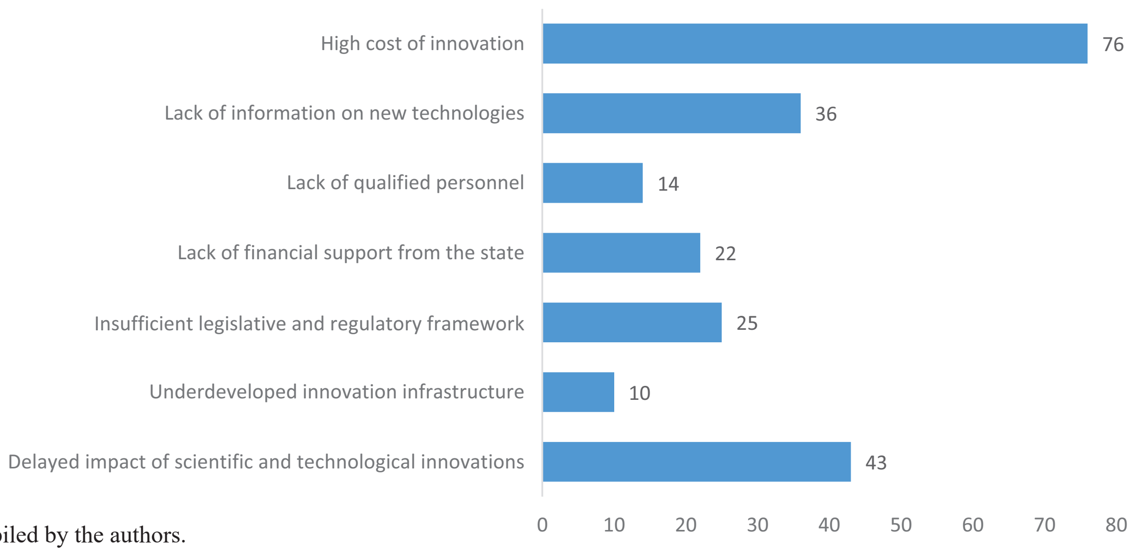
Analysing Table 3, we can conclude that the average share of R&D costs related to product innovation in the turnover of the companies in the sector will be 1.22% in 2022. The average return on sales of the companies studied is 21.43%.

A regression analysis was then carried out, resulting in a linear regression equation:

$$ROS = 1{,}8227 Iprod + 0{,}1921. \quad (3)$$

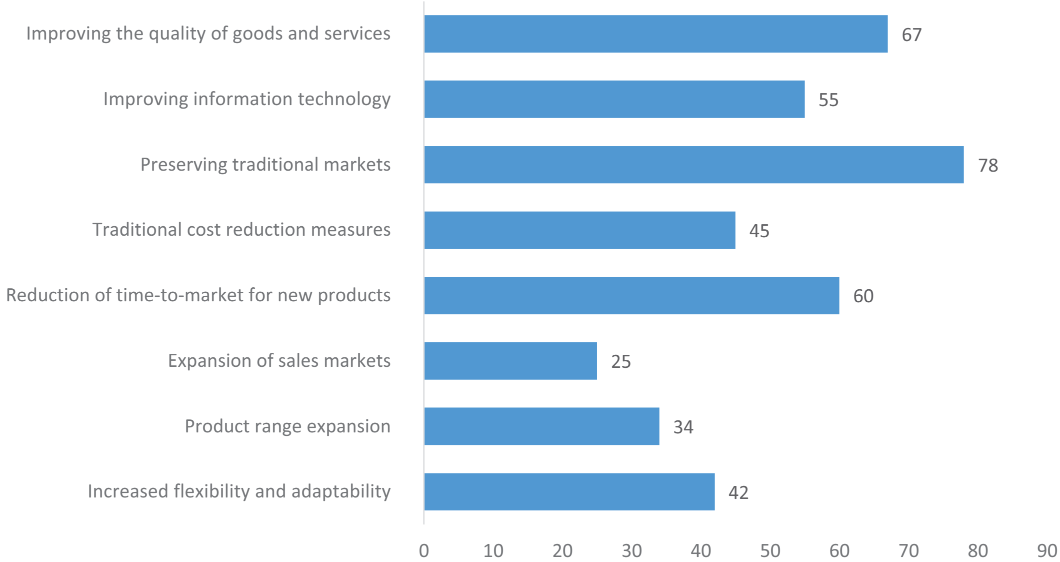
Analysing the regression equation, we can draw the following conclusions:

Fig. 3. Distribution of answers to the question 'What factors hinder innovation in your company?' (% of respondents)



Source: compiled by the authors.

Fig. 4. Distribution of answers to the question 'What results does innovation bring to your company?' (% of respondents)



Source: compiled by the authors.

Table 1
Expenses of Russian companies on product innovation in 2022

Sector	Number of sample companies	Average company expenditure on research and development related to product innovation by industry (thousand rubles)
Gas production	7	450605431
Petroleum extraction and refining	22	300006727
Ferrous and non-ferrous metallurgy	9	101156735
Heavy engineering	5	33170567
Pharmaceutical industry	16	4984037
Chemical and petrochemical	14	1509873
Electric power industry	8	741143
Nuclear industry	2	716688
Aerospace industry	3	353806
Defence industrial complex	24	216596
Automotive industry	3	180725
Transport industry	4	160297
Building materials production	7	50073
Telecommunications	3	8621
Food industry	10	6346
Total	137	

Source: compiled by the authors.

Table 2
Financial results of Russian companies in 2022 (thousand rub)

Sector	Average sales revenue	Average net profit
Gas production	6388987167	2684456626
Petroleum extraction and refining	785977975	220947263
Ferrous and non-ferrous metallurgy	792927899	278191681
Heavy engineering	855897262	313662262
Pharmaceutical industry	1963646793	18763461
Chemical and petrochemical	528497978	149293771
Electric power industry	7593831523	602930206
Nuclear industry	60639706	1102689
Aerospace industry	350588729	17630466
Defence industrial complex	190106300	50856772
Automotive industry	770347840	272910012
Transport industry	1888308109	513220494
Building materials production	1069309679	142659528
Telecommunications	2389317290	635468324
Food industry	103032996	6421178

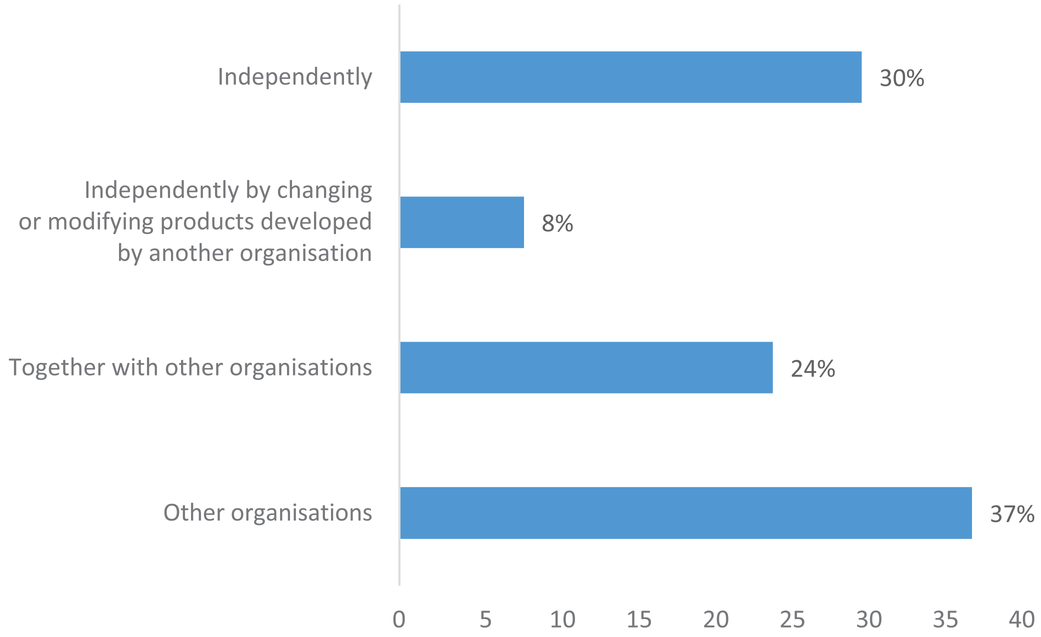
Source: compiled by the authors.

Table 3
Statistical data (%)

Sector	R&D costs related to product innovation as a percentage of company turnover	Return on sales
Gas Production	7.05	42
Petroleum extraction and refining	3.95	8
Ferrous and non-ferrous metallurgy	4.23	27
Heavy engineering	1.76	27
Pharmaceutical industry	0.25	1
Chemical and petrochemical	0.14	13
Electric power industry	0.39	27
Nuclear industry	0.14	28
Aerospace industry	0.04	37
Defence Industrial Complex	0.03	28
Automotive industry	0.18	6
Transport industry	0.02	35
Building materials production	0.08	2
Telecommunications	0.00	5
Food industry	0.00	35

Source: compiled by the authors.

Fig. 5. Distribution of answers to the question 'Who develops process innovation for your organisation?' (% of respondents)



Source: compiled by the authors.

1. If the share of R&D costs related to product innovation in the company's sales is 0, the minimum return on sales is 19.21%.

2. The coefficient of Iprod indicates the degree to which sales profitability is dependent on R&D costs related to product innovation as a percentage of sales. In our case, this coefficient is 1.8227, which indicates a fairly high correlation between the indicators studied, i.e. the higher the share of R&D costs related to product innovation in sales, the higher the profitability of sales.

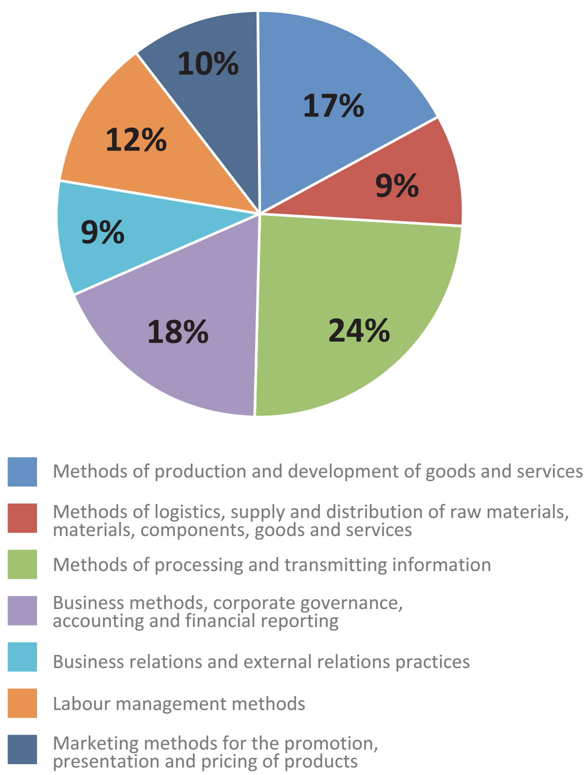
Thus, by analysing the relationship between the share of completed R&D costs related to product innovation in sales and the profitability of sales of Russian companies, the authors found that this relationship is present, positive and statistically strong. Consequently, conducting R&D related to product innovation can increase the profitability of sales, i.e. the revenues of Russian companies.

4. The impact of process innovations on the financial results of Russian companies

One of the questions asked of respondents was: 'Who develops process innovations for your organisation?' Respondents' answers are shown in Fig. 5.

To develop process innovations, 37% of companies use the help of third parties, 30% develop innovations themselves, 24% prefer to collaborate with other companies and 8% create process innovations by changing or modifying the products of other organisations.

Fig. 6. Distribution of answers to the question 'What types of process innovation is your company implementing?' (% of respondents)



Source: compiled by the authors.

Table 4
Expenses of Russian companies on process innovation in 2022

Sector	Number of sample companies	Average cost of R&D related to process innovation per company in the industry (thousand rubles)
Gas production	7	459376426
Petroleum extraction and refining	22	188293285
Ferrous and non-ferrous metallurgy	9	161668167
Heavy engineering	5	93198302
Pharmaceutical industry	16	76676948
Chemical and petrochemical	14	64548921
Electric power industry	8	61244838
Nuclear industry	2	51955611
Aerospace industry	3	46942082
Defence industrial complex	24	36278171
Automotive industry	3	16368424
Transport industry	4	15852212
Building materials production	7	7704331
Telecommunications	3	6001255
Food industry	10	1162721

Source: compiled by the authors.

A similar question was asked about product innovation. Comparing the responses, we can conclude that Russian companies are more likely to trust other organisations to develop process innovation than product innovation.

Answers to the question: ‘What types of process innovation does your company undertake?’ are shown in Fig. 6.

Russian companies engage in different types of process innovation depending on their needs, type of activity and other factors. According to the survey results, the majority of companies develop and implement new ways of analysing and disseminating information (24% of respondents), new ways of doing business, corporate governance, finance and accounting (18%), new ways of producing and developing goods and services (17%). According to Rosstat, only 4.3% of organisations had costs for process innovation in 2022[2].

Similar to the study of the relationship between product innovation and financial performance of Russian companies, the relationship between process innovation and financial performance was also investigated. For this purpose, additional information on R&D costs for process innovation was selected from companies’ annual reports.

Table 4 provides information on Russian companies’ expenditure on process innovation R&D by industry in 2022.

Expenditures for R&D related to process innovations in 2022 range from 459,376,426 thousand rubles to 1,162,721 thousand rubles. The largest expenditures on product innovations were made by gas extraction enterprises (459,376,426 thousand rubles), oil extraction and refining enterprises (188,293,285 thousand rubles), and ferrous and non-ferrous metallurgy enterprises (161,668,167 thousand rubles). It is worth noting that the turnover and net profit of companies in these industries are also the highest of all companies in the sample. In addition, they occupy a leading position in terms of R&D costs related to product innovation. A comparison of the costs of product and process innovation incurred by the largest Russian companies in 2022 allows us to draw the following conclusions:

1. The largest expenditures on product and process innovation in 2022 were made by companies in gas extraction, oil extraction and refining, and ferrous and non-ferrous metallurgy.

2. Most Russian companies spend more on process innovation than on product innovation.

To determine the impact of process innovation on the financial performance of Russian companies, the relationship between the share of process innovation R&D expenditure in sales and sales profitability was also examined. For this purpose, the share of process innovation R&D costs in sales was calculated for each company. The initial data are shown in Table 5.

Analysing the table, we can conclude that the average R&D expenditure on process innovation as a percentage of sales will be 5.29% in 2022. This is 4.07% more than the average R&D expenditure for product innovation as a percentage of sales.

It is worth noting that the ratio of spending on process innovation to the financial results of enterprises is higher than the ratio of spending on product innovation to the financial results by 3.24%, i.e. the relationship between the financial results of Russian enterprises and process innovation is stronger than with product innovation.

A regression analysis was then carried out, resulting in a linear regression equation:

$$ROS = 1{,}8235 Iproc + 0{,}116. \qquad (4)$$

[2] https://rosstat.gov.ru/statistics/science.

Table 5
Statistical data (%)

Sector	Research and development costs related to process innovation as a percentage of company turnover	Return on sales
Gas production	2.95	42
Petroleum extraction and refining	6.05	8
Ferrous and non-ferrous metallurgy	6.77	27
Heavy engineering	3.24	27
Pharmaceutical industry	4.75	1
Chemical and petrochemical	4.86	13
Electric power industry	8.61	27
Nuclear industry	6.86	28
Aerospace industry	8.96	37
Defence industrial complex	5.97	28
Automotive industry	5.82	6
Transport industry	8.38	35
Building materials production	1.92	2
Telecommunications	2.20	5
Food industry	2.00	35

Source: compiled by the authors.

Analysing the regression equation, we can draw the following conclusions:

1. If the R&D costs associated with process innovation as a percentage of the company's sales is 0, the minimum return on sales is 11.6%.

2. The coefficient of Iproc indicates the degree of dependence of sales profitability on the share of R&D costs related to process innovation in sales. In our case, the coefficient is 1.8235, which indicates a fairly high relationship between the indicators studied, i.e. the higher the share of R&D costs associated with process innovation in sales, the higher the profitability of sales.

When analysing the existence of a relationship between the share of the cost of completed R&D related to process innovations in sales and the profitability of sales of Russian companies, we found that this relationship is present, positive and at the same time statistically strong. As a result, conducting R&D related to process innovation can increase the profitability of sales, i.e. the revenues of Russian companies.

Thus, after a study devoted to the analysis of the relationship between the innovative activity of Russian companies and their financial results, we can conclude that the relationship between the studied characteristics is indeed present, positive and at the same time statistically strong. It should be noted, however, that process innovation has a slightly greater impact on the financial results of Russian companies than product innovation.

The results confirm both hypotheses: that there is a relationship between product innovation and the financial performance of Russian companies, and that there is a relationship between process innovation and the financial performance of Russian companies. It was concluded that the relationship is slightly stronger in the second case, which means that it is more profitable to develop and implement process innovations, as they have the greatest impact on the financial results of Russian companies.

5. Conclusions and application of the results obtained in the practical activities of Russian companies

The empirical study confirmed both hypotheses:

- investment in R&D has a positive impact on the company's financial results;
- the financial performance of companies depends on the type of innovation (product or process) they undertake.

The results of the study indicate that investment in R&D has a positive impact on a company's financial performance. Undertaking research and development related to product and process innovation can increase the profitability of sales, which characterises the financial performance of companies. It was also concluded that the relationship between process innovation and financial performance is stronger than that between product innovation and financial performance, which means that it is more profitable to develop and implement process innovation.

Since the first hypothesis about the impact of R&D investment on financial performance is confirmed, companies should focus on finding funding for R&D investment. It could be:

- attracting external investors: a company can attract external investment by selling or issuing shares or bonds to raise additional funds to finance innovation;
- loan: a company may take out a loan from a bank or other financial institution to obtain the funds it needs;
- government grants and subsidies: a company can apply for a grant or subsidy from government organisations that fund innovative projects;
- partnership: a company can partner with another company that is willing to invest in innovation;
- crowdfunding: a company can use crowdfunding platforms to raise money from the general public for its project;
- deferred payment: a company may negotiate additional time to pay its debts to suppliers or creditors in order to gain more time to develop innovations;
- leasing: a company can lease the equipment it needs instead of buying it, saving money that can be used to fund innovation.

In addition, the results of the study showed that for Russian companies, the relationship between process innovation and financial performance is higher than that between product innovation and financial performance. In this regard, companies should encourage process innovation by:

- training and development of employees: The company must invest in the training and development of its employees so that they can better understand new technologies and processes and adapt to changing market demands;
- collaboration with external experts: the company can attract external experts to help develop innovative ideas and projects;
- implementing innovative methods and technologies: the company can use new methods and technologies such as design thinking, agile, blockchain and artificial intelligence;
- forming partnerships: a company can form partnerships with other companies or start-ups to jointly develop new products and technologies;
- use of innovative financing models: A company can use innovative financing models such as crowdfunding, venture capital, ICO and others to raise funds to develop new ideas and projects;
- establishing an innovative culture: The company must develop an innovative culture so that employees can freely and dynamically generate and experiment with new ideas.

Product innovation also has a positive impact on financial results, which is why it is necessary:

- to focus on customer needs and solving their problems: The company must focus on solving the problems and needs of its customers in order to develop innovative products and services that will be in demand;
- to create a stimulating environment: Companies need to provide a comfortable and motivating work environment for employees, where they can freely express their ideas and receive feedback;
- to train and support employee development: The company should provide employees with access to training and development so that they can continue to develop their skills and knowledge about new products and services;
- to organise employee participation in innovation projects: the company should organise internal innovation projects or participate in external projects - this will help stimulate innovative ideas and enable employees to create new products for the company.

One of the ways to stimulate innovation in Russian companies is the development in Russia of the concept of open innovation, which involves going beyond the organisation and interacting with external experts, start-ups, scientific and educational institutions to create new products, processes or services. However, it is worth noting that the open innovation model is still in its infancy in our country. To date, certain elements of the national innovation system have already been put in place: activities and institutions in the legal and financial fields, innovation infrastructure, etc., which create a favourable climate for innovation.

At the moment, only large companies are interested in the new business model. They want to increase their competitiveness through innovation, which involves improving existing products and technologies rather than creating new ones. It is necessary to extend the use of open innovation to small and medium-sized enterprises and to improve the interaction between all participants in the innovation process. To this end, the government has created a system of development institutions that provide financial, information and advisory support to innovative projects at all stages of the cycle. This system is called the ‘innovation lift’.

In addition, technology platforms act as a mechanism for interaction between participants in the innovation process. A technology platform is understood as a communication tool whose purpose is to intensify efforts aimed at creating promising commercial technologies, new products (services), attracting additional resources for research and development based on the participation of all stakeholders (business, science, government, civil society), improving the regulatory framework in the field of scientific, technical and innovative development.

Thanks to the technology platform, it is possible to build interaction to solve strategic problems of scientific and technological development between different organisations and institutions. To this end, each platform will identify research and development priorities, scientific cooperation mechanisms, consortia and training programmes, assess directions for the development of scientific infrastructure, and establish standards and certification systems.

In summary, the Russian market is constantly changing and companies that want to develop and grow must be prepared for constant changes in the environment in which they operate. In order to compete and succeed in the market, companies must not only improve their processes, but also innovate their products.

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The use of Digital Twins to improve the operational efficiency in the extractive industries

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Abstract

The article examines the impact of Digital Twins on the business processes of mining companies. Mining companies can optimise their operations, from stripping and mining to enrichment and transportation. By modelling different scenarios, identifying bottlenecks and making informed decisions, companies can improve resource efficiency, reduce downtime and increase productivity, making a positive impact on their operational efficiency. Predictive maintenance strategies implemented with the help of Digital Twins help increase efficiency by minimising unexpected equipment failures and maximising uptime.

The main technological effects of the use of Digital Twins in the mining industry, which affect the operational efficiency of the company, are: (1) an increase in the volume of output of commercial products after coal enrichment; (2) an increase in the coefficient of output to the production line of mining equipment.

These effects lead to an improvement in the operating efficiency of the mining company, which increases indicators such as EBITDA and cash balance at the end of the period. This impact on operating efficiency is achieved by increasing the volume of commercial products, improving the efficiency of production processes, and by reducing the fixed and operating costs of the business.

In order to assess the impact of the use of Digital Twin technology on mining companies, a methodology has been developed to assess the impact of the use of Digital Twin technology on mining companies. According to the results of the survey, a number of key production processes have been identified where the introduction of a Digital Twin is expected to have an impact.

As a result of the empirical study, the expected increase in EBITDA from the implementation of the Digital Twin was 28%, the actual increase in EBITDA over the study period was 21%. The expected increase in free cash at the end of the period was + 593 million rubles (+130%), the actual increase in free cash for the period under study was 441 million rubles (+96%).

The introduction of Digital Twins in mining companies has shown great potential for improving operational efficiency and solving complex challenges facing the industry.

Keywords: Digital Twin, digital transformation, business processes, operational efficiency, digital technologies.

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应用数字孪生提高采矿行业企业的运营效率

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简介

文章探讨了数字孪生对采矿企业业务流程的影响。采矿企业可以从开采和采矿开始，一直到选矿和运输，优化其运营流程。通过建模不同场景，识别瓶颈并做出合理决策，企业可以提高资源利用效率，缩短停工时间，提高生产力，从而对其运营效率产生积极影响。通过数字孪生实施的预测性维护策略有助于提高效率，通过最小化设备意外故障和最大化无故障运行时间来实现。

数字孪生在采矿业中对企业运营效率产生影响的关键技术效应包括：在煤炭精矿化后增加产品产量和提高采矿设备生产线性能系数。这些效应导致了采矿企业运营效率的改善，增加了EBITDA和期末现金余额等指标。这种对运营效率的影响是通过增加产品产量和提高生产过程效率以及减少企业固定和运营成本实现的。

作者开发了一种评估数字孪生技术对采矿企业影响的方法。根据调查结果，确定了一系列关键生产流程，并预期了数字孪生技术的实施效果。

根据进行的实证研究，预期的数字孪生技术引入带来的EBITDA增长率为28%，而实际上研究期间的EBITDA增长率为21%。预期期末自由现金余额增长为5.93亿卢布（增长130%），而实际上研究期间的自由现金余额增长为4.41亿卢布（增长96%）。

数字孪生技术在采矿企业的应用展示了提高运营效率和解决行业复杂问题的巨大潜力。

关键词：数字孪生、数字化转型、业务流程、运营效率、数字技术。

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Introduction

Managing a modern mining operation is a complex task that requires the use of a variety of methods and tools to achieve set goals and reduce costs. Modern trends in the development of production imply profound changes in the operating conditions of enterprises, such as the widespread introduction of new technologies and software, increasing costs of labour and material resources, the need for rapid restructuring of production processes to replace the product range, and the constant intensification of competition. These factors require an organisation's business processes to be flexible and able to adapt to changing conditions without compromising productivity.

The concept of digital twins can be useful for a company to solve the problems described above. It is worth noting that digital twins can be used not only to digitise physical objects, but also to perform analysis, planning, forecasting and modelling without the need for physical objects.

The use of digital twin technology can lead to changes in outdated process and organisational designs in the mining industry, which in turn can improve operational efficiency, increase productivity, improve safety, reduce costs and limit negative environmental impacts. In addition, the real-time data and analytics provided by digital twins can improve business decision-making by identifying patterns and trends in operations, making informed decisions and developing more effective strategies.

The findings and recommendations of the study can be applied to various industries and sectors undergoing similar changes as a result of the introduction of innovative digital technologies. As such, this work can contribute to the general field of digital transformation and broaden the understanding of how digital twin technology can be used to assess improvements in operational efficiency and sustainability.

1. Literature review

Digital twin technology is gaining popularity due to its ability to simulate the behaviour and operation of physical assets, processes and systems in a virtual environment. This technology enables companies to analyse and optimise their operations, reduce costs and increase efficiency.

A digital twin is a virtual copy of a physical asset, process or system that is used to simulate its behaviour and operation in a virtual environment. It is a combination of the physical and digital worlds where data from physical assets and processes is collected, analysed and modelled in a digital environment.

The concept of digital twins has been widely discussed and researched in recent years. However, there is no generally accepted definition of a digital twin. Different authors present different definitions of digital twins, but many of them have some drawbacks or limitations.

One of the earliest definitions of digital twins was presented by M. Greaves in his work 'Virtual Reality and the Transformation of Product Development' [Greaves, 2002]. He defined a digital twin as 'a virtual representation of a physical product or process used to understand and predict the performance characteristics of the product or process'. This definition focuses on the use of digital twins for product development and performance prediction. Since then, the concept has evolved and digital twins have become an integral part of Industry 4.0, where data-driven decision-making and optimisation are key success factors.

Another definition of digital twins has been proposed by the National Institute of Standards and Technology (NIST, USA) in its 2018 publication 'Taxonomy and Terminology for Cyber-Physical Systems'. NIST defines a digital twin as 'a virtual representation of a physical system or process that uses data to enable understanding, learning, and reasoning'. This definition emphasises the use of data to enable understanding and reasoning, which is important for many digital twin applications. However, it does not clearly define the purpose of using a digital twin or its relationship to the physical system it represents[1].

In 2018, Gartner introduced a more comprehensive definition of digital twins. According to it, a digital twin is 'a software representation of a physical object or system that simulates its physical properties, behaviour and dynamics in a virtual environment and can be used for analysis, prediction, monitoring and optimisation'[2]. This definition includes several important aspects of digital twins, such as their software representation, simulation of physical properties, and reuse. However, it does not address the use of digital twins for learning or reasoning, which is a key aspect of the NIST definition.

In 2021, the authors of [Tao et al., 2019] presented a more detailed classification of digital twins, identifying five types based on their characteristics and functions: analytical digital twins, cyber-physical digital twins, hybrid digital twins, physics-based digital twins, and data-driven digital twins. This classification provides a deeper understanding of the different types of digital twins and their applications. However, it may be too complex for some users and does not take into account the purpose of digital twins or their relationship to physical systems.

According to the definition given in [Borovkov et al., 2018], a digital twin of an enterprise is a collection of data in various forms of representation (drawings, diagrams, documentation, historical archives, algorithms and

[1] NIST Trustworthy and Responsible AI NIST AI 100-2e2023. https://nvlpubs.nist.gov/nistpubs/ai/NIST.AI.100-2e2023.pdf.
[2] Top 10 Strategic Technology Trends for 2018: Digital Twins. https://www.gartner.com/en/documents/3867164.

software of control systems, complex multidisciplinary mathematical models with a high degree of adequacy to real materials, structures, and physical and mechanical processes) describing the dynamic behaviour of an object and its components over time.

According to M.V. Samosudov, a digital twin of an enterprise is a product of digitalisation (digital copy) of the production processes of an enterprise, which helps to optimise activities and increase their efficiency [Samosudov, 2018].

The concept of a ‘digital twin of a company’ should be distinguished from the concept of a ‘digital twin of a product’.

According to the definition of R.A. Isaev, a digital twin of a product is a system consisting of a digital model of a product and two-way information links with the product (if there is a product) and/or its components [Isaev, 2023, p. 44].

In general, the understanding of the digital twin is rather vague. The study of different opinions and materials made it possible to identify a number of approaches to defining the concept of ‘a digital twin’ (Table 1).

2. Concept and classification of digital twins

In general, existing definitions of digital twins have some shortcomings or limitations. Some focus on specific aspects of digital twins, such as their use for product development or data analysis, while others may be too complex or vague. A more precise and comprehensive definition of digital twins should include the following elements:

- a digital twin is a software representation of a physical system or process [Karapetyan et al., 2020];
- a digital twin simulates the physical properties, behaviour and dynamics of a physical system or process in a virtual environment [Kritzinger et al., 2018];
- a digital twin is used for analysis, prediction, monitoring, optimisation, learning or reasoning [Merdan et al., 2022];
- a digital twin is closely linked to the physical system or process it represents and can be updated with data from sensors, IoT devices or other sources [Barricelli et al., 2019].

Including these elements provides a more complete understanding of what a digital twin is and how it can be used in different applications. This definition also allows for flexibility in the specific types and functions of digital twins, while emphasising their relationship to physical systems and processes.

The essence of digital twins lies in their ability to replicate the behaviour and operation of physical assets and processes in a digital environment. The essence of digital twins lies in their ability to replicate the behaviour and operation of physical assets and processes in a digital environment. Digital twins use real-time data from sensors, IoT devices and other sources to simulate the behaviour and operation of physical assets and processes in a virtual environment.

There are several ways of classifying digital twins, depending on the criteria used. These are some of the most common:

1) based on the application in which they are used. For example, there are digital twins for manufacturing, healthcare, finance and transportation [Arenkov et al., 2019];

2) by level of detail. Some digital twins provide a high-level overview of the system, while others provide detailed information about individual components and processes [Barricelli et al., 2019];

3) based on the data source they use. Some digital twins use data from sensors and other physical sources, while others use data from computer systems and other digital sources [Bao, 2020];

4) by level of sophistication. Some digital twins are relatively simple, modelling only a few components or processes, while others are very complex, modelling entire systems [Grieves, Vickers, 2017].

Digital twins are also classified according to their level of maturity (Table 2).

Let’s take a closer look at each level.

The first level is the pre-digital twin, or the precursor to the digital twin. A highly accurate model created before the digital shadow of a physical object appears. In the scientific literature, it is also referred to as the ‘digital twin of the design phase’.

The second stage is a classic digital twin. Appears at the stage when the 'physical object - digital twin’ pair has already been formed and the digital twin model is refined based on the digital shadow.

The third level is the adaptive digital twin. The models used in this digital twin level are constantly updated in real time based on data transmitted from the physical site. Such a digital twin is already capable of real-time planning and decision-making during operation or maintenance.

The fourth level is an intelligent digital twin. In addition to the characteristics of a third-level digital twin, the fourth level adds the capability of machine learning, i.e. such a digital twin can recognise objects and patterns found in the information environment. This means that the digital twin already has enough autonomy to analyse data about the performance, health and maintenance of the physical asset in more detail.

Digital twins are therefore a tool that can help businesses improve efficiency, productivity and profitability. By creating virtual models of physical systems, companies can optimise their processes, predict future outcomes and identify areas for improvement. By

Table 1
Scientific approaches to defining a Digital Twin

Approach	Features and sample definitions
General approach	A digital twin is a digital copy of a living or non-living physical entity. By connecting the physical and virtual worlds, data is transferred, allowing the virtual entity to exist simultaneously with the physical entity [Saddik, 2018].
Virtual model	A digital twin is a digital dynamic model in the virtual world that fully corresponds to its physical object in the real world, with the ability to simulate its properties, behaviour, lifecycle and performance [Zhuang et al., 2018]. A digital twin is the modelling of a production system based on simulation rules as part of forecasting and production planning; a digital representation of an active unique product or unique product-service system, including its selected characteristics, properties, conditions and behaviour through models, information as well as data within one or more phases of the life cycle [Stark, Damerau, 2018].
Data exchange tool	The defined approach emphasises the need to exchange information between two spaces through sensors, models and actuators [Negri et al., 2017]. A digital twin is a virtual dynamic representation of a physical system that is connected to it for bi-directional data exchange throughout its life cycle [Trauer et al., 2020].
Cyber-physical system element	A digital twin is an exact virtual copy of a physical system that truly represents all of its functionality, or an element of a cyber-physical system that represents data about the production system for employees [Alam, Saddik, 2017].
Digital technology complex	The digital twin is a set of digital technologies that use approaches from statistical analysis, machine learning, chemistry, physics, control theory, reliability theory, queuing theory, numerical modelling, and optimisation.
Functional approach	A digital twin is a learning system made up of a set of mathematical models of varying complexity, refined on the basis of the results of full-scale experiments, which makes it possible to obtain the first full-scale sample of a product that meets the requirements of the technical specifications and also predicts its behaviour throughout its life cycle. A digital twin involves using the best available physical models, sensors and historical data to accurately reflect the life of its counterpart - a physical object [Glaessgen, Stargel, 2012]. The digital twin is designed to reflect all manufacturing defects and updates, taking into account wear and tear from use, and has intelligent control functions

Source: compiled by the author.

understanding the different types and classifications of digital twins, organisations can choose the approach that best suits their needs and make the most of this powerful technology.

It is worth noting that on 1 January 2022 the world's first national standard in the field of digital twins was introduced in the Russian Federation - GOST R 57700.37-2021 'Computer models and simulation. Digital twins of products. General provisions', which brings certainty to the terminology and specifies the technical requirements for solutions of this class. It directly states: 'A digital twin is a system consisting of a digital model of a product and two-way information links with the product (if there is a product) and/or its components'[3].

Let's summarise and differentiate the definition of the term 'digital twin' in Fig. 1.

Thus, the evolution of the term continues, and the digital twin has not outlived the characteristics of its predecessor. In addition, the definition of a digital twin may change as technologies change.

3. Applications of digital twins

Today, digital twins are increasingly in demand in industry. This trend is being driven primarily by large enterprises in the oil and gas and mining industries, i.e. industries with continuous production. Digital twin technology makes it possible to increase output or reduce wear and energy consumption without having to replace and rebuild expensive industrial equipment - a significant amount of money that covers all the risks and costs of implementing an innovative solution in a matter of months.

There are many examples of digital twins being used in the mining industry at all stages (extraction, transport and processing), helping to reduce the company's capital costs and speed up production. This technology is particularly relevant for mining in hard-to-reach areas.

Digital twins are increasingly being used in the mining industry to optimise mining operations, reduce costs and improve safety. The coal industry is no exception and there are several use cases for digital twins in this sector.

One of the main applications of digital twins in the coal mining industry is equipment monitoring and maintenance. By creating a digital twin of equipment, operators can monitor equipment performance, identify potential problems and schedule maintenance activities. This can minimise downtime, reduce maintenance costs and improve safety. For example, Joy Global (now Komatsu Mining Corp.) has developed a digital twin of its underground longwall system that allows operators to

[3] GOST R 57700.37-2021 Computer modelling and simulation. Digital twins of products. General regulations. https://files.stroyinf.ru/Data/758/75810.pdf?ysclid=lte5z2k0n4828230466.

Table 2
Maturity level classification of Digital Twins

Level	Level of model complexity	Physical object	Receiving data from a physical twin
1. Predigital twin	Virtual model with focus on technology/technical risk mitigation	Does not exist	Cannot apply
2. Digital twin	Virtual model of a physical object	Exists	Technical condition, performance, updating, maintenance
3. Adaptive digital twin	Virtual model of a physical object with an adaptive interface	Exists	Technical condition, performance, updating, maintenance; real-time data update
4. Intelligent digital twin	Virtual model of a physical object with adaptive interface and training	Exists	Technical condition, performance, updating, maintenance; update in batch update mode

Source: compiled by the author.

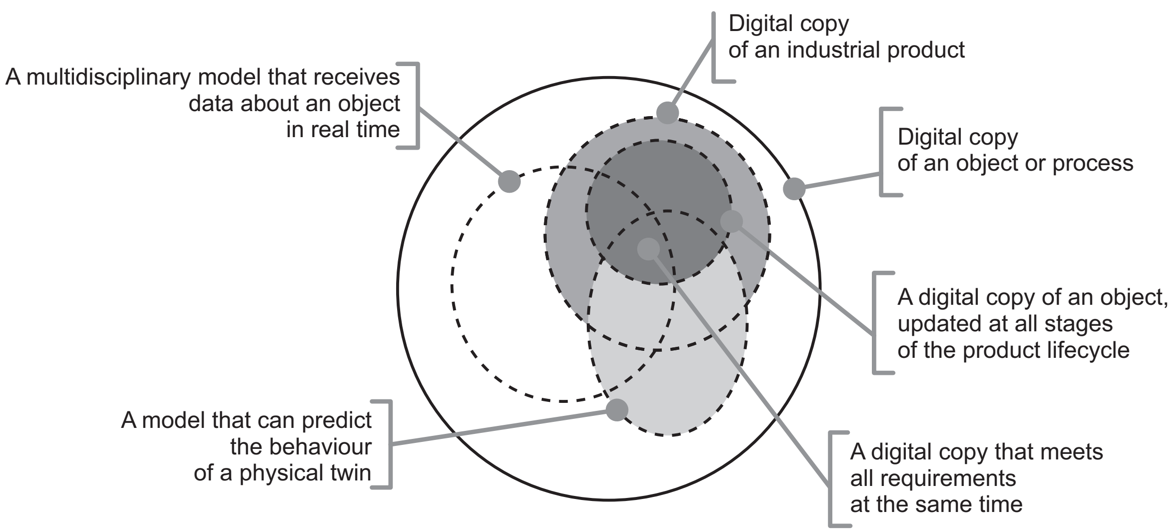
monitor equipment performance in real time and predict maintenance needs[4].

Digital twins can also be used to optimise mine planning and design. By creating a digital twin of a mine site, operators can simulate different scenarios and assess the impact of various factors on mining operations. This helps identify inefficiencies and opportunities for improvement, as well as optimising equipment use and minimising waste. Mining software company Maptek, for example, offers a digital twin solution that allows mines to be planned and designed in 3D[5].

Digital twins can also be used for environmental monitoring in the coal mining industry. By creating a digital twin of a mine site, operators can monitor air and water quality, monitor the environmental impact of mining operations and plan remediation efforts. This helps ensure compliance with environmental regulations and improves the sustainability of the business. Consulting firm GHD, for example, has developed a digital twin of a coal mine in Australia to monitor environmental factors in real time[6].

Digital twins can also be used for safety management in the coal mining industry. By creating a digital twin of

Fig. 1. The limits of the 'Digital Twin' definition



Source: compiled by the author.

[4] Mining technology. Digital transformation Anglo American. 21.11.2019. https://www.mining-technology.com/features/anglo-americans-digital-transformation/.
[5] Id.
[6] https://www.ghd.com/en/expertise/digital/digital-intelligence.

a mine site, operators can model potential safety risks and evaluate the effectiveness of safety protocols. This helps to identify areas for improvement and improve worker safety. For example, engineering and technology company Sandvik has developed a digital twin of an underground mine that allows operators to assess safety risks and plan safety protocols[7].

Digital twins can also be used for training and simulation in the coal mining industry. By creating a digital twin of a mine site, operators can simulate different scenarios and train workers on safety protocols and work procedures. This can improve safety and efficiency, minimise downtime and reduce costs. Mining technology company Immersive Technologies, for example, offers a digital twin solution that enables training and simulation of various mining scenarios[8].

Digital twins offer a range of potential applications in the coal mining industry, including equipment monitoring and maintenance, mine planning and design, environmental monitoring, safety management, and training and simulation. By harnessing these capabilities, coal mining companies can optimise operations, reduce costs, improve safety and achieve sustainability. In recent years, several coal mining companies have introduced digital twins into their operations.

BHP Billiton, one of the world's largest mining companies, has implemented a digital twin at its Olympic Dam mine in South Australia. The digital twin contains real-time data on mine operations, including equipment and processes, and is used to optimise production, reduce downtime and improve safety. The digital twin also allows BHP Billiton to simulate different scenarios and test the impact of changes before implementing them in the real mine. This has led to significant improvements in productivity and safety, as well as reduced costs[9].

Rio Tinto has implemented digital twins at several of its coal mining operations. One example is the Hail Creek mine in Queensland, Australia, where a digital twin was used to improve the efficiency of the mine's concentrator plant. The digital twin has enabled Rio Tinto to optimise plant operations, reduce downtime and improve the quality of the coal produced. The digital twin also allowed Rio Tinto to simulate different scenarios and test the impact of changes before implementing them in the real factory[10].

Peabody Energy, one of the world's largest coal mining companies, has implemented a digital twin of its North Antelope Rochelle mine in Wyoming, USA. The digital twin contains real-time data about a mine's equipment, processes and environment and is used to optimise production, reduce downtime and improve safety. The digital twin also allows Peabody Energy to simulate different scenarios and test the impact of changes before implementing them in the real mine. This innovation has led to significant improvements in productivity and safety, as well as reduced costs[11].

Glencore, a multinational mining company, has implemented digital twins in several of its coal mining operations. One example is the Bulga mine in New South Wales, Australia, where a digital twin has been used to optimise mine production and reduce downtime. The digital twin allowed Glencore to simulate different scenarios and test the impact of changes before implementing them in the real mine, resulting in significant improvements in productivity and safety, as well as cost reductions[12].

Anglo American, a global mining company, has implemented digital twins in several of its mining operations, including coal mines. One example is the Moranbah North mine in Queensland, Australia, where a digital twin was used to optimise the mine's ventilation system. The digital twin allowed *Anglo American* to simulate different scenarios and test the impact of changes before implementing them in a real mine, significantly improving safety and productivity[13].

The above examples illustrate the benefits of implementing digital twins in coal mining operations, which include increased productivity, reduced downtime, improved safety and cost savings. The above examples illustrate the benefits of implementing digital twins in coal mining operations, which include increased productivity, reduced downtime, improved safety and cost savings.

Digital twins are used in various business processes of coal mining companies to improve operational efficiency, reduce costs and improve safety. Some of the key business processes where digital twins are used include:

- geological exploration - digital twins can be used to create virtual models of the geology of the mining area, helping to identify potential mineral deposits and optimise exploration processes;
- design and planning of open pits and mines - digital twins can be used to create virtual models of the mine site to optimise the design and planning of the mine. This includes the design of infrastructure such as roads, power lines and water pipes, as well as the layout of the mine itself;
- optimisation of equipment performance - digital twins can be used to create virtual models of mining equipment, allowing operators to optimise equipment performance and minimise downtime.

[7] Mining technology… https://www.mining-technology.com/features/anglo-americans-digital-transformation/.
[8] Id.
[9] BHP Billiton 2021 Annual Report. https://www.bhp.com/media-and-insightsreports-and-presentations/annual-reports.
[10] Rio Tinto. Innovation in mining. https://www.riotinto.com/invest/capital-programs-and-projects/rio-tinto-innovation-in-mining.
[11] Peabody Energy. Digital twin. https://www.peabodyenergy.com/sustainability/safety/d.
[12] https://www.glencore.com/publications.
[13] Anglo American will expand its use of digital twins to optimise operations. https://www.mining-technology.com/news/anglo-american-digital-twins-optimise-operations/.

For example, digital twins can be used to predict equipment failures before they occur, allowing maintenance to be planned in advance;
- production optimisation - digital twins can be used to create virtual models of the production process, allowing operators to optimise flow and minimise waste. This includes optimising blasting, loading, transport and processing;
- safety - digital twins can be used to create virtual models of a mine site, allowing operators to identify potential safety hazards and take action to mitigate them. For example, digital twins can simulate emergency scenarios, allowing operators to test emergency response plans in a safe and controlled environment.

Optimisation has the greatest impact on the operational efficiency of a coal mine:
- predictive maintenance of specialised equipment;
- transportation of coal and rock mass;
- warehouse management;
- design of the mine site, resulting in a reduction in the stripping ratio;
- coal enrichment.

Digital twins can help coal mining and processing companies to optimise their processes, reduce costs, increase productivity and improve safety. Although the use of digital twins is a complex and time-consuming process, their implementation in manufacturing business processes is preferable and effective because the expected effect of using a digital twin is more predictable.

4. Research methodology

The implementation of a mining company's digital twin is expected to have a number of positive effects that can significantly improve operational efficiency and overall productivity. These expected effects include: an increase in production volumes, an increase in plant productivity and a reduction in the cost of producing marketable products.

To assess the potential impact of digital twins on mining operations, a survey was conducted using a methodology that identified key business processes from an asset management perspective and characteristics of open pit mines.

The study consisted of several stages. The first stage was to select mining operations that were already using digital twins or considering using them in the future.

The following companies were included in the sample: 'Antratsit Invest Proyekt', Siberian Coal Energy Company, 'Vorkutaugol', 'Meltek', 'Amurugol', New Mining Management Company ('Sibuglemet'), 'Beringpromugol' и 'Karakan Invest'. Each of these companies operates an open pit mine, so we can assume that the survey results are comparable.

The next step was to identify key business processes across these assets that management felt should be combined with digital twins. These processes included stripping, drilling and blasting, mining, reserve management, coal preparation and processing, and rock and coal haulage.

The survey also sought to identify specific ways in which digital twins could optimise these business processes. These include: geological exploration, mine design and planning, equipment operation optimisation, production optimisation and industrial safety.

To assess the expected impact of digital twins on mining companies, the survey focused on the existing/expected impact of implementation and the identification of key production processes (Table 3).

Employees of coal mining companies, such as Siberian Coal Energy Company, 'Antratsit Invest Proyekt', 'Meltek', 'Sibuglemet', etc. (Fig. 2).

Each of the respondents holds a management position at the level of Deputy Director General and above:
– has a scientific interest in the field of digital technologies in coal mining;
– has an idea or knows of examples of the use of digital twins in mining companies;
– potentially interested in testing digital twins;
– has a clear understanding of the production processes used by mining companies.

Based on the study of the impact of digital twins on coal mining companies, the following conclusions can be drawn:

1. The main limiting factors, from the point of view of the top management of coal mining companies, are: difficulties in purchasing mining equipment, coal quality, geology and seasonality of production (Fig. 3).

However, difficulties in acquiring mining equipment are a situational problem caused by external macroeconomic and geopolitical factors in 2022-2023. At the same time, the quality of the coal, the geology and the territorial location of production are among the constant factors influencing business activities.

2. Only two of the companies surveyed use digital twins in their sections: 'Invest Proyekt' and Siberian Coal Energy Company. At the same time, the head of Siberian Coal Energy Company commented, 'The digital twin is not being used at all SUEK fields because all the fields are quite old and have infrastructure built under the USSR; many of the company's assets are nearing depletion. Digital twins were only used in areas where there was potential for long-term development and a process of improvement.'

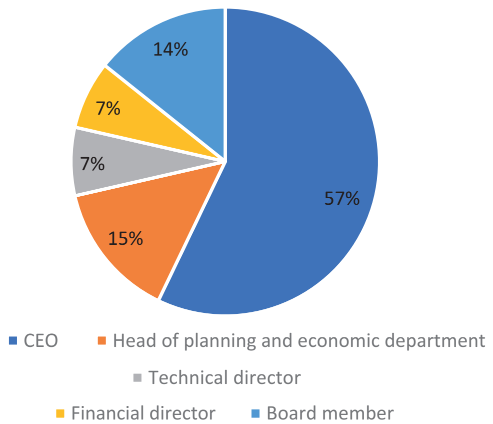
We can therefore conclude that, despite the improvements expected from the introduction of this technology, it is only being used in cases where there is an expectation of a long-term effect from its implementation.

Table 3
The survey form in the mining company

Question	Answer
Full name	
Company name	
Position	CEO
	Financial director
	Head of planning and economic department
	Technical director
	Board member
	Other
Coal production volumes (thousand tons/year)	Up to 1000
	1000–2000
	2000–3500
	3500–6500
	Over 6500
Do you have a processing plant?	Yes/No
What are the main limiting factors to your activities? (You can choose more than one answer)	Geology
	Coal quality
	Geographical location (seasonality)
	Stock depletion
	Difficulties in obtaining the necessary mining equipment
	Sales markets
FCA coal cost (USD/tonne)	
Do you use digital twin technology on your sites?	Yes/No
If not, are you considering/ have you considered such an opportunity for yourself?	Yes/No
Which business processes at your plant have the greatest impact on costs?	Overburden
	Drilling and blasting works
	Mineral extraction tax
	Coal storage, crushing and loading at the open pit Enrichment
	Road maintenance
	Maintenance of separate divisions (warehouses, household infrastructure)
	General production
	Maintenance of railway infrastructure
	Transportation of products to the railway station warehouse
	Coal storage and loading at the railway station
	Wagon supply and cleaning
	International certification (SGS, INCOLAB)
	Management company, property tax
What business process do you think is key to your asset?	Intelligence service
	Development
	Production
	Transportation
	Enrichment
	Warehousing
	Marketing
For which processes do you find it most useful to use digital twins?	Geological exploration
	Design and planning
	Optimisation of equipment operation
	Production optimisation
	Industrial safety
What impact do you expect the implementation to have?	Reducing costs by optimising variable costs
	Increased production volumes due to higher equipment productivity
	Improved industrial safety
	Improving the quality of planning and design
By what percentage do you expect production volumes to increase?	
By what percentage do you expect the cost of commercial products to fall?	
By what percentage do you expect the project's annual EBITDA to grow?	
Comment	

Source: compiled by the author.

Fig. 2. Positions of the employees interviewed



Source: compiled by the author.

This hypothesis is confirmed by the practice of 'Antratsit Invest Proyekt,' LLC. The organisation's chief technologist notes, 'The digital twin has been implemented relatively recently, and the company is actively increasing production volumes and training production staff. Not all processes can be influenced by a digital twin. In the future, however, it will significantly reduce the cost of mined coal, which will be particularly noticeable when production volumes increase to 6.5 million tonnes per year. It was the right decision to start implementing it at the business development stage, as it helps to identify and focus management attention on bottlenecks in ongoing processes, but it will take another two to three years for the technology to reach its full potential.'

We can therefore conclude that it is advisable to introduce a digital twin at the stage of business development, but at the same time this tool needs time to unfold its potential and have a significant impact on the company's business processes.

3. Among companies that do not use digital twin technologies, opinions are divided on the advisability of implementing them.

The management of Amurugol', Karakan Invest and Vorkutaugol' do not believe that the introduction of digital twins in their companies will have a significant effect.

AmurUgol' and KarakanInvest do not consider the possibility of introducing a digital twin due to the fact that lignite is mined and sold on the territory of the Russian Federation, and the open pit mines have good geology, which makes it possible to mine coal with a low stripping ratio, which ensures low costs.

VorkutaUgol' has an open-cast mine that produces less than 400,000 tonnes of coal a year, and the main production takes place in the Komsomolskaya mine, the largest and deepest mine since the times of the USSR. A digital twin is not used there for the same reasons that Siberian Coal Energy Company has not implemented a digital twin at all its sites.

At the same time, New Mining Management Company (Sibuglemet), Meltek and Beringpromugol' are planning to introduce a digital twin of their mines.

New Mining Management Company anticipates the development of the new Mrassky coking coal site and is considering the integration of a digital twin to improve operational efficiency. From a management perspective, there are two key issues that the implementation of a digital twin will help to address:

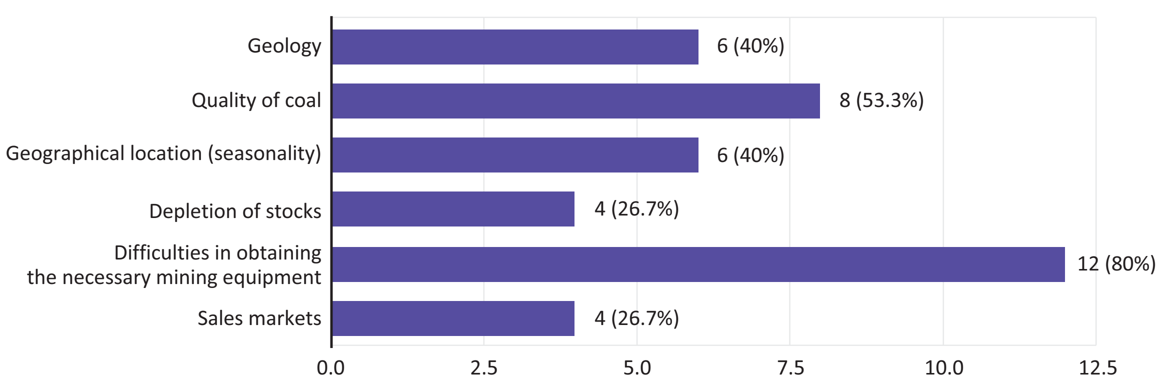
– the new site is combined with the main field, which will be depleted by the end of 2023, increasing the distance for overburden transport and mining;
– the high spontaneous ignition of coal requires better organisation of storage operations.

The introduction of technology in the working areas is impractical due to the depletion of reserves in the main field in 2023 and in the mines in 2025.

Meltek and Beringpromugol are exploring the possibility of introducing a digital twin at operating coal mines.

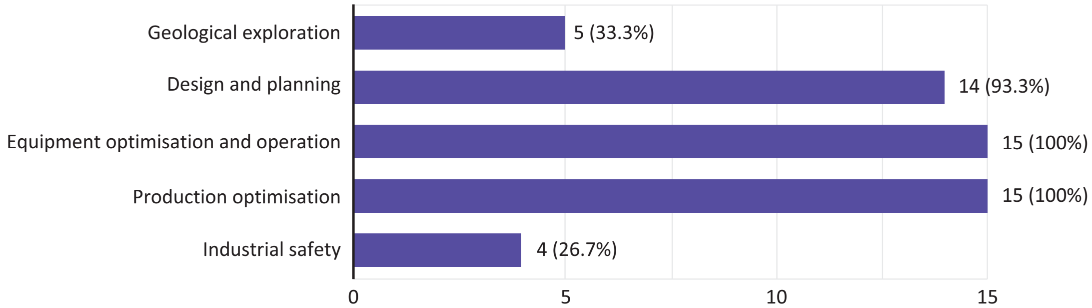
Meltek faces geological constraints that require significant investment to prepare the mine for large-scale production. According to the company's CEO, 'A digital twin could increase the productivity of the rock stripping equipment; currently the stripping ratio is around 12, which is almost the same as the stripping ratio in mining.' Meltek plans to develop its facility to produce 10 million tonnes of coal per year and, like New Mining Management

Fig. 3. Obstacles to the introduction of Digital Twins



Source: compiled by the author.

Fig. 4. Priority areas for the application of Digital Twins



Source: compiled by the author.

Company, sees the digital twin as a tool to help develop its new internal investment project.

Beringpromugol is also an investment project that will reach a production volume of 1.2 million tonnes of coking and thermal coal per year by 2022. By 2030, the plant plans to increase its production volume to 6 million tonnes per year, but it has very different needs, for which it plans to integrate a digital twin. The coal is mined throughout the year, but is sold through a seasonal port that can only handle coal during the summer season. Optimising the road transport logistics of commercial products from the mine to the port will enable increased sales volumes. It will also be necessary to integrate a digital twin into the port to optimise shipments.

As a result, each organisation will have its own unique characteristics when identifying the need to integrate a digital twin, and will expect different benefits from its implementation. At the same time, there is a logic in which management considers the introduction of this technology in promising investment projects with relatively high coal costs to be inappropriate at the moment due to insufficient debugging of key business processes.

4. Key business processes for which the use of digital twins is recommended include optimising equipment operation and optimising production (Fig. 4).

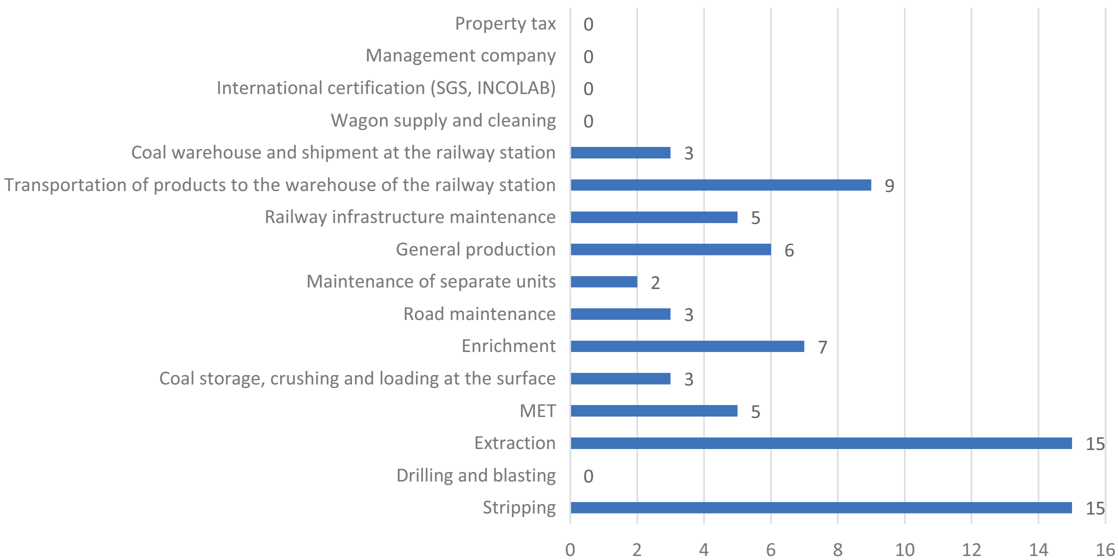
At the same time, respondents expect that the main impact of implementing a digital twin will be to reduce the cost of commercial products by optimising variable costs and increasing production volumes without additional capital investment in specialised equipment, which together will have a positive impact on the operational efficiency of the company.

Mine design and planning is also a promising area for implementing a digital twin, but this process has less impact on the operational efficiency of a mining company.

5. During the survey, coal mine management identified processes such as stripping, mining, beneficiation and transportation of coal and rock as key and having the greatest impact on the operational efficiency of a coal mine (Fig. 5).

The digital twin has the potential to influence and improve the efficiency of these manufacturing processes. As evidence of this hypothesis, we can cite an example provided by the head of Antratsit Invest Proyekt. ‘The

Fig. 5. The most significant business processes for cost formation



Source: compiled by the author.

digital twin has had the greatest impact by optimising the transport of coal from the mine stockyard to the rail stockyard (75km), increasing the number of daily road hauls from four to five through route optimisation and thus increasing the volume of coal shipments. The digital twin has also been integrated into the coal enrichment process, virtually eliminating middle fraction coal.'

6. All of the companies surveyed expect to see a significant improvement in their financial results as a result of introducing a digital twin into their operations. The average expert estimate of annual EBITDA growth was 14%, driven by the full implementation of a digital twin of the business and the debugging of business processes. The range of annual EBITDA growth from the implementation of a digital twin among respondents was 6.5% to 30%, as each expert assessed this effect based on their company's unique external parameters and the degree of streamlined business and production processes at that time.

The operational efficiency effects of using a digital twin can be divided into effects that affect production volumes and effects that reduce fixed costs, depending on the production processes used. The most important and common production processes have been identified as stripping, mining, processing and transportation of overburden and coal. Introducing digital twins into these processes means optimising equipment operation and production.

The main impacts on production processes that affect the operational efficiency of mining companies are therefore: increasing the productivity of mining equipment, increasing the yield of coal after the beneficiation process, and increasing the productivity of equipment used to transport marketable products.

5. Methodology for assessing the impact of a digital twin on the operational efficiency of a mining company

Based on the research conducted, it is possible to make the necessary key assumptions to assess the complex effect of using a digital twin in coal mining companies. The research conducted allows us to make assumptions about the potential impact of a digital twin on a coal mining company and to determine the specific coefficients of the potential impact on the production processes of coal mining companies, which can be used to model the expected impact on operational efficiency.

In order to identify these specific coefficients, it is necessary to resort to the method of weighting expert judgements: the weights are distributed according to the effects expected by the respondents (Table 4). The weights are distributed to take into account the size of the company and the position of the expert to further determine the weighted average of the effect, as the sample of respondents includes both large holdings, such as Siberian Coal Energy Company, and assets operating at a coal mine, such as Antratsit Invest Proyekt, LLC.

Table 4
Weights for the placement of points

Parameter	Points
Up to 1000	1
1000–2000	2
2000–3500	3
3500–6500	4
Over 6500	5

Parameter	Points
CEO	4
Financial director	2
Head of planning and economic department	1
Technical director	3
Board member	4

It is also necessary to take into account the actual results of the Siberian Coal Energy Company, Antratsit Invest Proyekt, Vostokugol' and Mechel-mining, since this information reports on the effects that have already occurred within the first three years of using digital twin technology (Table 5).

Once the points have been allocated, it is necessary to identify the weighted average results that will be applied as an assumption to the company for which the digital twin integration is planned:

$$S = \frac{\sum_m^n (V1n + V2n) \times Qn}{\sum_m^n (V1 + V2)},$$

where $S1$ - is the weighted average expected increase in the coefficient of reaching the productivity line of mining equipment - 8.4%, $S2$ - is the weighted average expected increase in the output of marketable products after enrichment - 5.4%, $S3$ - is the weighted average expected increase in the coefficient of reaching the productivity line of dump trucks carrying out transport of coal from the warehouse at the open pit to the warehouse at the railway station - 5.1%.

Having obtained the specific coefficients S1, S2, S3, which reflect the expected impact of the use of a digital twin on a mining company, it is necessary to carry out a series of steps to assess the impact of the use of a digital twin on operational efficiency.

Step 1. Creation of a financial and economic model of the company

The financial and economic model must include a detailed calculation of the productivity of specialised equipment and the operation of mining complexes. Such a calculation will make it possible to determine possible production volumes according to the productivity of mining complexes and to identify changes in the on-line coefficient due to the integration of a digital twin.

A similar calculation is used to determine the efficiency of transporting commercial products from the open pit warehouse to the rail yard warehouse to determine the productivity of the dump trucks that reach the line.

To analyse the effect of the introduction of a digital twin in the operation of a washing plant, it is sufficient

Table 5
Ranking of the expected effects of Digital Twin usage

Company	Position	Extraction volumes (thousand tonnes/year)	*V1*	*V2*	*Q1 (%)*	*Q2 (%)*	*Q3 (%)*
Antratsit Invest Proyekt	Board member	1000–2000	4	2	10,0	6,0	6,0
Antratsit Invest Proyekt	Financial director	1000–2000	2	2	7,5	4,0	4,0
Antratsit Invest Proyekt	CEO	1000–2000	4	2	15,0	7,2	8,0
Antratsit Invest Proyekt	Head of planning and economic department	1000–2000	1	2	10,0	7,0	6,0
Antratsit Invest Proyekt	Technical director	1000–2000	3	2	8,5	6,0	6,0
Antratsit Invest Proyekt	Board memeber	1000–2000	4	2	10,0	7,5	8,0
Siberian Energy Company	Head of planning and economic department	Over 6500	2	5	10,0	6,5	4,0
Siberian Energy Company	CEO	Over 6500	4	5	8,5	5,5	8,0
Vorkutaugol’	CEO	Up to 400 000	4	1	6,5	2,5	4,0
New Mining Management Company	CEO	Over 6500	4	5	15,0	8,0	3,0
Karakan Invest	CEO	3500–6500	4	4	10,0	4,5	5,0
Meltek	CEO	3500–6500	4	4	12,5	6,5	6,0
Meltek	CEO	3500–6500	4	4	4,5	8,5	4,0
Amurugol’	CEO	2000–3500	4	3	7,5	4,5	3,0
Beringpromugol’	CEO	1000–2000	4	2	8,0	12,0	5,0
Implementation practice							
Siberian Coal Energy Company		Over 6500	8	5	4,5	3,5	6,0
Antratsit Invest Proyekt		1000–2000	8	2	6,0	4,0	4,3
Vostokugol’		Over 6500	8	5	7,5	—	5,4
Mechel-mining		Over 6500	8	5	5,5	6,5	3,2

Note. *V*1 – weight by position / Weight for factual information; *V*2 – weight by production volume; *Q*1 – expected increase in online productivity of mining equipment; *Q*2 – expected increase in marketable product yield after enrichment; *Q*3 – creduce transportation distances.

Source: compiled by the author.

to highlight in a separate line the yield coefficient of the enriched coal sent for resale.

Step 2. Application of the previously calculated coefficients S1, S2 and S3 to the compiled production processes

The outcome of this phase will be to determine the expected impact of the use of a digital twin on production processes, and to further contribute to changes in production and sales volumes.

Step 3. Calculation of total operating expenses incurred during the year

The result of this stage will be an indicator in the form of a changed specific cost of 1 tonne of commercial products, which can be compared with the cost of 1 tonne of commercial products without the use of a digital twin, thus identifying the specific effect of introducing a digital twin per 1 tonne of commercial products.

Step 4. Preparation of P&L and CF to determine changes in annual EBITDA and cash flow of the company at the end of the year

The result of this phase is an assessment of the operational efficiency of the mining company using a digital twin.

Step 5. It is necessary to compare the financial result with the result of the expected effects of introducing a digital twin into the production processes and without it, thus calculating the effect of introducing a digital twin on operational efficiency

The outcome of this phase will be the desired assessment of the impact of using a digital twin on the operational efficiency of a mining company.

This calculation method allows:

1) to recalculate possible production volumes according to the productivity of special equipment;
2) to identify the lack of equipment capacity at the plant, both at the mining stage and at the stage of transporting coal from the coal stockyard at the open pit to the coal stockyard at the railway station;
3) to regulate the coal yield after enrichment.

It is therefore possible to assess the expected impact of the introduction of digital twins in mining companies on business processes related to the production of commercial products (optimisation of equipment operation, optimisation of production) by introducing specific coefficients. These include the weighted average expected increase in the coefficient of reaching the productivity line of mining equipment; the weighted average expected increase in the yield of marketable products after enrichment; the weighted average expected increase in the coefficient of performance of dump trucks transporting coal from the open pit to the stockyard at the railway station.

6. Calculation of the complex effect of the introduction of a digital twin at Anthratsit Invest Proyekt, LLC

In order to verify the relevance of the developed methodology for assessing the impact of the use of digital twin technology on the operational efficiency of mining companies, it is proposed to consider the period from the second quarter of 2022 to the first quarter of 2023 (hereinafter referred to as the study period), since it is during this period that the implementation of the digital twin began to have an impact on the operational efficiency of this coal mining company.

Firstly, it is necessary to calculate the cleared performance of special equipment from the digital twin. It is proposed to use the performance of the first quarter of 2022 as an indicator, as the impact of the introduction of the digital twin will not have been felt during this period.

The productivity of mining complexes as of the first quarter of 2022 is shown in Table 6.

Thus, in 12 months the existing mining complexes can provide a volume of stripping of coal rock - 8,064 thousand m3 and a production volume of 1,613 thousand tonnes of coal, which corresponds to the stripping coefficient for a given volume of rock (the stripping coefficient is 5). It is confirmed by the IMC report and the opinion of McKinsey&Company consultants.

Yield after coal enrichment as of Q1 2022 was 68%. Accordingly, the volume of sales of commercial products for 12 months could not exceed 1097 thousand tonnes of coal.

The existing 38-tonne SHACMAN dump trucks made four trips a day to transport the coal from the open-cast mine stockpile to the stockpile at the railway station, with an annual capacity to transport 1094,000 tonnes of coal for sale.

Based on these inputs, it is possible to make an assessment of the operational efficiency of Antratsit Invest Proyekt, LLC without using a digital twin (Table 7).

Thus, EBITDA for the period under review without digital twin amounted to 1,662,141 thousand rubles. The cash balance at the end of the study period without digital twin amounted to 457,490 thousand roubles.

It is then necessary to apply the previously calculated coefficients S1, S2, S3 to the model (Table 8).

Thus, in 12 months, the existing mining complexes are able to extract 8741 thousand m3 of coal and produce 1740 thousand tonnes of coal, which corresponds to the extraction coefficient for a given volume of rock (the extraction coefficient is 5).

The yield after coal enrichment will be 73.2%, taking into account the expected increase in efficiency due to the introduction of a digital twin; accordingly, the volume of sales of commercial products over a 12-month period could not exceed 1274 thousand tonnes of coal.

The existing 38-tonne SHACMAN dump trucks will make five trips a day to transport coal from the open-cast mine stockpile to the stockpile at the railway station, and taking into account the expected increase in efficiency from the introduction of a digital twin, the annual capacity to transport coal for sale will be 1,368,000 tonnes of coal.

Based on these inputs, it is possible to make an assessment of the operational efficiency of using the Anthratsit Invest Proyekt digital twin (Table 9).

Thus, the expected EBITDA of the study period after the implementation of the digital twin is 2,133,971 thousand roubles. The expected cash balance at the end of the study period with the expected effect of the implementation of the digital twin will be 1,050,854 thousand roubles.

Next, it is necessary to compare the results obtained before and after the implementation of the digital twin (Table 10).

The expected EBITDA increase from the implementation of the Digital Twin was 28%, the actual increase for the period was 21%. The expected increase in free cash flow at the end of the period was RUB 593 mln. (+130%), the actual increase during the period was 441 mln. (+96%).

These differences are due to the time cost of the resulting optimisation of production and business processes when implementing a digital twin of a mining company at an asset (Table 11).

The expected result from the implementation of digital twins differs from the actual result within 3%, which allows us to conclude that the results obtained are reliable. The best way to assess the impact of the use of digital twin technology on the operational efficiency of mining companies is to determine the number of trips made by dump trucks to transport coal.

This method has been adopted and used by Antratsit Invest Proyekt, LLC and Evolution Holding Company. The integration of the digital twin has a positive impact

Table 6
Productivity of potential mining complexes from the first quarter of 2022

Variables	Excavator 7 m^3, 90 t power	Excavator 7 m^3, 130 t power	Excavator 12 m^3, 90 t power	Excavator 12 m^3, 130 t power
Bucket volume (m^3)	7	7	12	12
Loosening coefficient (units)	1.45	1.45	1.45	1.45
Bucket capacity in rear view (m^3)	4.8	4.8	8	8
Excavator cycle time (sec.)	27	27	29	29
Excavator net operating time (hours)	10.5	10.5	10.5	10.5
Regulated downtime within a shift (min.)	90	90	90	90
– shift changes (min.)	30	30	30	30
– lunch (min.)	30	30	30	30
– refuelling and personal needs (min.)	30	30	30	30
Truck loading cycle time (min.)	4.4	5.7	3.1	4.4
– time to set up a dumper for loading (min.)	0.7	0.7	0.7	0.8
– number of buckets to load a dumper (units)	7	10	4	6
– dump truck loading time by pass (min.)	3.2	4.5	1.9	2.9
– dump truck departure time from loading (min.)	0.5	0.5	0.5	0.7
Average manoeuvre time per hour (moving along the face, preparing the site for loading) (min.)	6	6	7	7
Net operating time per hour (min.)	54	54	53	53
Hourly excavator productivity (m^3/hour)	447	493	609	626
Excavator shift capacity (m^3/shift)	4692	5173	6394	6577
Estimated daily excavator productivity (m^3/day.)	9385	10345	12788	13154
Number of days per month	30	30	30	30
– duration of repair (maintenance, repair) (days)	1	1	1	1
– number of working days per month	29	29	29	29
Estimated monthly excavator productivity (thousand m^3)	272.2	300.0	370.8	381.5
Output rate (line usage)	0.80	0.80	0.80	0.80
Monthly excavator productivity considering CTG 0.85 (thousand m^3)	218	240	297	305
Dumper load capacity (t)	90	130	90	130
Rock density (t/m^3)	2.5	2.5	2.5	2.5
Body capacity (m^3)	36.0	52.0	36.0	52.0
Time to set up a tipper for loading (sec.)	42.0	42.0	42.0	48.0
Charging time (min.)	3.2	4.0	1.9	2.9
Dump truck departure time after loading (sec)	30.0	30.0	30.0	42.0
Transportation distance (km)	1.5	1.5	1.5	1.5
Average driving speed of the tipper (km/h)	19.5	18.5	18.5	18.5
Time to prepare a dumper for unloading (sec.)	42.0	42.0	42.0	48.0
Dump truck unloading time (sec.)	60.0	60.0	70.0	70.0
Travel time (round trip) (min.)	9.2	9.7	9.7	9.7
Turnaround time per flight (min.)	15.3	17.1	14.7	16.1
Trips per hour (units)	3.9	3.5	4.1	3.7
Productivity (m^3/hour)	141.4	182.1	146.6	193.8
Trips per shift (units)	41.0	36.0	42.0	39.0
Dump truck shift capacity (m^3/shift)	1476.0	1872.0	1512.0	2028.0
Flights per day (units)	82.0	72.0	84.0	78.0
Estimated daily productivity of the dumper (m^3/day)	2952.0	3744.0	3024.0	4056.0
Output rate (line usage)	0.8	0.8	0.8	0.8
Trips per month (units)	1902.0	1670.0	1949.0	1810.0
Monthly productivity of a dumper, taking into account the coefficient for the use of shift time (thousand m^3)	68.5	86.9	70.2	94.1
Dump truck requirements for maximum excavator performance (units)	3.2	2.8	4.3	3.3

Source: compiled by the author.

Table 7
Calculation of the financial result of the study period without the use of a Digital Twin in 2023

Stripping ratio	5.0
Volume of overburden (thousand m^3)	8040
Coal production (thousand tonnes)	1608
Coal sales (thousand tonnes)	1093
Average FCA price (USD/t)	59
Share of products sold (%)	68
Dollar exchange rate (RUB/USD)	75
Average calorie content (kcal)	5440
Coal transported by rail (thousand tonnes)	1093
Income statement	
Turnover (thousand roubles)	4875517
Total - domestic market (thousand roubles)	2302188
Total - export (thousand roubles)	2573329
Cost of goods sold (thousand roubles)	3086793
Gross profit (thousand roubles)	1788725
Direct variable costs (thousand roubles)	2028326
– Drilling and blasting	257542
– stripping	793768
– production	147581
– enrichment	323208
– MET	285841
– coal storage, crushing and loading at the open pit	53583
– transportation of products to the railway station warehouse	166803
Indirect variable costs (thousand roubles)	69485
Costs of organising shipments (thousand roubles)	42833
– locomotive hire	14753
– other costs (feeding, cleaning wagons, etc.)	28080
Expenses for support of shipments (thousand roubles)	26653
– international certification	26653
Marginal profit (thousand roubles)	2777706
Indirect fixed costs (thousand roubles)	1536100
Total production costs (thousand roubles)	1058466
– maintenance of railway infrastructure	25966
– maintenance of roads	155101
– maintenance of public utilities	168254
– property tax	88029
– general production	621115
Other operating expenses (thousand roubles)	143605
– storage and transport to the railway station	143605
Administrative and management expenses (thousand roubles)	334029
– For reference: depreciation included in cost	420536
EBITDA (thousand roubles.)	1662141
Cash at the beginning of the period (thousand roubles)	316324
Cash and cash equivalents at the end of the period (thousand roubles)	457490
Financial activities (thousand rubles)	5347321
– Receipt of loan funds CA 0051/21	4012228
– Receipt of loan funds CA 0758/21	1335093
– Receipt of loan funds from participants	–
Operating activities (thousand roubles)	6712427
– Other revenue	–
– Revenue from sales	4875517
– Cash received on deposits	405434
– VAT refund - operating expenses	180686
– VAT refund - investments	1228032
– VAT refund - leasing	22757
Total revenues (thousand roubles)	12059748
Financial activities (thousand roubles)	1838637
Interest payments (thousand roubles)	1278637
– payment of interest on participants' loans	183662
Debt payment (thousand roubles)	560000
Operating activities (thousand roubles)	4067582
– Operating expenses (excluding VAT)	3853963
– Adjustment for royalties paid in advance	74844
– VAT - operating expenses	288463
Investment activity (thousand roubles)	6012363
– investment activities	3871556
– investment activities of an engineer	1335093
– leasing and replenishment of security account	805714
Total disposal (thousand roubles)	11918582

Source: compiled by the author.

on the operational activity of coal mining companies, in particular Anthratsit Invest Proyekt, LLC.

It is possible to identify a number of shortcomings in the proposed methodology for assessing the impact of the use of digital twin technology on the operational efficiency of mining companies: the method does not take into account

1) the period of implementation and increasing the effect of the digital twin;
2) changes in external factors affecting the performance of equipment, such as seasonality.

These shortcomings motivate further research into the impact of digital twins on the operational efficiency of mining companies.

7. Discussion and further research

The methodology developed to assess the impact of using digital twin technology on the operational efficiency of mining companies allows us to evaluate the impact of implementing a digital twin and help management formulate a position on the feasibility of implementation. However, in order to clarify the results obtained, it is necessary to clarify a number of parameters, such as the factors for modifying the external parameters, the characteristics of the mined coal grades during enrichment, the expected effects affecting the reduction of the stripping ratio, etc.

Table 8
Productivity of potential mining complexes

Variables	Excavator 7 m³, 90 t power	Excavator 7 m³, 130 t power	Excavator 12 m³, 90 t power	Excavator 12 m³, 130 t power
Bucket volume (m³)	7	7	12	12
Loosening coefficient	1.45	1.45	1.45	1.45
Bucket capacity in rear sight (m³)	4.8	4.8	8	8
Excavator cycle time (sec)	27	27	29	29
Net excavator working time (hour)	10.5	10.5	10.5	10.5
Regulated downtime per shift (min.)	90	90	90	90
– shift changes (min.)	30	30	30	30
– lunch (min.)	30	30	30	30
– refuelling and personal needs (min.)	30	30	30	30
Truck loading cycle time (min.)	4.4	5.7	3.1	4.4
– Time to set up the dumper for loading (min.)	0.7	0.7	0.7	0.8
– Number of buckets for dumper loading (units)	7	10	4	6
– Dump truck loading time according to the pass (min.)	3.2	4.5	1.9	2.9
– Dump truck departure time from loading (min.)	0.5	0.5	0.5	0.7
Average manoeuvring time per hour (moving along the face, preparing the site for loading) (min.)	6	6	7	7
Net operating time per hour (min.)	54	54	53	53
– hourly excavator productivity (m³/hour)	447	493	609	626
– shift productivity of the excavator (m³/shift)	4692	5173	6394	6577
– estimated daily productivity of the excavator (m³/day)	9385	10345	12788	13154
Number of days per month	30	30	30	30
– Duration of repair (maintenance, repair) (days)	1	1	1	1
– Number of working days per month	29	29	29	29
Estimated monthly excavator productivity (thousand m³)	272.2	300.0	370.8	381.5
Output rate (line usage)	0.88	0.88	0.88	0.88
Monthly excavator productivity considering TRC 0.85 (thousand m³)	241	265	328	337
Dump truck load capacity (t)	90	130	90	130
Rock density (t/m³)	2.5	2.5	2.5	2.5
Body capacity (m³)	36.0	52.0	36.0	52.0
Time to set up a tipper for loading (sec.)	42	42	42	48
Loading time (min.)	3.2	4.5	1.9	2.9
Dump truck departure time after loading (sec.)	30	30	30	42
Transportation distance (km)	1.5	1.5	1.5	1.5
Average speed of the tipper (km/h)	19.5	18.5	18.5	18.5
Time to set up a tipper for unloading (sec.)	42	42	42	48
Dump truck unloading time (sec.)	60	60	70	70
Travel time (round trip) (min.)	9.2	9.7	9.7	9.7
Turnaround time per travel (min.)	15.3	17.1	14.7	16.1
Trips per hour (units)	3.93	3.50	4.07	3.73
Productivity per hour (m³/hour)	141.4	182.1	146.6	193.8
Trips per shift (units)	41	36	42	39
Dump truck shift capacity (m³/shift)	1476.0	1872.0	1512.0	2028.0
Trips per day (units)	82	72	84	78
Estimated daily productivity of the dumper (m³/day)	2952	3744	3024	4056
Output rate (line usage)	0.88	0.88	0.88	0.88
Travels per month (units)	2102	1846	2153	2000
Monthly dumper productivity considering coefficient for the use of shift time (thousand m³/month)	75.7	96.0	77.5	104.0
Dump truck requirements for maximum excavator performance (units)	3.2	2.8	4.3	3.3

Source: compiled by the author.

Table 9
Evaluation of the operational effectiveness of using the Digital Twin 'AnthracitInvestProject' in 2023

Stripping ratio	5
Volume of overburden (thousand m³)	8700
Coal production (thousand tonnes)	1740
Coal sales (thousand tonnes)	1274
Average FCA price (USD/t)	59
Share of products sold (%)	73
Dollar exchange rate (RUB/USD)	75
Average calorie content (kcal)	5440
Coal transported by rail (thousand tonnes)	1274
Profit and loss account (thousands roubles)	
– revenues from sales	5679186
– total - domestic market	2681675
– total - export	2997510
– cost of goods sold	3399226
– gross profit	2279959
Direct variable costs (thousand roubles)	2339691
– Drilling and blasting	305424
– stripping	925205
– production	160121
– enrichment	349740
– MET	330174
– coal storage, crushing and loading at the open pit	62137
– transportation of products to the railway station warehouse	206 889
Indirect variable costs (thousand roubles)	78507
Costs of organising shipments (thousand roubles)	47461
– locomotive hire	14753
– other costs (feeding, cleaning wagons, etc.)	32708
Expenses for support of shipments (thousand roubles)	31046
– international certification	31046
Marginal profit (thousand roubles)	3260988
Indirect fixed costs (thousand roubles)	1538258
Total production costs (thousand roubles)	1059535
– maintenance of railway infrastructure	25966
– maintenance of roads	156170
– maintenance of public utilities	168254
– property tax	88029
– general production	621115
Other operating expenses (thousand roubles)	144694
– storage and transport to the railway station	144694
Administrative and management expenses (thousand roubles)	334029
– for reference: depreciation included in cost	411241
EBITDA (thousand roubles)	2133971
Cash at the beginning of the period (thousand roubles)	316324
Cash and cash equivalents at the end of the period (thousand roubles)	1050854
Financial activities (thousand roubles)	5347321
– receipt of credit funds CA 0051/21	4012228
– receipt of credit funds CA 0758/21	1335093
– loans received from participants	–
Operating activities (thousand roubles)	7524220
– Other revenue	–
– Revenue from sales	5679186
– Cash received on deposits	405434
– VAT refund - operating expenses	188810
– VAT refund - investments	1228032
– VAT refund - leasing	22757
Total revenues (thousand roubles)	12871541
Financial activities (thousand roubles)	1838637
Interest payments (thousand roubles)	1278637
– payment of interest on participants' loans	183662
Debt payment (thousand roubles)	560000
Operating activities (thousand roubles)	4286009
– operating expenses (excluding VAT)	4059299
– adjustment for royalties paid in advance	74844
– VAT - operating expenses	301555
Investment activity (thousand roubles)	6012363
– investment activities	3871556
– investment activities – technology	1335093
– leasing and replenishment of collateral account	805714
Total disposal (thousand roubles)	12137010

Source: compiled by the author.

Further research into the impact of digital twins on mining operations will contribute to the spread of this technology and the development of the industry. As mining, and coal in particular, is one of the key sectors of the global economy, the spread of digital twin technology can indirectly affect global economic growth.

It is advisable to continue research and refine the resulting methodology to assess the impact of using digital twin technology on the operational efficiency of mining companies. There are several promising areas of research that can be explored to assess the impact of digital twins on mining companies. These include:

1) taking into account not only changes in the productivity of the equipment, but also changes in external parameters affecting its productivity, such as transport distance, weight of rock, etc. As mentioned earlier, in addition to predictive maintenance to reduce downtime, the digital twin can optimise transport routes. Such a study would make it possible to clarify the calculated specific coefficients and increase the accuracy of the assessment of the impact of a digital twin on a coal mining company;

2) expanding the sample of experts from coal mining companies, both Russian and international. Such an approach would provide a more accurate estimate of the expected impact of the digital twin on coal mining companies, and may also identify other business processes that have a significant impact on the operational efficiency of a coal mining company. In particular, the study would make it possible to clarify the calculation method and introduce regional coefficients both within the Russian Federation, depending on the deposit and quality of the coal, and by country;

3) as different seams contain different grades of coal, they have different washability characteristics, such as

Table 10
Comparison of the results obtained for the period from the second quarter of 2022 to the first quarter of 2023

Variable	Without digital twin	Expected outcome of implementing a digital twin	Actual result of implementing a digital twin
Stripping ratio	5	5	5
Volume of overburden (thousand roubles)	8040	8700	8522
Coal extraction (thousand roubles)	1608	1740	1704
Coal sales (thousand roubles)	1093	1274	1227
Average FCA price (thousand roubles)	59	59	59
Yield of sold coal after enrichment (%)	68	73	72
Dollar exchange rate (RUB/USD)	75	75	75
Rail transport of coal (thousand rubles)	1093	1274	1227
Physical indicators at the end of the period			
Performance ratio of mining equipment (%)	0.8	0.884	0.86
Yield of marketable product after enrichment (%)	0.68	0.732	72
Coefficient of performance of the dump trucks transporting the coal from the open-cast mine to the railway station stockyard	0.72	0.774	0.763
Number of SHACMAN travels 38 tonnes per day	4	5	5
Direct variable costs (thousand roubles)			
Drilling and blasting (thousand roubles)	257542	305424	293083
– stripping	793768	925205	894252
– production	147581	160121	154225
– enrichment	323208	349740	342600
– MET	285841	330174	318748
– coal storage, crushing and loading at the open pit	53583	62137	60281
– transportation of products to the railway station warehouse	166803	206889	196420
EBITDA (thousand roubles)	1662141	2133971	2009158
Cash balance at the end of the period (thousand rubles)	457490	1050854	898022
Cost of 1 tonne of commercial products (thousand roubles)	39	37	38

Source: compiled by the author.

Table 11
Deviations in natural indicators (%)

Variables	Expected outcome of implementing a digital twin	Actual result of implementing a digital twin	Deviation from natural indicators
Line-to-line performance ratio of mining equipment	88.4	86.0	–3.0
Percentage of marketable product yield after enrichment	73.2	72.0	–2.0
Coefficient of performance of dump trucks transporting coal from the stockyard at the open-cast mine to the stockyard at the railway station.	77.4	76.3	–1.0
Number of SHACMAN trips 38 tonnes per day	5	5	0

Source: compiled by the author.

ash content and Y-Y. The proposed studies would make it possible to clarify the expected yield coefficient of washed coal, which is used to assess the effectiveness of introducing a digital twin in washing plants;

4) taking into account the influencing factors for better planning of section development and geological exploration. As mentioned earlier, digital twins are used for production planning and exploration, among other things. Thanks to the work of the digital twin, it is possible to optimise the formation of edges and the extraction of coal seams, which will lead to a reduction in the coefficient. This process is not directly related to the operational efficiency of a coal mine, but can have an indirect impact on it by optimising the stripping ratio: the lower the stripping ratio, the more coal can be extracted while maintaining the current productivity of the specialised equipment;

5) considering the impact of improved industrial safety on the plant. Reducing the risk of incidents and coal losses at various stages of the production process can lead to increased productivity. Improving safety also has an indirect impact on operational efficiency, as it reduces the risk of breakdowns, losses and incidents that can cause operational downtime;

6) analysing the implementation of technologies for the release of pollutants such as greenhouse gases, waste disposal, etc. This process has no direct impact on operations, but can reduce the risk of being fined for pollution;

7) training and staff development. Research can be conducted to determine the impact of digital twins on staff training and development. This can be done by analysing the training needs of the workforce and the effectiveness of training programmes. Such a study can take into account the time required to train staff to use the digital twin effectively, and assess productivity improvements;

8) reducing payroll expenses by optimising administrative business processes, which will have a direct impact on operational efficiency.

In addition to these areas of research, focused on the formation of additional specific coefficients and the clarification of those used in the current methodology, it is necessary to pay attention to the developed methodology for assessing the impact of the use of digital twin technology on the operational efficiency of mining companies. This involves modelling the impact of the introduction of digital twins.

Future directions for research into the impact of digital twins on the operational efficiency of mining companies could also focus on stock optimisation. This would make it possible to identify the impact on stock turnover and optimise the fixed costs associated with its maintenance, which could potentially affect the operational efficiency of the business as a whole.

In order to clarify the developed method for assessing the impact of the use of digital twin technology on the operational efficiency of mining companies, it is advisable to consider more detailed natural indicators that take into account the individual real characteristics of the equipment and the conclusions of a technical audit on them.

The methodology developed to assess the impact of using digital twin technology on the operational efficiency of mining companies can be openly applied to other mining companies with similar mining technology, such as those involved in the extraction of gold, manganese, ilmenite, etc.

A promising area of research for this method of assessing the impact of digital twin technology on mining operations is to examine the impact of digital twins on underground mining assets. The digital mine concept is relatively popular among mining companies, but the production processes used in the proposed methodology may not be key to underground mining.

Thus, the proposed method for assessing the impact of using digital twin technology on mining companies has the potential for a wide range of applications and leaves ample room for further research and refinement. Each of the subsequent studies will extend and clarify the proposed approach, but will not affect it conceptually, only complement it.

One of the key directions for further research and refinement of the methodology for assessing the impact of using a digital twin on the operational efficiency of a mining company is to identify indirect factors and risk mitigating factors to complement the developed methodology for assessing the impact of using digital twin technology on the operational efficiency of mining companies.

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