SCIENTIFIC
AND PRACTICAL
REVIEWED JOURNAL

ISSN 2618-947X (Print)
ISSN 2618-9984 (Online)

strategic decisions & risk-management

Vol. 15, № 2/2024

16+

Strategic Decisions and Risk Management
战略决策和风险管理

Published since 2010

WWW.JSDRM.RU

SCIENTIFIC AND PRACTICAL
REVIEWED JOURNAL

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ISSN 2618-9984 (Online)

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DOI: 10.17747/2618-947X-2024-2

Decisions and management risks-management «Decisions and management risks-management»
Journal Is registered by Federal Service for Supervision in the sphere of communication, information technologies and mass communications (Roscomnadzor). Certificate ПИ № ФС 77–72389 dated 28.02.2018

Periodicity – 4 times per year

Founder – The Finance University under the Government of the Russian Federation (Finance University), Real Economy Publishing House

Publisher – Real Economy Publishing House

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EDITORIAL TEAM

Publisher's address: 190020, St. Petersburg, 43–45 B, Staro-Petergofsky pr., of. 4H
Editor's office address: 190020, St. Petersburg, 43–45 B, Staro-Petergofsky pr., of. 4H
Tel.: (812) 346–5015, 346–5016
www.jsdrm.ru, e-mail: info@jsdrm.ru
"Tipografiia Litas+" LLC, 190020, St. Petersburg, 3, Lifliandskaia ul.
Using the materials it is obligatory to include the reference to "Strategic Decisions and Risk Management"
Circulation of 1900 copies.
Subscription through the editors or the Agency "Rospechat", the directory of newspapers.
- Agency "ARZI", the catalog "Press of Russia" – subscription index 88671
- Agency "Ural-press" LLC in all regions of the Russian Federation www.uralpress.ru – subscription index 33222
- Subscription to electronic version through the website Delpress.ru, LitRes

科学
同行审稿期刊

ISSN 2618-947X (印刷版)
ISSN 2618-9984 (在线版)

strategic decisions & risk management

战略决策和风险管理

自2010年开始出版
DOI: 10.17747/2618-947X-2024-2
该期刊物重新于俄罗斯联邦通信、信息技术和大众传媒监督局（Roskomnadzor或RKN）登记。28.02.2018 第FS-72389号PI证书
以前的标题是“有效的危机管理”
出版频率：每年四刊

创办者： 联邦国家预算高等教育机构“俄罗斯联邦政府金融大学”（FinU）、“实体经济”出版社有限责任公司
出版商： “实体经济”出版社“有限责任公司（LLC Publishing house “Real economy”）

“战略决策和风险管理“ 是一本国际同行审稿开放期刊，出版在战略管理的关键领域，有先进的理论和应用研究成果的原创研究文章、管理决策的基本原理以及风险管理政策的形成。该期刊向读者介绍了未来可能出现的情况，以便在正确的时间做出正确的战略决策，并了解风险、决策和战略形成之间的关系。

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编辑

出版商地址： 190020, St. Petersburg, Staro-Petergofsky pr. 43/45, lit. B, of. 4N
电话： +7（812）346-50-15，346-50-16
网址： info@jsdrm.ru
在线版 —— www.jsdrm.ru

“LITAS+印刷厂”有限责任公司：190020，St. Petersburg, Liflyandskaya ul., 3

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Strategic Decisions and Risk Management
Vol. 15, № 2/2024
战略决策和风险管理
2024第15卷第2期

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DOI: 10.17747/2618-947X-2024-2-100-117
JEL L16

Industrial microgrids as tools for managing the energy efficiency in industrial regions

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Abstract

The integration of electricity grids with technologies for small-scale distributed generation based on natural gas consumption is one of the most important innovative directions for improving the reliability and energy efficiency of power systems. Synchronous operation of large energy consumers and distributed generation systems is a new element of the electricity system. This element is an industrial microgrid, which has a unique ability to control the operating modes of the electrical energy system compared to conventional industrial electricity consumers. The aim of this study is to develop a theory and methodology for the use of microgrids in industrial areas under the market-based conditions of electricity and natural gas purchase. An analysis of trends in the use of small-scale distributed generation shows that the operation of distributed generation based on renewable energy sources is not economically feasible in all countries. In some countries, such as Russia, for example, the use of distributed energy sources powered by natural gas is the most important. The study of pricing principles for the purchase of energy in the wholesale and retail electricity markets and for the purchase of natural gas from regional suppliers and on commodity exchanges shows that managing the volatility of energy demand schedules can have a significant impact on the prices of electricity and natural gas used by industrial companies and large consumers of energy resources. As part of a unified power system, industrial enterprises and small distributed generation systems simultaneously consume electricity from the Unified Energy System, generate electricity through a distributed generation system into the internal network of the enterprise and external network the power system, and consume natural gas through the enterprise consumption system and the distributed generation system. Synchronised operation of an industrial enterprise and a small system of distributed generation system in the unified control system of a microgrid enables the enterprise to reduce the combined costs of purchasing energy resources and increase the efficiency and reliability of power supply to equipment. The article presents a system of factors influencing the demand of microgrids for electricity and natural gas consumption and develops a model for the integrated control of industrial microgrids under their integration with the technology for managing the demand of industrial enterprises for electricity and natural gas consumption. The control algorithm developed for a microgrid takes into account the cross effects of changes in its energy and gas demand, energy market price factors, internal constraints for industrial load management, external external of the Unified Energy System and the Unified Gas Supply System, and the ability to meet the energy demand of external consumers of the microgrid. The paper is of scientific and practical importance and can be used in the process of developing, implementing and managing microgrids at industrial enterprises in Russia and around the world.

Keywords: industrial power supply, power cost, distributed generation, industrial energy management, energy consumption, natural gas consumption, electricity market.

For citation:

Dzyuba A.P., Semikolenov A.V. (2024). Industrial microgrids as tools for managing the energy efficiency in industrial regions. *Strategic Decisions and Risk Management*, 15(2): 100-117. DOI: 10.17747/2618-947X-2024-2-100-117.

工业区域中作为能源效率管理工具的分布式发电工业系统

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简介

将电网与基于天然气消费的小型分布式发电技术相结合，是提高电力系统可靠性和能源效率的关键创新方向之一。 大型能源消费者与分布式发电系统的同步运行构成了电力系统的新元素。该元素即工业微电网，与传统工业用电消费者相比，具备独特的电力系统运行模式管理能力。 本研究的目的是在电力和天然气市场条件下，制定在工业区使用微电网的理论和方法。对小型分布式发电使用趋势的分析表明，基于可再生能源的分布式能源在所有国家中并不都是经济上可行的。 例如，在俄罗斯，使用以天然气为燃料的分布式能源是最为切合实际的。研究在批发和零售电力市场上采购电力以及向区域供应商和商品交易所采购天然气的定价原则表明，管理能源需求波动可以显著影响工业企业和大型能源消费者所用的电力和天然气价格。 工业企业和小型分布式发电系统作为统一能源综合体的一部分，同时从统一能源系统消耗电力，通过分布式发电系统向企业内部网络和外部能源系统网络发电，并同时通过工业企业的燃气系统和分布式发电系统消耗天然气。在统一的主动能源综合管理系统框架内，同步工业企业与小型分布式发电系统的运行，可以降低企业能源资源采购的综合成本，提高设备的能源供应效率和可靠性。本文提出了影响主动能源综合体电力和天然气消费需求的因素体系，并开发了一种在与工业企业电力和天然气消费需求管理技术相结合的条件下，对主动能源综合体进行综合管理的模型。所开发的主动能源综合体管理算法能够考虑主动能源综合体内电力和天然气需求变化的相互影响、电力和天然气市场的价格因素、工业企业内部负荷调节的限制要求、统一能源系统和统一供气系统的外部系统限制，以及满足主动能源综合体外部用户电力需求的可能性。研究结果可以在俄罗斯和全球工业企业开发、实施和管理主动能源综合体的过程中使用。

关键词： 工业电力供应、电力成本、工业能源管理、能源消耗、天然气消耗、电力市场。

引用文本：

Dzyuba A.P., Semikolenov A.V. (2024). 工业区域中作为能源效率管理工具的分布式发电工业系统。战略决策和风险管理, 15(2): 100–117. DOI: 10.17747/2618-947X-2024-2-100-117.

Introduction

Since the dawn of industrialisation, the global fuel and energy sector has undergone significant changes, creating a number of specific industries, such as electricity, oil, gas, and coal. The energy systems of most countries have become the most important infrastructure and backbone sectors of the economy, the efficiency of which determines the quality and cost of the products manufactured in a country. In today's conditions, the fuel and energy sectors determine the vector of strategic industrial and territorial development of the countries of the world. The global fuel and energy sector is characterised by ever-increasing demand for the consumption of energy resources. Over the past 50 years, the average annual increase in the world's consumption of fuel and energy resources has amounted to 2.1%. The economic development of any territorial entity is inseparable from an increase in the consumption of energy resources to ensure the functioning of growing industries and territorial agglomerations, as well as the growing needs of the population.

The main fuels and energy resources consumed in the world are oil, natural gas, coal, and nuclear energy, the use of which is converted into electricity and thermal energy. Electricity is generated by hydroelectric and renewable power plants, which are primarily based on the conversion of solar, wind and hydroelectric energy.

Figure 1 shows the world consumption profiles for different fuel and energy resources in the period 1965–2020. The consumption of fuel and energy resources is increasing in all cases, but at different rates. For example, the growth of natural gas consumption is characterised by the same rates for all 56 years, while the rate of an increase in consumption of oil, coal, and nuclear energy varies significantly.

Irregularities in the consumption patterns of different fuels and energy resources are mainly related to economic, technological and environmental characteristics. The decline in the rate of oil consumption since the early 1970s is due to rising prices on world oil markets. The decrease in the growth rate of nuclear energy consumption is due to environmental restrictions and the suspension of the construction of many nuclear power plants following the accident at the Fokushima-1 nuclear power plant in Japan in 2011. The increase in coal consumption since 2007 is due to the growth of Asia-Pacific economies with their access to coal reserves. The growth in electricity generation based on renewable energy technologies (RES) is due to the intensification of their development after the beginning of the 2000s.

The difference in the structure of consumption of fuel and energy resources is not only in the level of development of the world fuel and energy sector. The structure of the energy mix is highly differentiated in the territorial and national contexts. Figure 2 shows the structure of fuel and energy consumplion for electricity generation in the countries of the world in 2020. While natural gas accounts for 38% of electricity generation in North America, it accounts for 18% in South America. In the Middle East, 28% of electricity is generated from oil, and in Europe, APAC, and the CIS, the share is no more than 2%.

Taking into account the constantly increasing cost of primary energy resources on world markets, the depletion of primary fuel and energy resources in most countries, the intensive growth of energy demand and the significant environmental impact of the energy industry, most countries are currently developing the concepts of 'energy transition', or 'energy turnaround' (German: Energiewende). The concept of energy transition is based on the gradual replacement of fossil fuels with renewable energy sources.

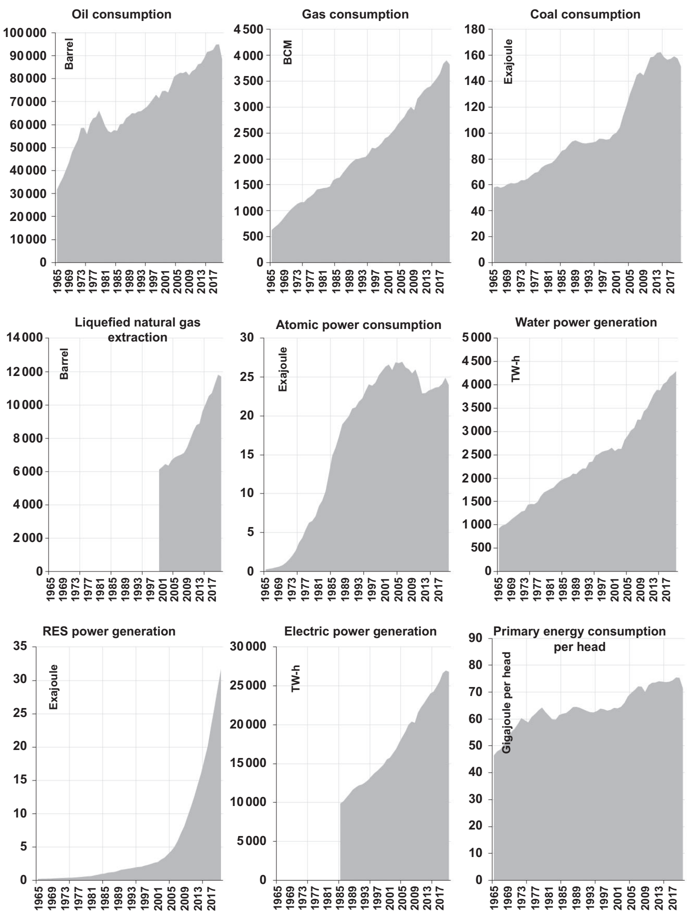
Figure 3 shows graphs of the installed capacity of RES power plants in 2011–2020. The growth rate of installed solar capacity in the last decade of the period was 29% per year, while wind generation averaged 14% per year. According to 2020 results, the share of electricity consumption based on RES was 98.4% in Norway, 84.1% in Brazil, 80% in New Zealand, 68.4% in Sweden, 67.7% in Canada, etc. These statistics include both large hydro plants and distributed generation. The fact that the share of renewable energy generation is high in many countries and is increasing year on year once again confirms the prospects for the development of distributed energy and RES around the world.

Figure 4 shows statistics on the volume of production and import (export) of different types of energy resources in 2020 for the top 10 largest countries. As can be seen from the graph, Russia is the third largest producer of energy resources in the world, after China and the United States. Russia's share in the global energy mix is 10% of the global energy resources consumed. In 2020, 47.6% of the energy produced was exported. Russia is the world's second largest oil producer after the United States. In 2020, 45.7% of oil produced was exported. In terms of natural gas production, Russia is second only to the United States, and well ahead of most of the world's economies that produce natural gas, accounting for 17.6% of the world market. The share of Russian exports of produced natural gas is 34.2% in 2020. Russia is the third largest exporter of liquefied natural gas (LNG), a market that is actively developing. Russia ranks sixth in the coal production market, with 45.9% of coal production exported. In 2020, Russia was the world's fourth largest electricity producer.

The share of natural gas consumption in the structure of fossil fuels used in Russia in 2020 was 75.5%. In most countries of the world, this figure is significantly lower, averaging 33.4%. The domestic production of natural gas in Russia determines the pricing policy for natural gas on the domestic market, the cost of which is one of the lowest in the world. It averages $ 100 per thousand cubic metres, which is more than 10 times lower than in Sweden, Spain, the Netherlands, Italy, France, etc., and more than 5 times lower than the average world price.

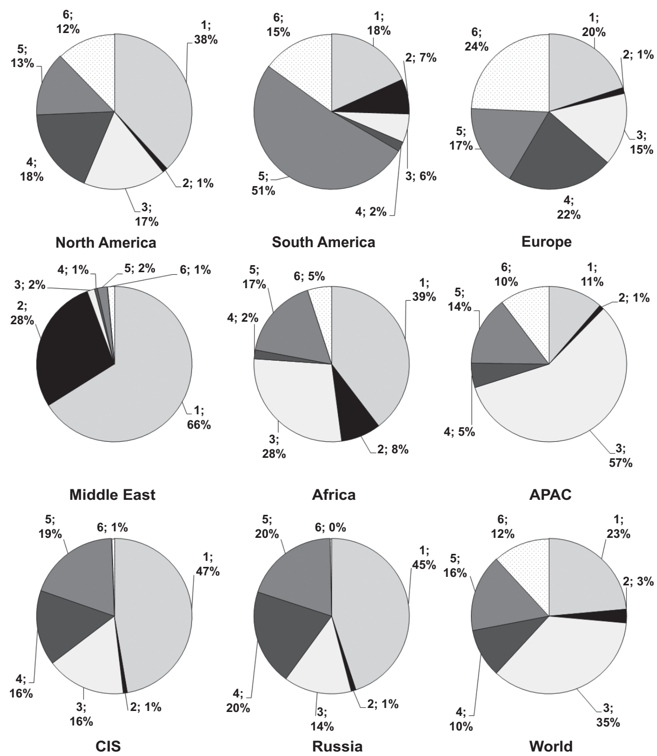
The cost of natural gas supplied to the Russian domestic market and the high share of natural gas consumption in the structure of electricity generation determine the prices of the supplied electricity sold to the country's domestic market. The average cost of a kilowatt-hour of electricity supplied in Russia is on average 8 cents, which is 2 times lower than in France, Spain, and Hungary and more than 3 times lower than in Great Britain, Germany, Denmark, etc.

Fig. 1. World consumption profiles for different fuel and energy resources for the period 1965–2020



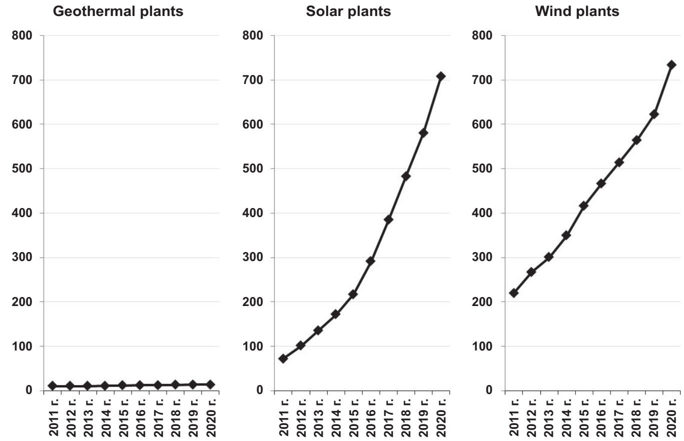
Source: Statistical review of world energy: Materials from the official British Petroleum website. https://www.bp.com/.

Fig. 2. Structure of consumption of fuels and energy resources for electricity generation in the regions of the world in 2020 (1 is natural gas, 2 is oil, 3 is coal, 4 is nuclear, 5 is hydro, and 6 is RES)



Source: Electricity information 2020 IEA. Report of International Energy Agency. http://data.iea.org.

Fig. 3. Installed capacity of RES power plants in 2011–2020 in GW



Source: Electricity information 2020 IEA. Report of International Energy Agency. http://data.iea.org.

The growing demands for electricity consumption and for the construction of new industrial facilities or increasing the capacity of existing technological links determine the need to find modern solutions to improve the efficiency of power supply to industrial enterprises. We believe that these circumstances determine the priority of the development of Russian small-scale distributed power generation based on natural gas.

The installation of small distributed generation systems (SDG) has a number of economic advantages.

- Payment for the cost of electricity transmission services and sales surcharges from regional electricity suppliers are excluded.
- Payment for the cost of electricity as part of electricity purchasing cost is excluded.
- Costs for technological connection and increase of operational connection capacity are excluded.
- Losses during the electricity and heat transportn are minimised [Abdulkareem et al., 2021].

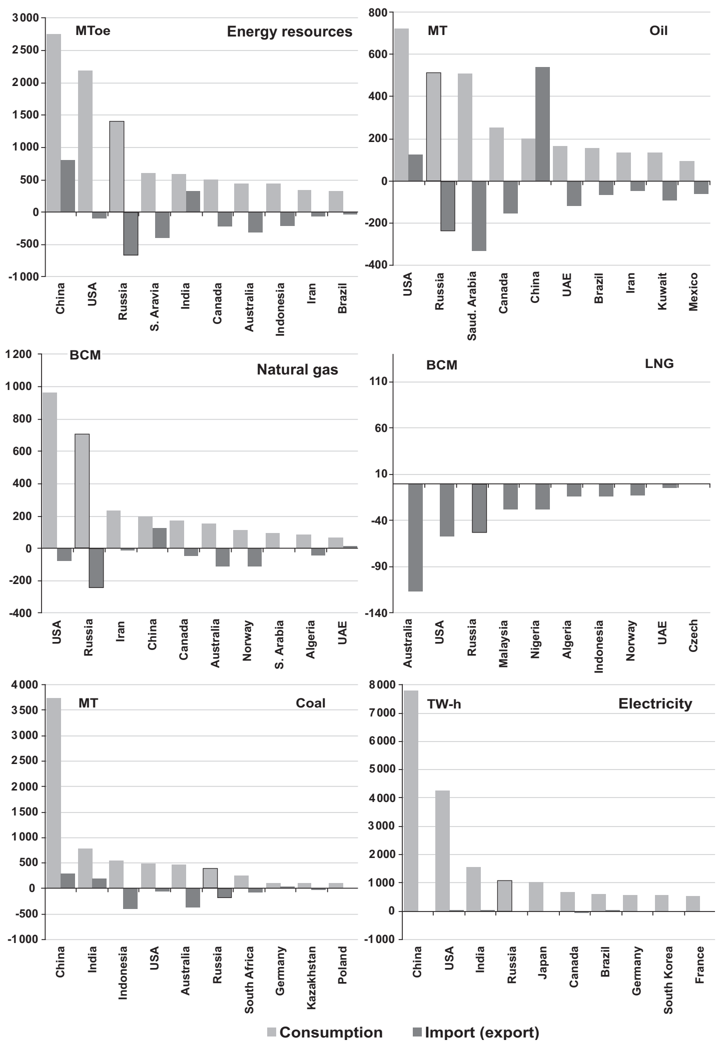
The low cost of electricity in Russia makes the global trend towards intensive deployment of renewable energy sources relatively less relevant for Russia. In 2020, the share of electricity generation from RES (excluding large hydroelectric power plants) was 41% in the UK, 28% in Finland, 19% in Brazil, 12% in Japan, but only 0.32% in Russia. The low share of RES electricity generation in Russia is related to the uncompetitive prices of RES electricity generation compared to conventional electricity sources using relatively cheap natural gas.

Now the trend in Russia is the growing demand for electricity from existing and new industrial enterprises. Russia's power grid infrastructure was built in the days of the USSR. Power transmission facilities are distributed among the industrial sites for which the power grids were built, and despite the fact that the distributed capacities are not fully utilised, their distribution in favour of other electricity consumers is impossible.

According to modern Russian and world legislation in the field of technological connection to power grids, with the exception of certain cases, the consumers of electricity pay all the costs of performing works to increase the permissible power for the consumer. Thus, if it is necessary to increase the permitted power consumption, the enterprise has to pay all the costs of increasing the power of supply transformers, strengthening cables, building cells, etc. In some cases, the cost of increasing the connected capacity of an industrial enterprise can be in excess of $ 1 million for 1 MW of additional allowable power.

Figure 5 shows the number of submitted and satisfied applications for technological connections to power grids with a maximum power of up to and over 670 kVA in Russia in 2012–2018. The number of applications submitted by consumers for technological connection to power grid facilities of power grid organizations significantly exceeds the number of concluded contracts for technological connection to power grid facilities. The same trend is observed in many countries of the world.

Fig. 4. Production and import (export) volumes of energy resources for the top 10 largest countries in 2020



Sources: World energy balances 2020 IEA. Report of International Energy Agency. https://www.iea.org/reports/key-world-energy-statistics-2020/energy-balances; Russian statistical yearbook. Rosstat, 2020.

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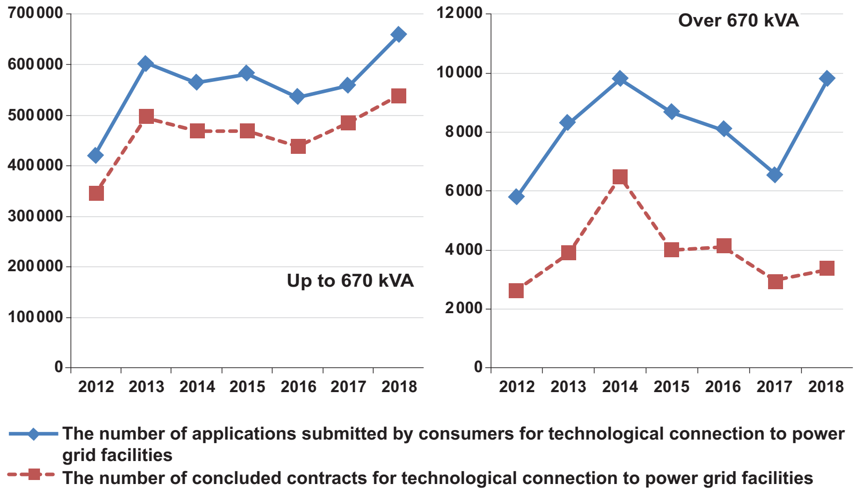
Fig. 5. Number of submitted and accepted applications for technological connections to power grids with a maximum power of up to and above 670 kVA



Sources: Ministry of Energy of the Russian Federation. https://minenergo.gov.ru/; PJSC "Rosseti". https://www.rosseti.ru/; Unified interdepartmental statistical information system. https://fedstat.ru/.

- The probability of overpaying for electricity and heat due to errors in the consumed energy resources is significantly reduced.
- Small distributed generation systems have the following technological advantages.
- It is possible to regulate the load of distributed generation according to the characteristics of a company's performance.
- The reliability of the energy supply increases.
- The quality of the electricity consumed increases.
- It is possible to control the reactive power balance [Liu et al., 2019].

According to the estimates of the EnergyNet Infrastructure Center, Russia, realising the potential of distributed energy will allow the Russian economy to receive economic benefits of up to 150 billion rubles ($ 2.5 billion) in 2020–2028, taking into account the deduction of investment costs [Lin et al., 2021]. One of the modern ways of using and developing the distributed generation (DG) systems is operate them as microgrids.

1. Analysis of research studies on the use of distributed energy

Modern foreign scientific research into the use of distributed generation technologies is largely devoted to simulating the operation of DG systems with a centralised power supply system and increasing the sustainability of consumer power supply. Studies [Beltrán, 2020; Matos et al., 2021] investigate increasing the stability of parallel operation of distributed generation systems with centralised power supply systems. Studies [Martínez et al., 2021; Sandhya, Chatterjee, 2021] focus on reducing failures and improving the quality of power supply for distributed generation systems. Studies [Anuradha et al., 2021; Baghbanzadeh, 2021] focus on reducing losses during operation and distribution of electricity generated by DG systems.

Many modern studies in the field of application of distributed generation systems deal with the problems of integration with modern digital control and management systems. The intelligent control of distributed generation systems is studied in [Howlader et al., 2015; Kakran, Chanana, 2018; Li, Chen, 2022]; the execution of digital behavior simulation of DG systems is carried out in [Belmahdi, El Bouardi, 2020; Valencia et al., 2021]; and the researches [Rahiminejad et al., 2016; Menke et al., 2019] focus on the improvement of digital monitoring and planning the operating modes of DG systems.

Since the development of electricity markets in most countries of the world has reached a high level, a significant part of the global studies in the field of distributed generation focuses on the integration of distributed energy with energy market pricing mechanisms. Examples of such works are studies [Craig et al., 2018; Abdulkareem et al., 2021] dedicated to improving the quality of planning and analysis of energy markets in the context of integration of the energy system with distributed generation sources. Studies [Yu et al., 2018; Liu et al., 2019] address the issue of economic modelling of options for the operation of DG systems in energy markets. Studies [Kumar et al., 2018; Lin et al., 2021] have contributed to the simulation of the distributed generation operation, taking into account the signals and characteristics of the energy market.

Much scientific research is devoted to the use of RES-based distributed generation [Garlet et al., 2019; Samper et al., 2021; Zhang et al., 2021] and industrial energy storage systems [Yanine et al., 2019]. Articles [Howlader et al., 2016; Nakada et al., 2016; Wang et al., 2018] focus on the integration of distributed energy with modern control and management technologies. The problem of improving the reliability of power supply to consumers, taking into account the operation of distributed generation systems based on demand response is studied in [Poudineh, Jamasb, 2014; Nejad et al., 2019].

Many Russian scientists have also devoted their work to the use of distributed energy systems. The problem of improving the reliability of power supply systems is studied in [Nepomnyashchiy, Ilyushin, 2013; Rytsova, 2018; Khudyakov et al., 2020]. Distributed energy systems in technologically isolated areas of the country are studied in [Chulyukova, 2019; Nurmukhametov, 2020; Sichevsky, Dolgopol, 2020]. The studies [Kuchin et al., 2010; Ragutkin, 2013; Abramovich, Sychev, 2016; Eljrushi et al., 2019; Pogodin, 2019; Tepchikov, Stashko, 2019; Lukyanov 2020] focus on improving the quality of electrical energy. Russian scientists devote their research to the issues of reducing power losses in distributed generation systems [Ilyushin et al., 2019; Myshkina, 2019]. The effectiveness of electricity cogeneration in distributed energy supply systems and highliting the advantages compared to generation of a single type have been evaluated in [Pivnyuk, 2008; Safonov et al., 2016; Dormidonov, 2019]. The problem of increasing the efficiency of distributed energy sources based on cogeneration technologies has been studied in [Lachkov, Fedyaev, 2015; Makarova et al., 2018; Nalbandian, Zholnerchik, 2018].

Despite the wide range of research areas in the field of distributed generation, not so many modern scientific studies pay attention to the use of microgrids and develop methodological approaches to the integrated control of electricity and natural gas purchase costs in the control of microgrids at Russian industrial enterprises [Dzyuba, Semikolenov, 2021a; 2021b; Dzyuba et al., 2022].

An industrial microgrid is an electric power generation facility with an installed generating capacity up to 25 MW, which has direct electrical connections with power receivers of an industrial electricity (power) consumer and only one electrical connection to the Unified Energy System and simultaneously regulates and controls power generation and consumption within a single balance flow. The control process takes into account the possibilities of pricing parameters for the purchase of electricity (power) and natural gas in the current conditions of the energy market and the existing technological restrictions on the permitted power consumption by the power receivers. All components of the industrial microgrid are synchronously controlled on the basis of intelligent functionally integrated devices.

2. Development of methodological foundations for microgrids of the electricity market

Distributed generation systems using natural gas are generally installed near the production sites of large industrial enterprises or directly on the territory of such enterprises. Usually, the electrical load of such enterprises is the main one for DG systems. When designing the power and operating conditions of a generation system, the characteristics of the electricity and power consumption of the base enterprises are taken into account.

It is advisable to locate distributed generation systems close to the sites of electricity consumers for the following reasons.

- Marketing of both electricity and heat energy is possible.
- The systems are located close to distribution gas pipelines.
- The generated electrical and thermal energy is transmitted directly to the consumer with low losses.
- It is possible to synchronise the operating modes of the plants when producing and consuming both electric and thermal energy.
- No need to pay for the transmission through regional electricity networks.
- No need to sell the generated electricity according to the rules for the subjects of the wholesale electricity (capacity) market.
- No need to control a power plant with the dispatching participation of regional and unified energy systems.
- The environmental impact when generating electricity and heat is reduced.
- It is possible to regulate the demand for electricity and natural gas consumption from the Unified Energy System and the Unified Gas Supply System (for enterprises operating in Russia) [Dzyuba, 2020; Dzyuba, Solovyeva, 2021a].

A distributed generation system has a direct electrical connection to the power receivers of an energy consumer, which provides a unified operating system for the consumer and the DG system. The power receivers of both the energy consumer and the DG system also have a parallel connection to the Unified Energy System, which determines the possibilities and limitations for controlling the microgrid system.

Figure 6 shows the structure of a microgrid based on a typical industrial enterprise. The industrial enterprise has consumers of electricity and natural gas that use energy resources for both basic production needs and for auxiliary needs of the enterprise.

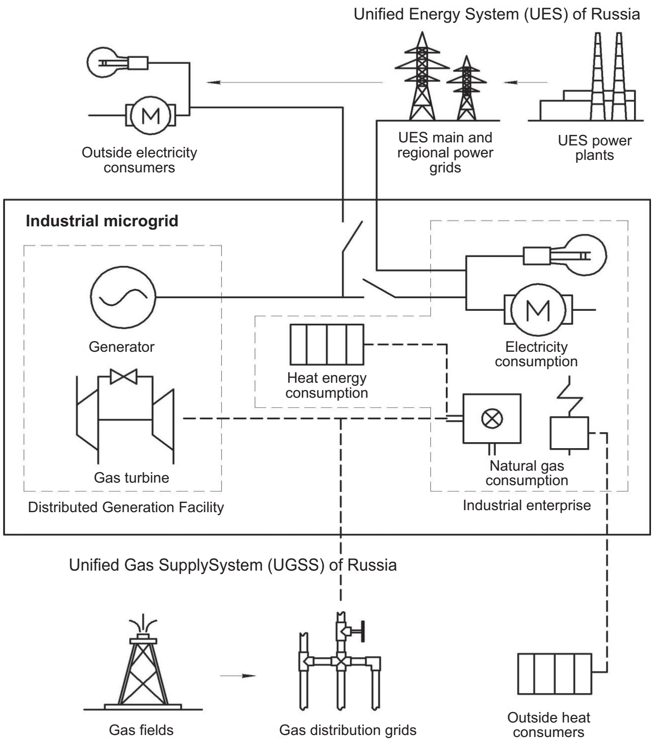
The distributed generation plant also has a generator that produces electricity and a gas turbine that produces high-pressure steam to run the generator. The gas turbine is connected to the gas supply system of an industrial enterprise and consumes natural gas to run the generator and generate electrical energy for the electrical network of an industrial enterprise. A system of electricity and gas supply to an industrial enterprise has technological connections with the Unified Energy System and the Unified Gas Supply System.

The operation modes of electricity and gas-consuming facilities of an industrial enterprise should be synchronised with each other not only directly, i.e. the generation of electricity by a generator, the consumption of electricity by an industrial enterprise, and gas consumption by a distributed generation system and the natural gas consumers of the enterprise, but also comprehensively, i.e. the system of generation and consumption of electricity should be synchronised with the consumption of natural gas.

The management of an industrial microgrid is further complicated by the fact that the power and gas supply systems of the industrial microgrid should be synchronised with the Unified Energy System and the Unified Gas Supply System, with which the industrial enterprise and the microgrid as a whole operate in parallel within a single technological, regulatory, and economic environmental control.

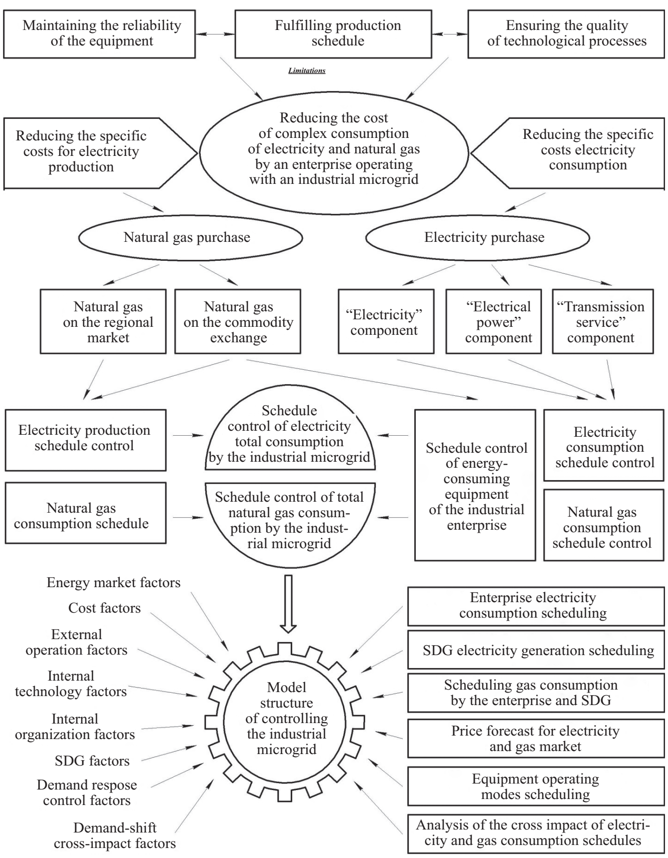
Figure 7 shows the proposed methodological approach to the control of industrial microgrids operating in industrial enterprises. The target function of implementing the methodological approach is to reduce the cost of complex consumption of electricity and natural gas by the industrial microgrid. The limits of the microgrid control are maintaining the reliability of the equipment of an industrial enterprise and

Fig. 6. Industrial microgrid structure



Source: compiled by the authors.

Fig. 7. Structure of a methodical approach to control microgrids of an industrial enterprise



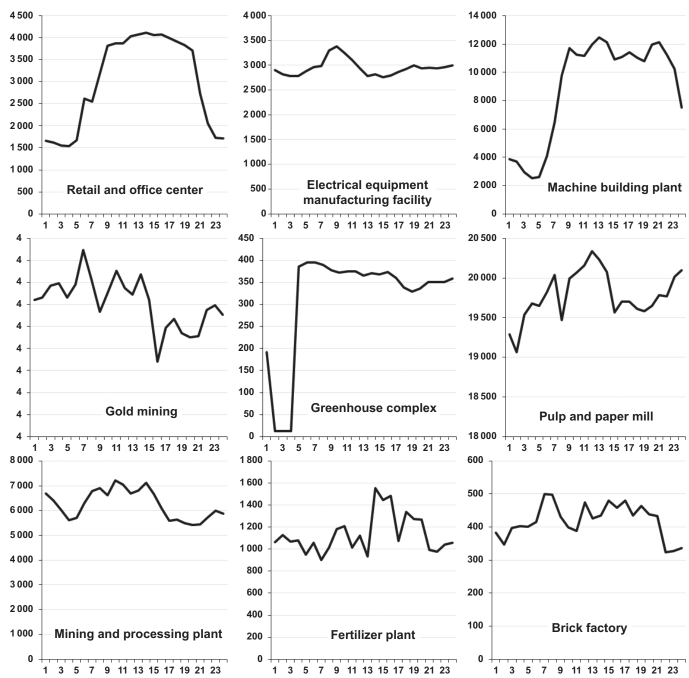
Source: [Dzyuba, Semikolenov, 2021b].

the distributed generation system, meeting the production schedule of the industrial enterprise and ensuring the quality of technological processes in the industrial enterprise and the DG system. In order to achieve the target function, it is necessary to achieve the conditions of synchronous simultaneous reduction of specific costs both for the electricity production by the DG system and for electricity consumption.

When controlling the cost of purchasing natural gas, it is necessary to take into account the cost of purchasing both on the regional market and on the commodity exchange. When purchasing electricity, it is necessary to take into account the purchase on both the wholesale and retail electricity markets for all main components: the cost of electricity and the cost of electricity transmission services.

The control of the electricity and gas purchase cost parts for an industrial microgrid is based on the total simultaneous control of the electricity production schedule of the distributed generation system. Electricity is supplied to the internal network of an industrial enterprise according to the schedule of electricity consumption of an industrial enterprise from the Unified Energy System and the schedule of natural gas consumption by a DG system and gas-consuming equipment of an industrial enterprise. This results in the control of the schedule of total electricity and natural gas consumption by the industrial microgrid. The proposed methodological approach to control the industrial microgrid of an industrial enterprise can be adapted to the infrastructure of energy markets in various countries of the world, where the circulation of electricity and natural gas is carried out within competitive pricing models.

Fig. 8. Hourly graphs of the standard day electricity demand for different types of consumers



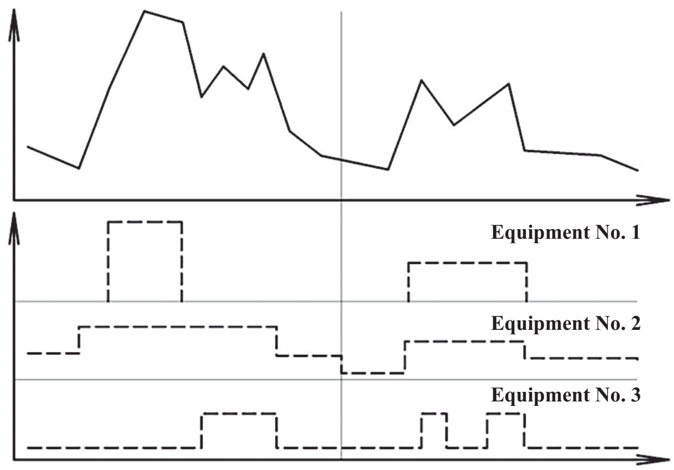
Source: [Dzyuba, Solovyeva, 2021b].

3. Industrial microgrid control integrated with the demand management technology

The shape of the electricity demand curve for an industrial enterprise operating in any country in the world is uneven due to the peculiarities of the operation of the main and auxiliary power consuming equipment [Matos et al., 2021]. Figure 8 shows examples of hourly graphs of standard day electricity demand for different types of consumers. Depending on the specifics of an industrial enterprise, the shapes of the electricity demand curves are individual, which is expressed in the nature of the daily peak, the volatility of the load schedule, the ratio between the daily maximum and the night minimum, etc.

The characteristics of the daily demand curves for different types of industrial enterprises result from the characteristics of the energy-consuming equipment that forms the demand for electricity, and the characteristics of the production processes and equipment operation schedules. Figure 9 shows examples of an energy consumption schedule and industrial equipment operation shedules. It shows that, depending on the modes and operating times of the equipment operating in an industrial enterprise, electricity is consumed from the Unified Energy System with an unevenness formed by the operation of production equipment.

Fig. 9. Electricity consumption schedules and operating schedules of industrial enterprise equipment



Source: [Dzyuba, Semikolenov, 2021b].

The unevenness of work schedules and control parameters of power-consuming equipment in industrial enterprises is associated with the influence of a number of the following factors.

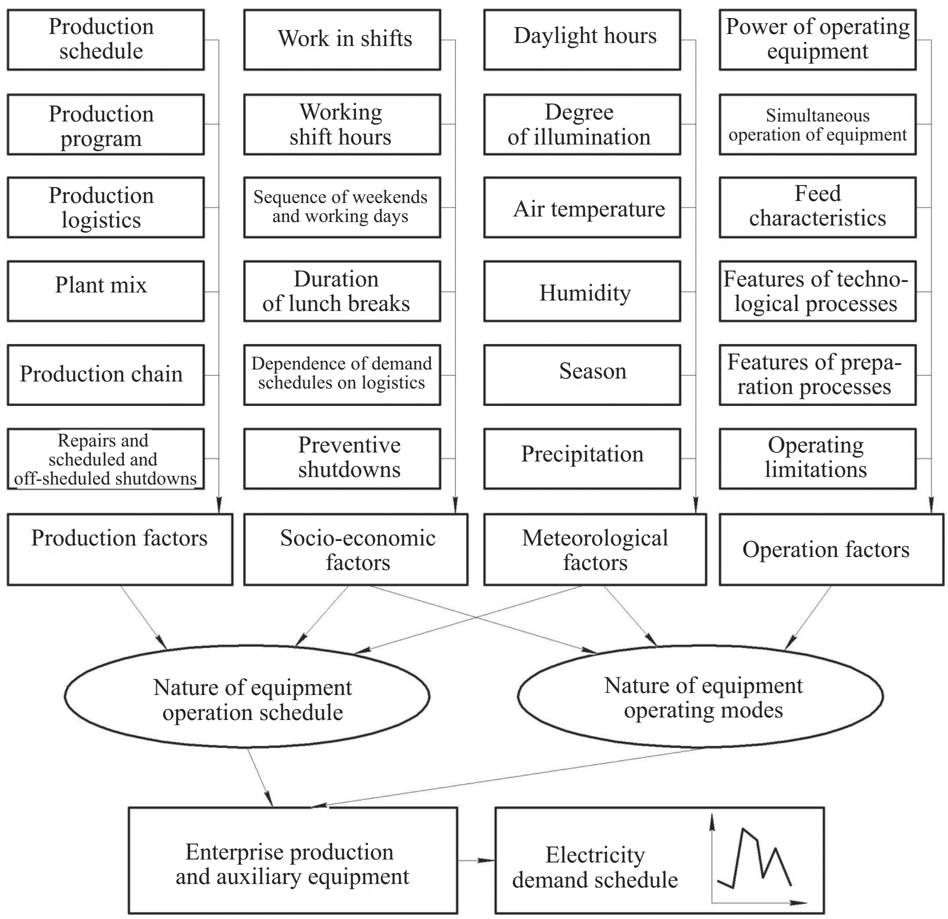
Production factors are factors that influence the change in the schedules of power consumption of industrial enterprises, related to the schedules of production processes and the schedules of the production equipment in an industrial enterprise.

Operational factors are factors influencing changes in the schedules of power consumption of industrial enterprises when controlling operating modes of equipment within the production of specified product groups.

Meteorological factors are factors influencing changes in the electricity consumption schedules of industrial enterprises caused by the influence of changes in environmental indicators, such as air temperature, illumination level, precipitation intensity, etc.

Socio-economic factors are factors influencing the change in the electricity consumption schedules of industrial enterprises associated with the influence of the schedules of

Fig. 10. Structure of the influence of different factors on the uneven demand for electricity consumption in an industrial enterprise



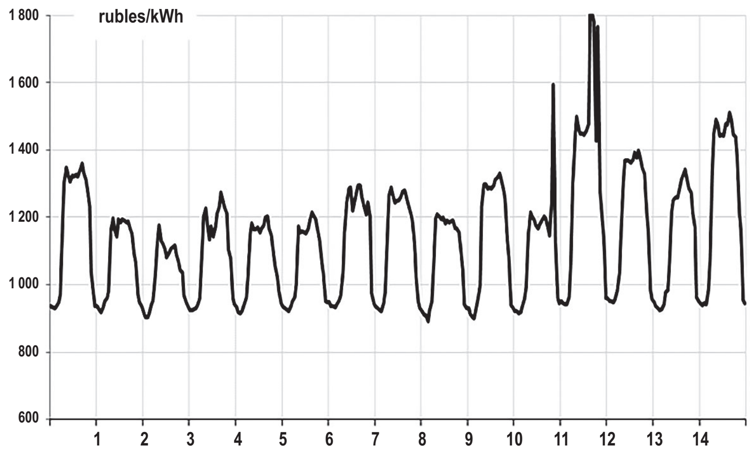
Source: compiled by the authors.

the enterprise, its work in shifts, and the sequence of weekends and working days.

Production and regime factors have a direct effect, while meteorological and socio-economic factors have an indirect effect on the working hours of production and auxiliary equipment in industrial enterprises. The structure of the influence of various factors on the uneven demand for electricity consumption at an industrial enterprise is shown schematically in Figure 10.

The existing instruments of the wholesale and retail electricity markets in Russia and in most countries of the world provide, firstly, for the formation of the final cost of electricity based on the cost of its individual components, and secondly, for the formation of each component of the cost for the industrial consumer individually. The peculiarities of the uneven schedule of electricity demand for a particular consumer should be taken into account.

Fig. 11. Hourly prices for electricity supply in the Tyumen Oblast in November 2021



Source: compiled by the authors.

The cost of electric energy purchased by Russian industrial enterprises consists of the cost of electricity, the cost of electric power, and the cost of electricity transmission services [Dzyuba, Solovyeva, 2020a; 2020b].

The 'Electricity' component of the cost reflects the payment per unit of electricity generated by the power plants of the electricity system. The 'Electric power' component of the cost reflects the payment by the consumer for the possibility of uneven consumption of electricity from the power system and an increase in the schedule of electricity consumption to the maximum permitted values. The 'electricity transmission service' component of the cost reflects the cost to the electricity system of transmitting and distributing the electricity generated, taking into account irregular demand.

The electricity cost is calculated according to the formula:

$$S_{e\_c} = \Sigma[W_t \times P_t], \quad (1)$$

where W_t is hourly electricity consumption of an industrial enterprise during the study period (kWh), P_t is the price for the purchase of the electricity component formed for an industrial enterprise (rubles/ kWh).

Figure 11 shows an example of hourly prices for electricity supply in Tyumen Oblast in November 2021. Taking into account that the prices of sold electricity are characterised by unevenness that repeats the form of volatility of the demand for electricity consumption, the cost of electricity sold on the wholesale and retail electricity markets increases during the day, and, on the contrary, decreases at night. The difference between the day and night prices can reach 55% on some days. Considering that the share of the electricity component in the structure of the total cost of purchasing electric energy by industrial enterprises can reach 40%, the difference between night and daytime peak prices can have a significant impact on the amount of an industrial enterprise's costs.

Therefore, by managing the daily fluctuations in an electricity in an industrial company's electricity demand schedule, it is possible to achieve a reduction in the cost of purchased electricity:

$$S_{e\_c} = f(W_t). \quad (2)$$

Such management of the electricity demand schedule is called price-responsive demand for electricity consumption, which is the management of the uneven schedule of hourly demand for an enterprise, consuming electricity from the Unified Energy System, depending on the price signals of the energy market environment according to the minimum cost criteria for purchasing electricity.

Price-dependent electricity consumption by industrial enterprises is a tool for managing the demand for electricity consumption, which is an initiative form of economic interaction between the electric power industry entities and electricity consumers aimed at jointly levelling the volatility of demand schedules for electricity consumption on the scale of the Unified Energy System [Baev et al., 2018].

The implementation of price-responsive electricity consumption mechanisms makes it possible not only to reduce the electricity purchase costs for each individual industrial enterprise, but also to cut down the expenditure of the Unified Energy System for uneven demand in the energy system of the country as a whole.

The electric power cost component is calculated according to the formula:

$$S_{ep\_c} = \mathrm{T}_{ep\_c\_m} \times P_{ep\_m}, \quad (3)$$

where $\mathrm{T}_{ep\_c\_m}$ is the power value accepted for calculating enterprise obligations for purchasing electric power per month *m* (kW per month), P_{ep_m} is the price for power that is valid for enterprise obligation payment for purchasing electric power per month *m* (rubles/kW per month).

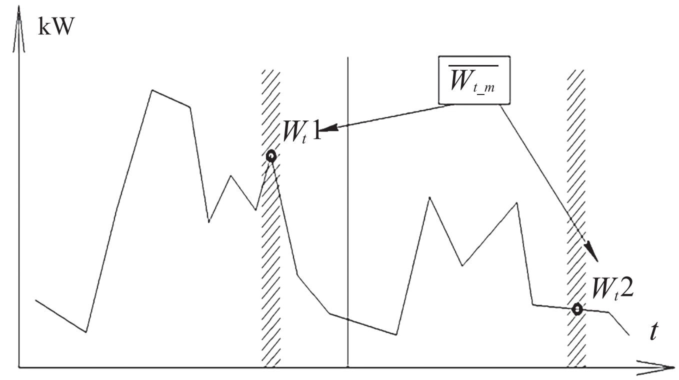
For each billing month, P_{ep_m} is formed based on the market pricing while $\mathrm{T}_{ep\_c\_m}$ is formed based on the personal power demand schedule of the industrial enterprise:

$$T_{ep\_c\_m} = \overline{W_{t\_m}} \ni T_{peak\_region\_SO}, \quad (4)$$

where $\overline{W_{t\_m}}$ is the average hourly electricity consumption of an industrial enterprise for a calendar month *m*(kW), $T_{peak\_region\_SO}$ is the peak hour of the regional electric power system on working days during the periods of planned peak hours determined by JSC 'System Operator'.

Figure 12 shows an example of the value $\overline{W_{t\_m}}$ formation for an industrial enterprise.

Fig. 12. An example of the value $\overline{W_{t\_m}}$ formation for an industrial enterprise (kW)



Source: compiled by the authors.

The value used to calculate the indicator $\overline{W_{t\_m}}$ per day is taken as the number of hours in which the peak hour of the regional electric power system was formed. The electricity consumption of an industrial enterprise per peak hour of the regional electricity system can be quite different. The consumption in this hour can be either very large or very small, which significantly affects the purchase cost in the electricity cost component.

In this way, it is also possible to reduce the cost of purchased electricity by managing the daily fluctuations in an industrial company's electricity consumption pattern:

$$S_{ep\_c} = f(W_t). \quad (5)$$

Table 1 shows peak hours of electricity systems in some regions of Russia for November 2021.

Despite the fact that the number of peak hours of the electricity systems in different regions is quite different, the number of peak hours in each region does not differ significantly, which allows their prediction with a sufficiently high degree of accuracy.

The electricity transmission cost component is calculated according to the formula below:

$$S_{t\_c} = (\mathrm{T}_{loss\_c} \times \sum W_{t\_m}) + (\mathrm{T}_{care\_c} \times \overline{W_{h\_m}}), \quad (6)$$

where T_{loss_c} is the cost rate of technological consumption (losses) within the two-part tariff for electricity transmission (rubles/kWh), T_{care_c} is the cost rate to maintain electricity networks within the two-part tariff for electricity transmission (rubles/kWh), $\sum W_{t\_m}$ is monthly electricity consumption of an industrial enterprise (kWh), $\overline{W_{h\_m}}$ is the average maximum hourly electricity consumption of an industrial enterprise during the planned peak hours of the power system in working days for a calendar month *m*(kW).

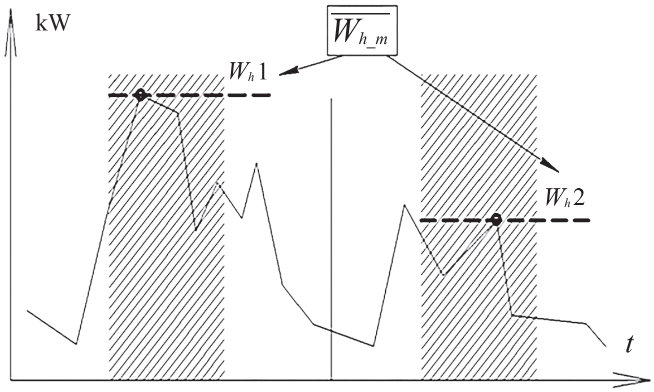
T_{care_c} is the most significant of the two summands of formula (3), and cost management for the T_{care_c} value considerably reduces the cost of purchasing electricity in its transmission

Table 1
Number of peak hours of electric power systems in some Russian regions for November 2021

Data	Kemerovo oblast	Krasnoyarsk oblast	Nizhny Novgorod oblast	Novosibirsk oblast	Perm oblast	Republic of Bashkortostan	Sverdlovsk oblast	Komi Republic	Oryol oblast
01.11.2021	15	15	11	11	17	17	17	18	19
02.11.2021	15	14	11	15	17	17	17	19	19
03.11.2021	15	14	11	7	17	17	17	18	11
04.11.2022									
05.11.2022									
06.11.2023									
07.11.2023									
08.11.2021	15	15	11	8	17	17	17	18	11
09.11.2021	15	15	11	6	17	17	17	18	11
10.11.2021	15	6	10	7	17	17	17	18	11
11.11.2021	15	14	10	15	17	17	17	18	18
12.11.2021	15	15	10	8	17	17	16	10	11
13.11.2021									
14.11.2021									
15.11.2021	15	14	11	8	17	17	16	18	10
16.11.2021	14	15	11	15	17	9	17	19	10
17.11.2021	15	14	11	8	17	17	18	18	11
18.11.2021	15	14	10	8	16	17	17	18	11
19.11.2021	15	14	11	8	11	17	10	18	10
20.11.2021									
21.11.2021									
22.11.2021	15	15	11	8	16	17	16	18	11
23.11.2021	15	15	18	15	17	17	16	19	10
24.11.2021	15	15	10	7	17	17	16	18	11
25.11.2021	15	14	11	7	17	17	16	18	11
26.11.2021	15	14	10	7	16	17	10	18	11
27.11.2021									
28.11.2021									
29.11.2021	15	14	10	8	17	8	17	18	11
30.11.2021	15	14	11	7	16	17	17	18	11

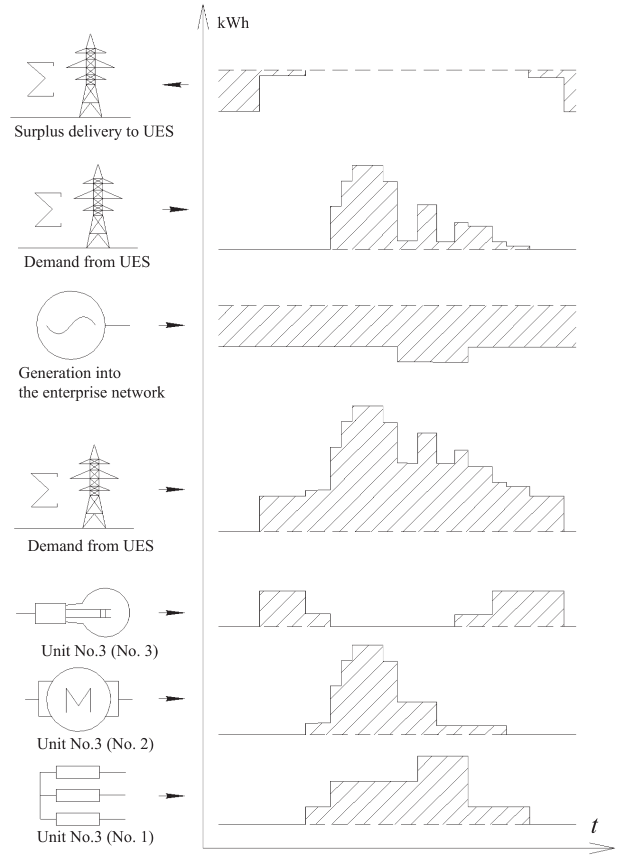
Source: compiled by the authors.

Fig. 13. An example of forming the value $\overline{W_{h\_m}}$ for an industrial enterprise



Source: [Dzyuba, Semikolenov, 2021a].

Fig. 14. Diagram of distributed power generation in the network of an industrial enterprise



Source: compiled by the authors.

service component. Depending on the level of the rated voltage, according to which the cost of the transmission service is calculated (LV, MV2, MV1, or HV), the transmission service cost component can reach 50–60% in the tariff structure.

Figure 13 gives an example of forming the value $\overline{W_{h\_m}}$ for an industrial enterprise. It shows that, regardless of external factors, the value $\overline{W_{h\_m}}$ depends only on the value of internal demand for the power consumption of an industrial enterprise, which the enterprise can manage.

Therefore, by managing the daily irregularity of the demand schedule for electricity consumption of an industrial enterprise, it is also possible to reduce the cost of electricity transmission:

$$S_{t\_c} = f(W_t). \quad (7)$$

Table 2 shows the periods of planned peak load hours of a power grid in the areas of the first and second price zones for the first half of 2022.

The periods of planned peak hours are approved before the beginning of the calendar year and are known to the industrial enterprises, enabling them to manage their demand schedules according to the cost-minimising indicators of the electricity transmission service.

Thus, all components of the cost of electricity purchased by an industrial enterprise on the retail and wholesale electricity market depend on the value of three components, namely the cost of electricity, electric power and electricity transmission services, the value of which is directly related to the nature of the enterprise's demand schedule:

$$S_c = S_{e\_c} + S_{ep\_c}\, S_{t\_c} = f(W_t), \quad (8)$$

where S_c is the cost of electricity purchased by an industrial enterprise (in roubles).

A distributed generation system, operating as part of an industrial enterprise, generates electrical energy in the internal network of the industrial enterprise, thereby substituting the enterprise's consumption of electricity from the Unified Energy System with the electricity generated in the enterprise's network. Managing the schedule of electricity generation into the network of an industrial enterprise makes it possible to control the demand schedule of the enterprise for consuming electricity from the Unified Energy System, and thus to manage all cost components of purchasing electricity, namely, the cost of electricity, electric power and transmission service (Figure 14).

Figure 15 shows the influence of external and internal factors on the operation of a distributed generation system in an industrial enterprise. Internal factors include electricity demand characteristics of the enterprise and the operating mode of the

Table 2
Periods of planned peak load hours of a power grid within the territories of the first and second price zones for the first half of 2022

Zones	January	February	March	April	May	June
First pricing zone	From 8th to 21th hours	From 8th to 13th and from 17th to 21th hours	From 8th to 21th hours	From 8th to 15th and from 18th to 21th hours	From 8th to 15th and from 20th to 21th hours	From 8th to 16th and from 20th to 21th hours
Second pricing zone	From 5th to 8th and from 11th to 17th hours	From 5th to 8th and from 12th to 17th hours	From 5th to 8th and from 13th to 17th hours	From 5th to 8th and from 13th to 17th hours	From 5th to 8th and from 13th to 17th hours	From 5th to 11th and from 13th to 17th hours

Source: [Dzyuba, Semikolenov, 2021a].

DG system. External factors include system constraints and the functional capabilities of the enterprise's power grid, including those for feeding electricity into the grid. Indirect factors affecting the operation of a DG system include price factors.

As an internal factor, the electricity demand characteristics of an industrial enterprise influence the operation of a distributed generation system, resulting in the peculiarities of the internal unevenness of the enterprise's electricity demand and determining the limitations and capabilities of the DG system to generate electricity into the industrial enterprise's network and control the production schedule.

External factors such as system constraints and functional capabilities of the enterprise power grid manifest themselves in possible cross-flow limitations, fuel limitations, fuel supply limitations, etc.

The main indirect factors influencing the operation of a distributed generation system are price factors, which are expressed in the prices for the production of electricity by the DG system, the alternative costs of purchasing electricity from the power grid. It is necessary to take into account the dependence on the time period and the nature of the irregular demand schedule, fuel prices, prices for repairing the DG system, etc.

Based on the study of the characteristics of the pricing of electricity supply to enterprises, the perculiarities of DG system operation, and the external and internal factors affecting their work, the authors have developed a model for the control of industrial microgrids, integrated with the technology for the control of electricity demand (Figure 16).

As part of the model implementation, the analysis of the electricity cycle is carried out in two main directions: the analysis of the domestic demand for electricity consumption by an industrial enterprise and the analysis of electricity generation by a distributed generation system. In the domestic demand direction, the industrial enterprise analyses its production schedules, raw material supply schedules, and the equipment operation schedules to project its planned hourly electricity consumption. Based on the planned hourly schedule of electricity consumption schedules, the parameters of the electricity purchase cost in its main components are predicted.

The obtained value of the planned cost of electricity makes it possible to analyse the possibilities of its optimisation on the basis of price-responsive demand schedules and to model various changes in the operating schedules of production equipment on the based on the criteria of minimising energy costs.

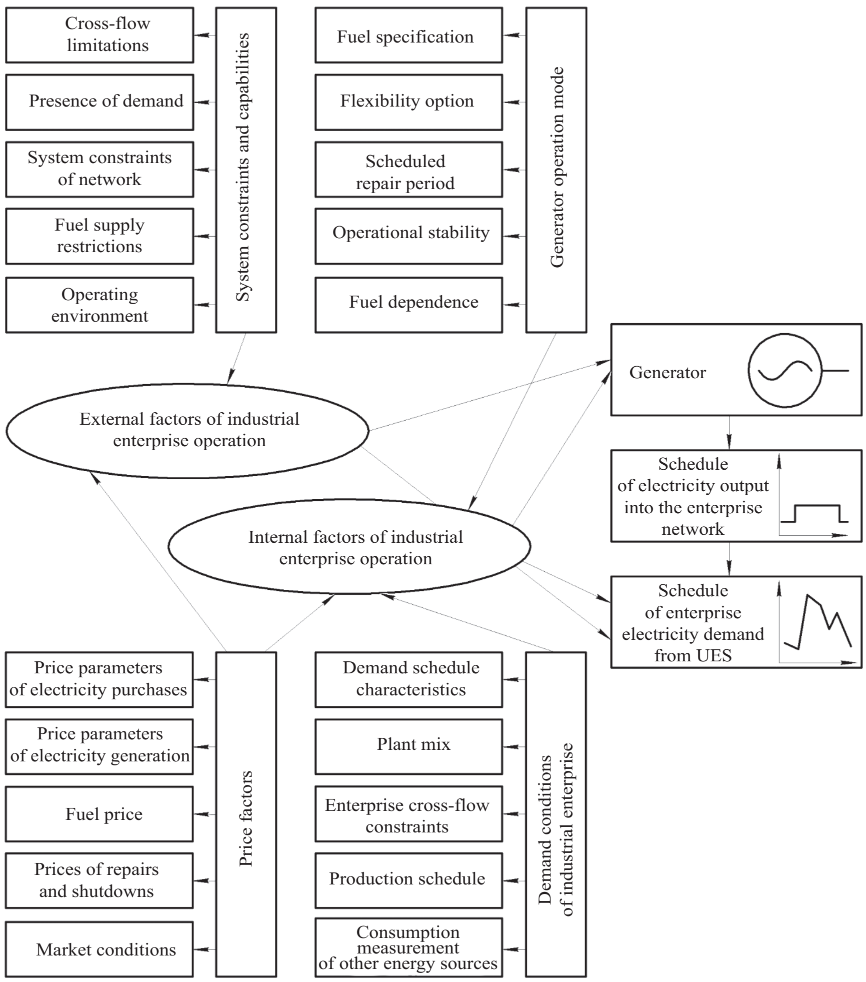
In the direction of DG generation, the planning of a schedule for DG generation into the industrial enterprise's grid is based on an analysis of hourly generation schedules, contractual gas consumption values, and shedules for repairs and equipment shutdowns. On the basis of the planned generation schedules, a forecast is made of the price parameters of the electricity produced by DG for the main cost components. The possibilities of optimising the generation costs and modelling different generation schedules according to the criteria of minimising the production costs of a DG system for an industrial enterprise are analysed.

Based on the results of the analysis of the two main areas, modeling the scenarios for the consumption of electricity by an enterprise and the generation of electricity by a distributed generation system within the framework of an industrial microgrid system are performed.

The modelling takes into account the existing constraints, such as the need to fulfil the production plan of the enterprise and to ensure the system reliability of the enterprise and the technological stability of the equipment of the enterprise and the DG system.

The results obtained are the basis for adjusting the planned hourly schedules for the operation of production and auxiliary equipment at the industrial enterprise, planning hourly schedules for electricity generation by the distributed generation system, and synchronising the planned parameters of the enterprise and

Fig. 15. Factors affecting the power consumption of an industrial microgrid

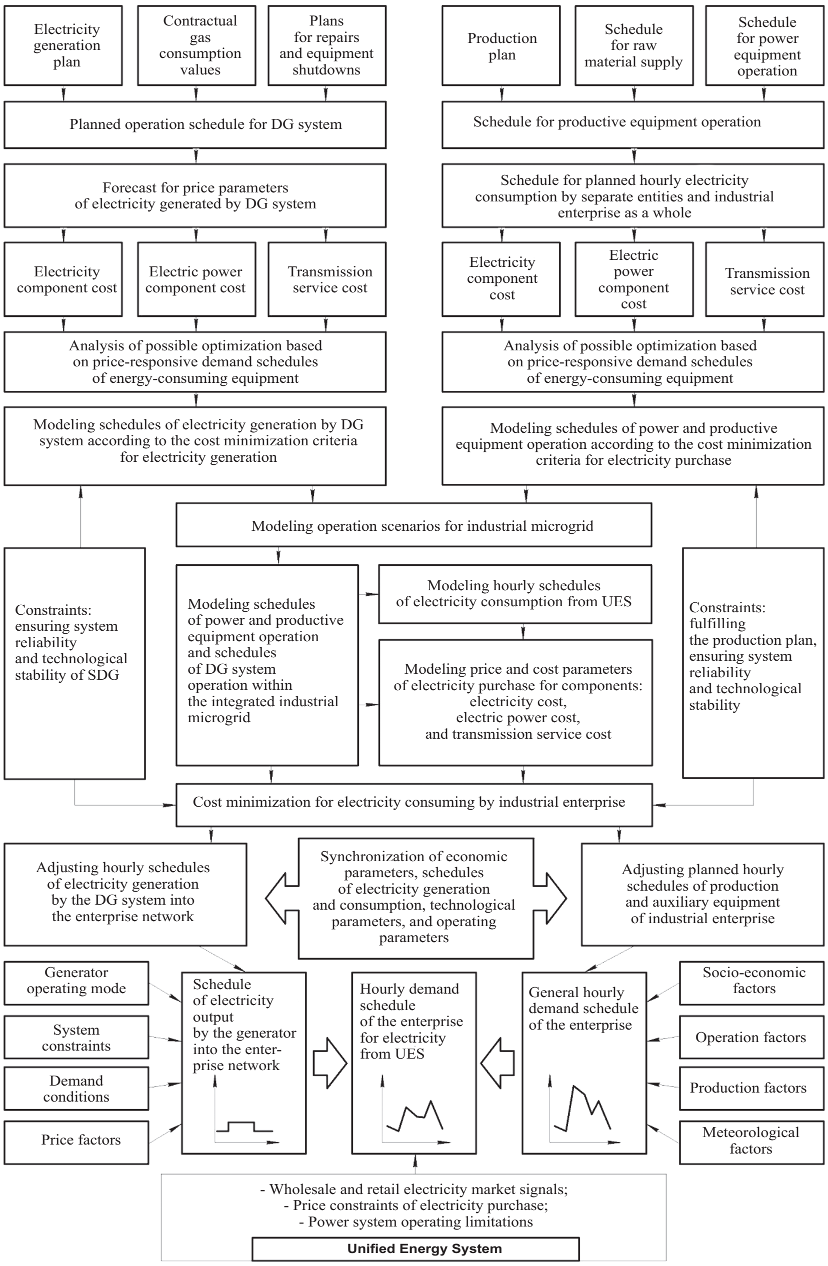


Source: compiled by the authors.

the DG system according to economic parameters, consumption schedules of electricity generation, technological parameters and operating conditions. Electricity consumption not covered by the generation of the distributed generation system is consumed from the Unified Energy System under the conditions of electricity supply from the wholesale or retail electricity markets, which is taken into account when modelling the operation of the industrial microgrid.

Thus, the management of industrial microgrids under their integration with the technology for the control of electricity demand includes the analysis of factors and the internal and external parameters of the enterprise and DG system operation

Fig. 16. Industrial microgrid control model integrated with electricity demand response technology



Source: compiled by the authors.

within a unified industrial microgrid system with simultaneous electricity consumption by an industrial enterprise from the Unified Energy System under the conditions of the wholesale and retail electricity market. The functioning of the model includes planning the operation of the industrial enterprise and distributed generation, forecasting the demand for electricity consumption and electricity market parameters, and modelling various scenarios for the operation of individual elements of the system and the industrial microgrid as a whole are carried out.

Despite the fact that the study and development of the industrial microgrid management model integrated with the technology for controlling electricity demand uses the pricing principles of the Russian wholesale electricity market, it is possible to apply the proposed methodological framework to consumers worldwide. In order to implement the developed management model, it is necessary to adapt it taking into account the peculiarities of the energy market functioning and the principles of pricing of electricity, depending on the volatility of the demand for electricity consumption of industrial enterprises.

4. Implementation of the research results in an industrial enterprise

The proposed management model received practical approval on the basis of a machine building plant operating in the Sverdlovsk region of Russia. The industrial enterprise purchased and installed a small distributed generation system powered by natural gas with an installed capacity of 2000 kW. Previously, the enterprise did not use a small distributed generation system as an industrial microgrid and provided electricity generation for its own consumption in order to increase the reliability of the enterprise's energy supply.

The obtained results of testing the developed model controlling the industrial microgrid in the conditions of integration with the technology of electricity demand management on the basis of the industrial enterprise confirmed the effectiveness of the developed solutions (Table 3).

The effect of using the small distributed generation system as part of the industrial microgrid was to reduce the cost of electricity consumption by 19%, i.e. 5,100,000 roubles per month ($ 80,000), which is approximately 1.275 rubles/kWh in terms of the cost of each kilowatt-hour purchased. Thus, for an industrial enterprise with an electric power consumption of 9 MW, the installation of a small distributed generation system within the industrial microgrid with a capacity of 3 MW enables to reduce energy consumption costs by 19%. This

Table 3
Results of the practical validation of the industrial microgrid control model in conditions of integration with electricity demand management technology

No	Parameter	Units of measurement	Before working in industrial microgrid	After working in industrial microgrid	Difference
1	Total enterprise electricity consumption	MWh	4000	4000	0
2	Enterprise electricity consumption from power system	MWh	4000	2500	-1 500
3	Enterprise electricity consumption from small-scale distributed generation system	MWh	0	1500	1500
4	Electricity generation from small-scale distributed generation system	MWh	0	1500	1500
5	Enterprise electricity consumption from power system	MWh	9	6	-3
6	Electricity transmission services to regional power system operators	MWh	10	7	-3
7	Price of purchasing the electricity component from the power system	rubles/ MWh	2100	2100	0
8	Price of purchasing the electric power component from the power system	rubles/ MWh	800000	800000	0
9	Price of services for electricity transmission to the power system	rubles/ MWh	1100000	1100000	0
10	Price of purchasing the electricity component from small-scale distributed generation system	rubles/ MWh	1500	1500	0
11	Price of purchasing the electric power component from small-scale distributed generation system	rubles/ MWh	500000	500000	0
12	Price of electricity transmission services from small-scale distributed generation system	rubles/ MWh	0	0	0
13	Total cost of purchasing the electricity component by the enterprise	rubles	8400000	7500000	-900000
14	Total cost of purchasing the electric power component by the enterprise	rubles	7200000	6300000	-900000
15	Total cost of transmission service for the enterprise	rubles	11000000	7700000	-3300000
16	Total cost of purchasing electric energy by the enterprise	rubles	26600000	21500000	-5100000
17	Total cost of purchasing electric energy by the enterprise	rubles/ KWh	6.65	5.375	-1.275
18	Total cost of purchasing electric energy by the enterprise	%	100%	81%	-19%

Source: compiled by the authors.

saves more than 60 million roubles per year and covers the cost of purchasing a small-scale distributed generation system, as well as construction and installation work to develop power grid infrastructure and automation systems. The results of the practical approval demonstrate the economic efficiency of using the developed model of industrial microgrid management both in Russia and in other countries of the world.

Conclusion

The research carried out enables us to draw the following conclusions.

1. Despite the development trends in the fuel and energy industry aimed at the gradual replacement of expensive hydrocarbon raw materials by cheaper and cleaner renewable energy sources, in a number of countries, such as Russia, due to the relatively low cost of electricity generation by traditional sources of electricity, the large-scale introduction of RES technologies is not economically justified. Therefore, the vector of power industry development in the countries with a relatively low power generation costs will be different from the global one, and this will continue for the next 20–30 years.

2. Despite the relatively low cost of electricity generation in Russia, there is a significant shortfall in the capacity of the distribution grid infrastructure. The capacity of the distribution grid infrastructure cannot meet the growing electricity consumption of industrial enterprises in the country. In such conditions, the most effective solution is the use of small-scale distributed generation systems powered by natural gas, which makes it possible to meet the demand for electricity and offers many technological and economic advantages.

3. One of the modern directions in the development and use of small distributed generation systems is the use of industrial microgrids. Such microgrids are integrated facilities for the production and consumption of electricity, operating within a unified control system, synchronising the parameters of production and consumption of electrical energy, and allowing industrial enterprises to reduce the costs of final energy consumption.

4. The methodological approach developed by the authors to control industrial microgrids operating on the basis of industrial enterprises takes into account all components of the cost of purchasing energy resources of industrial enterprises, includes the management of production process schedules for the operation

of equipment, schedules for the generation of electricity by a small distributed generation system. It also takes into account the impact of multiple factors acting on the uneven demand for electricity consumption. The methodological approach provides for planning the modes and parameters of synchronous operation of each element of the system under centralised management of the industrial microgrid.

5. The results of the study of price parameters for the purchase of electric energy for industrial enterprises in Russia showed that all components of the cost of electric energy, namely: the component of electric energy, the component of electric capacity, the component of electricity transmission services, are directly related to the type of the volatility of demand for electricity consumption of each industrial enterprise. Price-dependent management of power consumption schedules on industrial enterprises in terms of minimising the cost of electricity can significantly reduce the cost of purchasing electricity from the Unified Energy System.

6. The developed model for managing industrial microgrids integrated with electricity demand management technology is based on the analysis of internal and external operating parameters of an industrial enterprise and a distributed generation system, as well as factors within a unified industrial microgrid system, subject to simultaneous consumption of electricity by an industrial enterprise from the Unified Energy System in the conditions of the wholesale and retail electricity market. The model allows the industrial microgrid system to reduce the complex costs of purchasing electric power.

7. The practical significance of the developments is confirmed by the results of their practical approval at industrial enterprises, which showed a potential saving in the cost of electricity consumption for the enterprise by 20%.

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The article was submitted on 20.03.2024; revised on 10.04.2024 and accepted for publication on 25.04.2024. The authors read and approved the final version of the manuscript.
文章于 20.03.2024 提交给编辑。文章于 10.04.2024 已审稿．之后于 25.04.2024 接受发表。作者已经阅读并批准了手稿的最终版本。

DOI: 10.17747/2618-947X-2024-2-118-133

Systems literacy – A new perspective for innovation managers and engineers

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Abstract

The article presents the results of a study that confirms the high relevance of developing a new critical competence among specialists involved in technological modernisation and import substitution projects – systems literacy, which requires a holistic vision of the interdisciplinary relationships of complex systems. The authors demonstrate that systems literacy is based on systems thinking and systems engineering methodologies, which are particularly relevant to the development of sociotechnical systems that include components of different nature, and their operation throughout their life cycle. An analysis of the differences between engineering and management views of complexity has been carried out, justifying the need to train innovative teams that bring together specialists from different disciplines. The requirements for a new generation of educational products providing advanced training in engineering and economic skills necessary for the development of integrated solutions to complex problems are formulated, and the relevant experience of the Department of Energy and Industrial The management systems of the Ural Federal University, tested in the training of high-tech managers, are presented. The specificity of the application of systems literacy is illustrated by the example of the energy transition problem, which directly determines the achievement of technological sovereignty and involves deep transformations in various industries and market entities.

Keywords: systems literacy, systems approach, systems engineering, interdisciplinarity, modelling, life cycle, innovation.

For citation:

Gitelman L.D., Gavrilova T.B., Kozhevnikov M.V. (2024). Systems literacy – A new perspective for innovation managers and engineers. *Strategic Decisions and Risk Management*, 15(2): 118-133. DOI: 10.17747/2618-947X-2024-2-118-133. (In Russ.)

Acknowledgment

Research funding from the Ministry of Science and Higher Education of the Russian Federation (Ural Federal University Development Programme within the Priority-2030 Programme) is gratefully acknowledged.

系统思维是创新经理和工程师的新视角

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简介

文章中提供了研究结果，证实了在参与技术现代化和替代进口项目的专家中，形成一种新的关键能力——系统思维的高度重要性。这种能力意味着能够全面理解复杂系统之间跨学科的相互关系。研究表明，系统思维的基础是系统工程思维和方法的掌握，这在开发包含不同性质组件的社会技术系统，并在其整个生命周期内进行操作时尤为重要。分析了工程师和管理者在复杂性问题上的不同观点，从而论证了跨学科专家组成的创新团队的需求。 新一代教育产品的要求已经明确，这些产品实现了对工程经济能力的超前培训，这种能力对于解决复杂问题并采取综合性解决方案至关重要。文章提及了乌拉尔联邦大学能源与工业企业管理系在培养高科技业务领导者时所获得的相关经验。
系统思维的应用特点可以通过能源转型问题来展示，这直接影响到技术主权的实现，并预示在不同行业和市场主体中进行深刻变革。
关键词：系统方法，系统工程，跨学科，建模，生命周期，创新。

引用文本：

Gitelman L.D., Gavrilova T.B., Kozhevnikov M.V. (2024). 系统思维是创新经理和工程师的新视角。战略决策和风险管理, 15(2): 118–133. DOI: 10.17747/2618-947X-2024-2-118-133. (俄文)

感谢的话

研究得到了俄罗斯联邦教育与科学部在俄罗斯第一任总统鲍里斯·叶利钦命名的乌拉尔联邦大学“2030优先战略学术领导计划”框架内的财政支持。

Introduction

The rapid development of technology, global megatrends, the spread of digital ecosystems, the diversity of heterogeneous data, and the expansion of artificial intelligence usage – all contribute to a significant increase in the complexity of systems. The creation and management of these systems throughout their lifecycle require managers and engineers to develop a deeper understanding of their nature and the dynamics of the context in which they evolve. This necessitates a systemic perception of reality[1]. Systems literacy combines conceptual knowledge (the properties and behaviour of complex objects, processes, and phenomena) with analytical and cognitive skills (viewing problems in a broad context, across multiple levels of perspective, tracking complex interconnections, analysing endogenous and exogenous factors, recognising patterns, and predicting changes in system behaviour over time to prepare proactive decision options) [Sweeney, 2018].

The need for systems literacy is driven by the following reasons:

1. Changes in nature and society, under the influence of global trends, technological development, and increased interconnections and interdependencies between individuals, market, and governmental structures, demand new approaches to assessing situations, making decisions, and organising daily activities.

2. The traditional analytical approach, based on linear cause-and-effect relationships, is no longer applicable in these conditions (it leads to unforeseen consequences and generates new problems).

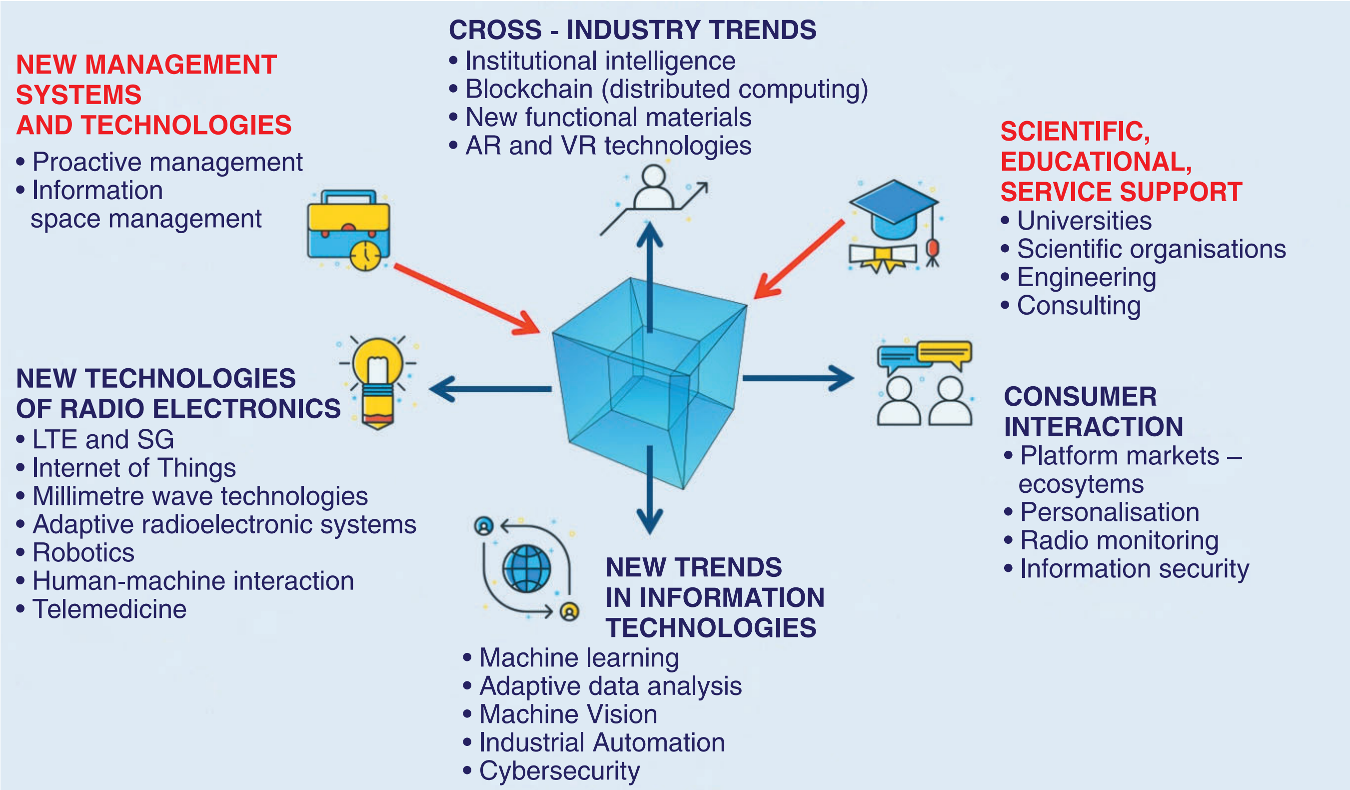
3. The systemic nature of the real world has become a defining factor – it can no longer be ignored. Global crises, climate change, accelerating changes in communication development, supply chains, and the creation of platform models and ecosystems in business can only be viewed from the perspective of a systems approach.

4. New ways of thinking, acting, and interacting require a comprehensive understanding of the structure and behaviour of systems from researchers, designers, managers, and specialists who prepare or make decisions.

A manager's ability to explain in a language understandable to stakeholders the system in which work is being performed, its key features, and what to expect from the system during its evolution also depends on their systems literacy [Dubberly, 2014][2]. Thus, systems literacy becomes the key to making complex engineering, financial, and organisational decisions when creating and developing systems, using a specialised professional language.

[1] Systems engineering vision 2035. Engineering solutions for a better world (2022). The International Council on Systems Engineering (INCOSE). https://www.incose.org/about-systems-engineering/se-vision-2035.
[2] See also: Sustainability studies: A systems literacy approach. (2023). https://courses.lumenlearning.com/suny-sustainability-a-comprehensive-foundation/chapter/sustainability-studies-a-systems-literacy-approach/.

Fig. 1. An example of a contextual analysis of the radio electronics and information technology industry



The foundational level of systemic literacy begins with the ability to represent a management object as a system. This involves understanding the interconnections within the system, the structure of its components, the characteristics of the system's behaviour in an external environment, and the functions it must perform throughout its life cycle. At this level, it is crucial to be able to clearly describe the system's context – the set of factors and circumstances surrounding the system that influence its condition and development.

The system context describes all external elements interacting across the boundary of the specific system of interest and provides sufficient insight into the elements within its boundaries. To fully understand the context, it is also necessary to identify the characteristics of the environment in which the system operates – the so-called systemic environment. Viewing systems in context allows us to focus on the system itself while maintaining a broader systemic perspective. As D. Martin [Martin, 2004] notes, it is important to account for the interdisciplinary influence of other systems, which to varying degrees determine the functioning and development potential of the system of interest throughout its life cycle. Additionally, it should be understood that the dynamics of the context largely depend on stakeholders, who often have differing, sometimes conflicting, views on the goals of creating systems and their interests in using them[3].

1. The Essence of the Systems Approach

The systems approach views an object (phenomenon, process) as a holon – an entity that is, in itself, a whole system, yet at the same time, part of another system, interacting with a mosaic of other holons within its broader environment, whilst also being composed of interacting parts [Koestler, 1967; Hybertson, 2009]. This means that an important skill in the systems approach is identifying 'natural holons' in problem situations and decision-making processes, as well as distributing their responsibilities for specific functions. Therefore, the systems approach defines problems, solutions, and the decision-making process itself according to the following requirements:

- Consideration of the problem as a whole, taking into account the boundaries of the problems and the interconnections of systems;
- Development of solutions that reduce organised complexity;
- Analysis of the context of the system, which generates potential problems and possible solutions (see Fig. 1).

The systems approach involves a comprehensive system perspective that encompasses the broader system context, including the engineering and operational environment, stakeholders, and the entire life cycle. A set of guiding principles has been proposed for implementing the systems approach [Hitchins, 2009].

[3] Systems literacy (2021). https://systemssciencesliteracy.org.

1. Systematic view – Any system of interest (SoI) must be considered within a broader system context.

2. Synthesis – Systems engineering should integrate all parts and develop solutions for the system as a whole.

3. Holism – When making decisions for individual elements, the impact on the entire system must always be considered.

4. Analogy with Organisms – The system should always be viewed as a living organism, changing its behaviour in response to environmental changes.

5. Adaptive Optimisation – Solve problems as they arise.

6. Progressive Entropy Reduction – At early stages of the life cycle, plan all necessary actions for maintenance, support, and system updates.

7. Adaptive Alignment – Design the system's life cycle based on the needs of critical-to-success stakeholders.

A significant application area for the systems approach is the practical use of systems engineering principles when creating and developing complex systems [Sillitto, 2010]. These principles form the foundation for guidelines on applying systems engineering processes. Depending on the purpose, application domain, and level of familiarity with the problem area, such guidelines vary widely – from heuristics (generalising practical experience) to models (developed based on theoretical work). They all support targeted judgements or actions in context, though they may differ significantly in scope, authority, and available capabilities. As experience accumulates, their applicability broadens. Systems engineering principles have diverse origins, being grounded both in practice and theory [Rousseau et al., 2022], and existing systems engineering standards and guidelines include many elements of the systems approach. Examples of principles proposed by the International Council on Systems Engineering (INCOSE)[4] include the following.

1.The application of systems engineering depends on stakeholder needs, the space and outcomes of system decisions, and changes in context throughout the system's life cycle. Consideration is given to budget, schedule, technical requirements, other expectations, and constraints.

2. Systems engineering forms a comprehensive view of the system, its elements, interactions between them, and various factors (political, economic, social, technological, environmental, legal).

3. A real system can only be described by an ideal representation, i.e., an ideal model.

4. Systems engineering decisions are made under conditions of uncertainty, taking risk into account.

5. Complex systems are developed by organised structures that are appropriate in complexity.

2. Systems literacy is developed through systems engineering methodologies

Socio-technical systems are the primary objects of design and support in systems engineering [Checkland, 1978]. These systems are inherently created for a specific purpose and require lifecycle maintenance.

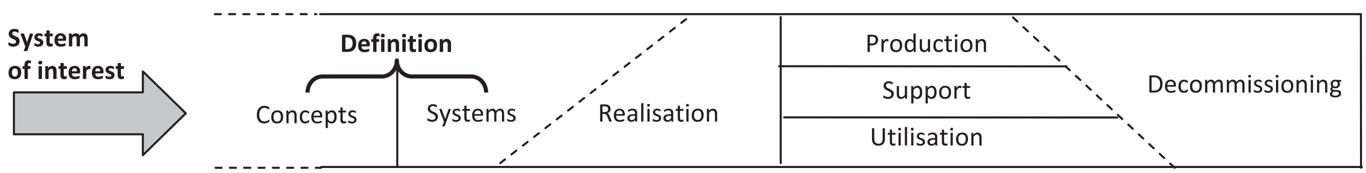
In systems engineering, the concept of the context of a designed system is used to define the system the lifecycle of which needs to be supported (SoI), as well as to identify and align key relationships between it and the systems with which it interacts directly or indirectly. The selection of the SoI boundary for specific activities depends on what can be changed and what must remain unchanged.

In the processes of design and participant interaction, it is useful to shift the boundaries: to view the system of interest narrowly, its overarching system broadly, and the immediate and broader environment as well. This way of presenting the object helps to find the most appropriate solutions in complex situations. It is also helpful to consider differences in the understanding of the system's goals and scope of use by various groups of stakeholders.

For systems engineering, overcoming complexity is of paramount importance, and several categories of complexity are distinguished. Structural complexity is determined by the number of heterogeneous elements and their interrelationships. Dynamic complexity is revealed by changes in the behaviour of the system as it performs its tasks in interaction with the external environment. Socio-political complexity is inherent in systems involving people, who add additional elements of complexity to the system's behaviour. Different types of complexity are interconnected and require attention when designing and operating systems.

Subjectively, complexity is measured by how easily an observer can understand the system or predict what will

Fig. 2. Basic model of the system life cycle



Source: adapted by the authors from: Guide to the systems engineering body of knowledge. http://sebokwiki.org/wiki/Guide_to_the_Systems_Engineering_Body_of_Knowledge_ (SEBoK).

[4] Systems engineering vision 2035… https://www.incose.org/about-systems-engineering/se-vision-2035.

happen to it in the future. Thus, it depends on the personal qualities of the observer (knowledge, comprehension).

Objectively, complexity is an attribute of complex systems, measurable within a range of values from order to complete disorder. It is defined as the degree to which it is impossible to predict the future state of the system based on knowledge of its current state and history. A range of characteristics of system elements and their interconnections is used to assess objective complexity: independence, interdependence, heterogeneity, and adaptability.

Systems engineering has accumulated extensive experience in applying the systems approach to identify and understand complex problems and opportunities, to synthesise alternative solutions, to analyse and choose the best one, and to apply the chosen solution, as well as the associated actions for deploying, using, and supporting the designed systems.

One of the fundamental principles of systems engineering is the focus on designing and supporting systems from a full lifecycle perspective. Systems engineering ensures a comprehensive study of the designed system at early stages, active engagement of all stakeholders, modification of system requirements as new information is obtained, interdisciplinary communications, and modelling of system behaviour throughout its lifecycle. This results in reduced risks and the ability to detect defects at early stages of the project. The overall lifecycle costs are significantly reduced. Projects are completed on schedule, as the time required to correct design errors is minimised. For the same reason, the risk of exceeding the project budget is reduced, and the quality of design and operational performance of the system is improved. This effect is most evident in systems characterised by rapid scalability, dynamism, interdependence, interaction with people, and the use of new and potentially hazardous technologies.

A lifecycle model identifies the key stages that a system goes through from the beginning to the end of its life (see fig. 2). Lifecycle models are mainly applied during the development stage and are closely linked to project management, planning, and decision-making.

The principal lifecycle model describes a set of lifecycle stages and their interconnections. For each stage to be successfully completed, specific technical and managerial actions are required. The set of such actions, associated with a particular stage of the lifecycle, is defined as a separate lifecycle process. The international standard defining lifecycle processes for systems, ISO/IEC/IEEE 15288:2015, includes managerial processes alongside technical ones. These include project processes, agreement processes, and organisational project-enabling processes.

The branch of systems engineering that supports the development of adaptive systems (Resilience Engineering) employs methods that prevent disruptions through proactive actions and enhance the system's survivability (restoring functionality after a failure). The characteristics of systems with resilience and the principles of their design are presented in the works of [Madni, Jackson, 2009; Jackson, 2016].

Resilience is the ability of a system to cope with adverse conditions and disruptive factors while maintaining critical functions at an acceptable level. A resilient system can withstand both predicted events and unexpected, unpredictable external changes. Resilience is achieved through built-in reserves during system creation and through self-recovery capabilities integrated into the design.

Here are examples of solutions from the energy sector aimed at increasing the resilience of energy systems:

– Complementing renewable energy sources (RES), which depend on natural conditions (temperature, wind), with mobile operational reserves (gas-turbine or combined cycle power plants);
– Implementing flexible power plants in addition to large nuclear power plants (adapting the generation structure to the load schedule);
– Developing small-scale energy solutions to regulate the balance of supply and demand. In this case, these active elements ensure reliability and meet the growing demand.

Resilience implies that a system possesses properties such as capacity, flexibility, tolerance, and cohesion [Madni, Jackson, 2009]. Capacity refers to the system's ability to survive under adverse conditions, flexibility denotes its ability to adapt when threats arise, tolerance is the system's capacity to avoid a sharp decline in functionality, and cohesion is the ability of the system's components to unite (to act as a whole) in the face of threats.

Agility is the ability of a system to successfully evolve in a constantly changing environment characterised by uncertainty and unpredictability. Agile systems possess both reactive and proactive capabilities. Generally, agility is ensured by introducing additional active elements that ensure readiness to respond, no matter what happens. For instance, in the energy sector, agility means complementing renewable energy sources with an operational reserve; this reserve increases the flexibility of the energy system, helping it adapt to the development of renewable energy.

To create agile systems and maintain their operation, it is necessary to understand the characteristics of the external environment, the nature of possible changes, and the required responses. Based on this understanding, the architecture of the agile system is developed and enhanced. The CURVE method is used for analysing external environmental factors, which structures the problem space based on key characteristics: Capriciousness, Uncertainty, Risk, Variability, and Evolution.

Based on the analysis of the problem space, the requirements for responding to changes, which the agile system may face in its operations, are formulated. For this purpose, a special tool – response situation analysis (RSA) – is used. The response requirements identified through the analysis determine the architecture of the agile system during the design process or serve as the basis for making changes to its architecture during operation.

Today, systemic solutions are in demand in various fields: for the creation of cyber-physical, service, and multi-component systems. Moreover, interest in systems engineering is growing not only in large-scale projects but also across a wide range of systems design of different complexities and sizes, as well as in the development of socio-technical systems. Furthermore, systems engineering is increasingly becoming a mandatory condition for implementing digital business transformations [Bone et al., 2019; Verhoef et al., 2021][5]. Its inherent transdisciplinary approach – involving the application of universal methods and categories from broader sciences to study specific subject areas of a particular discipline – creates conditions for generating new ideas and solving complex problems, reducing the number of errors, increasing flexibility, and strengthening user trust. Overall, the transdisciplinary approach is a way of expanding one's worldview (scientific cognition), enabling a new level of generalisation and comprehension, resulting in new insights and perspectives on current problems [Professionals in Competition, 2021].

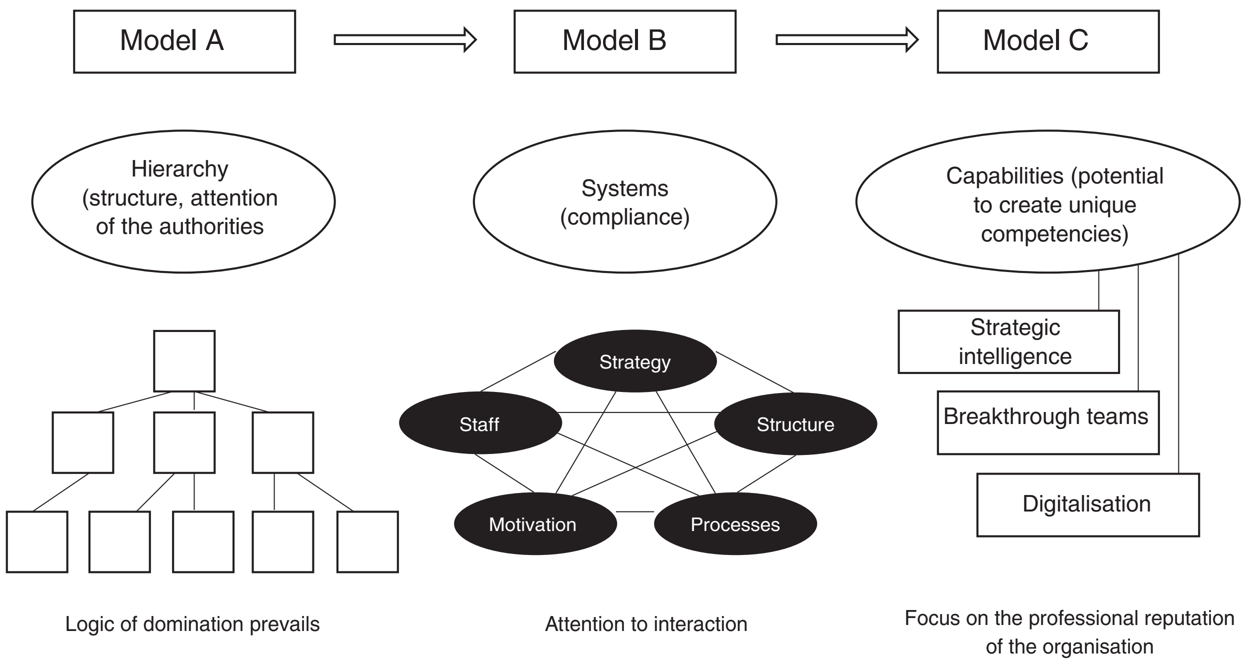
3. Engineering Perspective on Complexity

When creating and developing systems, engineers focus their efforts on overcoming objective complexity, which increases as technology advances and the field of systems engineering expands.

In the early stages of systems engineering, the main challenges were related to ensuring the coordinated operation of the system's diverse technical components and coordinating their developers. Corresponding engineering design methods were created to overcome these difficulties. These methods enable the development of complex technical systems and their maintenance throughout their lifecycle. Examples of such systems include drilling platforms, nuclear power stations, aeroplanes, and space stations. Even systems where complexity is caused by the disordered interaction of many similar elements (such as computer networks or power grids) can be modelled and regulated using statistical methods [Sheard et al., 2015].

The shift to working with higher-level complex systems has largely redirected engineers' efforts towards organised complexity [Weaver, 1948]. Organised complexity can be found in systems with many interconnected and diverse elements that exhibit certain emergent properties and phenomena, often seen in economic, political, or social systems. Such systems cannot be easily described using traditional analysis methods, nor can they be fully addressed with standard solutions or intervention methods. Therefore, the properties and functionality of such systems must be anticipated at the initial design stage (in architectural decisions), and then, by observing the system's behaviour throughout its lifecycle, necessary adjustments can be made to its structure, and their impact on the system's behaviour can be monitored.

Fig. 3. Types of organisational models and emphasis in their description



Source: [Ulrich, Jung, 2022].

[5] See also: Program managers guide to digital and agile systems engineering process transformation (2022). https://sercproddata.s3.us-east-2.amazonaws.com/technical_reports/reports/1666113204.SERC_A013_WRT-1051_Final%20Technical%20Report_V3.pdf.

Practical demands have sparked a wide range of applied research in the area of identifying and assessing system complexity. The results of these studies help in choosing the right approach to analysing, designing, and developing engineering systems. System complexity varies widely, from order to complete disorder; however, 'the real complexity of designed systems lies somewhere in the middle: they have more flexibility and variation than full order, and more stability than complete disorder' [Sheard, Mostashari, 2009].

Particular attention in the engineering view of complexity is given to the human factor. As systems scale up and socio-technical systems develop, the importance of research into human integration within systems increases manifold. When designing models of systems requiring coordinated interaction between humans and technology (e.g., flight control systems), the behaviour of people as system components, which contributes to the overall system complexity, is considered [Axelrod, Cohen, 1999]. Rational or irrational human behaviour in specific situations is a crucial factor in relation to complexity [Kline, 1995]. Some of this complexity can be reduced through education, training, and familiarisation with the system. However, certain factors are unavoidable and must be managed as part of the problem or solution. When designing socio-technical systems, this type of complexity requires separate consideration throughout the system's lifecycle [Checkland, 1999].

Thus, engineers predominantly focus on rigid systems (production complexes, equipment, machinery, units, and the information and communication networks that connect them). The primary goal for engineers is to achieve an optimal level of complexity in such systems to fulfil their functionality, ensure operational reliability for users, maintain relative ease of technical servicing, and guarantee functionality throughout the system's lifecycle.

4. Manager's Perspective: Handling Specific Models

Unlike engineers, managers deal with both hard and soft systems [Checkland, 1999]. This is due to the fact that managers work with a wider range of systems, and they must consider the interests of various stakeholders, focus on personnel motivation and training, and foster communication and collaboration. The priority for managers is business effectiveness, which leads to a specific set of criteria for evaluating systems and the processes occurring within them (see Figure 3).

In this context, the main task for managers is to reduce the subjective complexity of the systems around them, as this is directly linked to increasing the predictability of system behaviour, and, consequently, to improving control. This, in turn, allows for more accurate decision-making regarding system development, resource planning, the formation of business projects, and the creation of teams to implement them.

The problem is that the numerous objectives and outcomes of the systems for which managers are responsible often conflict with one another, are quite uncertain, and are dynamic in nature. The structure of the systems and the interests of their stakeholders, as a system-forming factor, are among the primary considerations that require attention in managerial modelling.

The ability to create models is one of the essential manifestations of systemic literacy in practice [Dubberly, 2014]. Various forms of graphical visualisation can be employed, such as feedback loops, value stream diagrams, goal and action trees, and process maps.

A model is a simplified representation of a system at a given moment in time or space, intended to facilitate understanding of the real system. As an abstraction of the system, it provides insight into one or more of its aspects: functions, structure, properties, performance, behaviour, and cost. The use of modelling and simulation at the early stages of designing complex systems allows for the documentation of functions and requirements for the system, estimation of the costs associated with its creation, identification of necessary trade-offs, and the organisation of continuous monitoring of the system's performance to enhance productivity, reduce risks, and manage costs.

Modelling and analysis can complement testing and evaluation, which occur at later stages of the life cycle. Advanced modelling, such as flight simulators and control centre simulations, can be a cost-effective method for training personnel alongside instruction on operational systems. Modelling helps to make concepts concrete and formal, enhances quality, productivity, documentation, and innovation, and reduces costs and risks associated with system development.

Modelling occurs at many levels: component, subsystem, system, and system of systems – throughout the entire life cycle of the system. Different types of models may be required to represent systems for supporting analysis, specification, design, and verification of system performance.

Fig. 4. Integrated view of the company

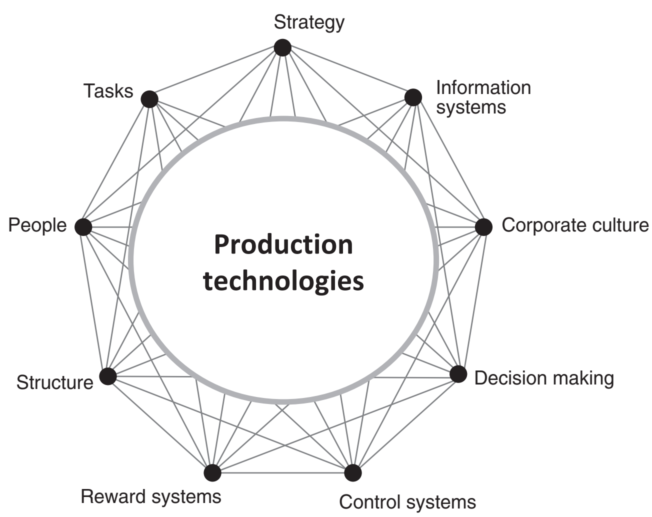
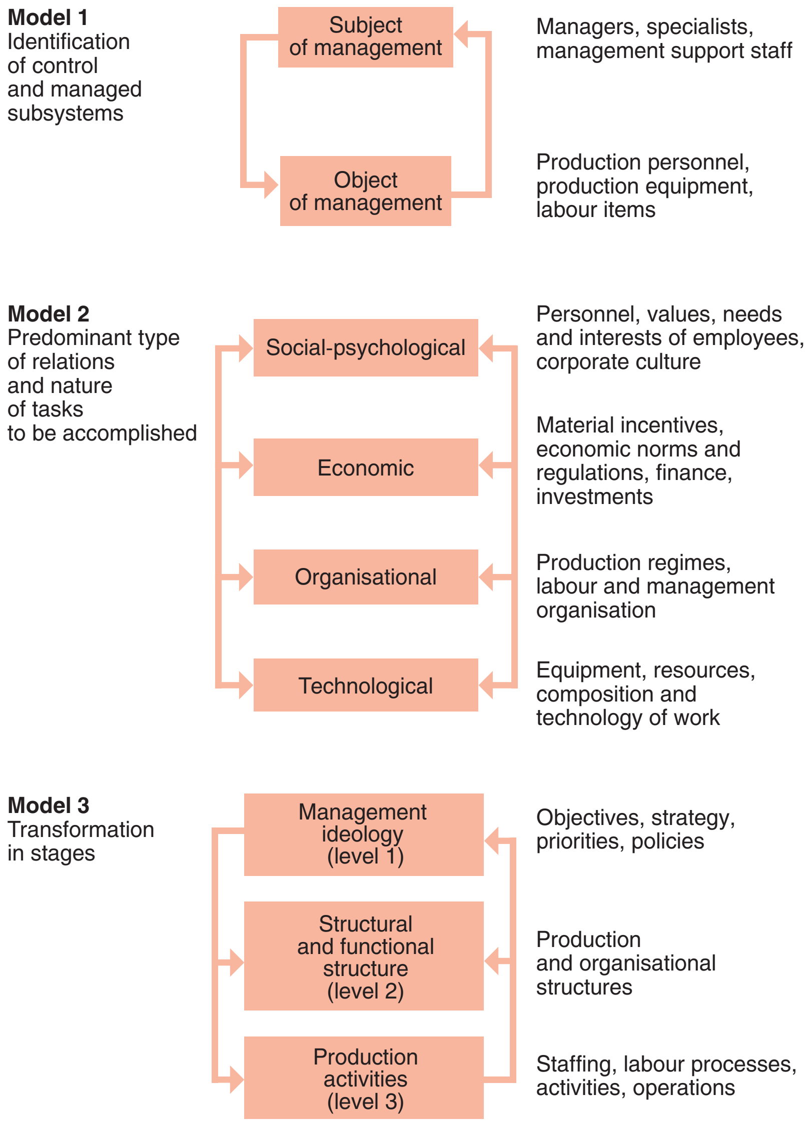


Fig. 5. Complex of business models



Modelling enables the resolution of developmental tasks: it helps to form a holistic view of activities (see Fig. 4), represent them as a structure of interconnected objects and processes, and identify the nuances of interaction with partners and customers. Therefore, for CEOs, top managers, project leaders, and innovation managers, proficiency in modelling techniques is one of the core professional competencies.

One of the most important tasks for managers, addressed through models, is the conceptual representation of business (see Fig. 5). It is this multi-faceted model representation that, by providing a more comprehensive description of the object of interest while considering the goal of accomplishing a specific task, allows for:

– working with each model and the elements (subsystems) within it using their inherent conceptual language;
– examining different aspects in the models from the perspective of interdependent requirements and proportional development of the highlighted levels, strategies, and subsystems;
– organising the staged process of change [Gitelman, 2011].

Transforming real production and management systems (see Fig. 6) is an interdisciplinary task that utilises laws, patterns, categories, and concepts from various sciences (engineering, economics, psychology, law, organisational theory, management, and others). Each of these sciences has its own theoretical foundation and conceptual apparatus. As a result, a wide variety of conceptual models and requirements are formed, which can be very challenging to reconcile in practice.

Fig. 6. Systematic approach to transformation

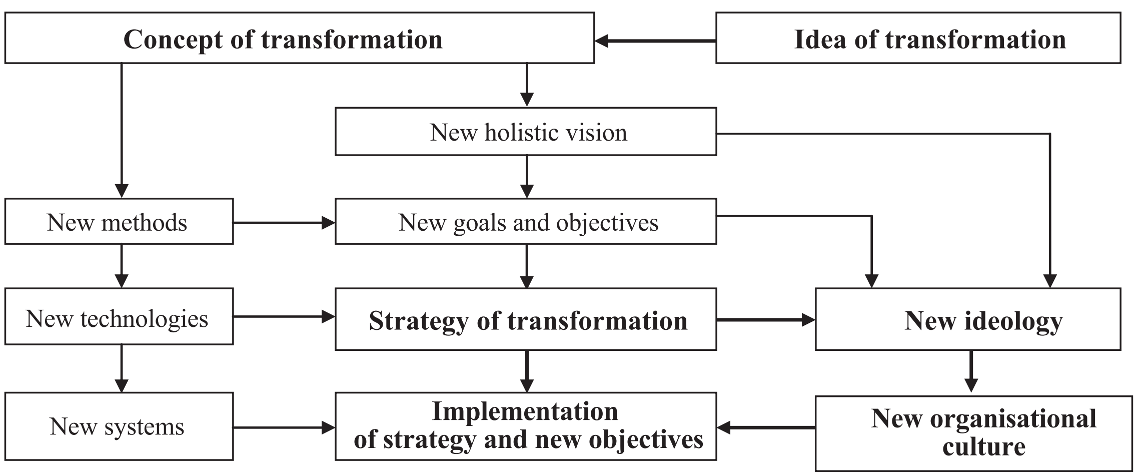


Table 1
Structure of technical and economic competences of managers

Competency clusters	Examples of competencies
Technical and economic	Economic evaluation of engineering solutions Comprehensive analytics Investment assessment in engineering innovations Cost determination and forecasting results of large projects Risk and resource efficiency assessment
Technical and managerial	Creation of early warning systems for threats and opportunities Designing the future of the company Development of leadership strategies Organisation of technological modernisation processes Managing project portfolios Organisation of proactive learning

5. A Critically Important Topic of Systems Literacy – Interdisciplinarity

By interdisciplinarity, the authors mean the synthesis of knowledge from various fields of science and practice and the identification of new interconnections between them, enabling the generation of qualitatively new solutions to complex problems. Understanding interdisciplinarity is particularly essential for managers in sectors that comprise highly complex engineering and technical systems, such as energy, telecommunications, nuclear and oil and gas industries, transport, and the aerospace sector. In these sectors, technology in the broadest sense – from targeted scientific research and engineering development to the implementation of innovations that require specific investments and corresponding financial outcomes – becomes the focal point for various kinds of connections [Gitelman et al., 2022]. Therefore, knowledge of the engineering fundamentals of production and scientific and technological trends, along with their impact on production economics, is a prerequisite for a manager to successfully perform their functions.

This thesis is well illustrated by the extremely relevant issue of the energy transition (hereafter referred to as ET) – the transformation of energy, related infrastructures, and electricity-consuming systems into a carbon-neutral model, realised through structural and technological changes that yield ecological, economic, and technological results [Balashov, 2023][6]. The implementation of the ET is an immensely complex, multifaceted, and ambiguous task, closely intertwining various interests – political, economic, ecological, scientific-technical, engineering, and social. It is evident that this is a complex systemic problem with a time horizon of at least 20–30 years, which is sufficient for realistic foresight and the consideration of breakthrough technologies in the areas of production, transmission, distribution, and, crucially, end-use of all types of energy resources [Gitelman et al., 2023b]. Consequently, the problem includes the potential for phased updating of decisions made at developmental crossroads, taking into account timely risk assessment and investment evaluation.

Interdisciplinary solutions taken during the development of ET projects require a systemic approach, accounting for all non-linear dependencies within complex systems and examining them from the perspective of their entire life cycle. For example, the specifics of employing a systemic approach to the development of the ET concept are as follows:

1) Consideration of energy production in unity and interconnection with electricity consumption through electrification and energy-saving processes.
2) Taking into account regional conditions and factors when forming the target structure of the energy system.
3) Developing the structure and operational regime of the energy system based on a multi-criteria approach that considers economic, ecological, and technical criteria and constraints.
4) A broad diversification of applied methods and organisational forms of electricity production and consumption, which complement one another, taking into account their advantages and problematic features.
5) Analysis of all consequences of using renewable energy sources, including the stages of installation production, operation, and disposal.

The most suitable methodology for making corresponding integrated decisions and their subsequent implementation is systems engineering. At the instrumental

[6] See also: Global energy transformation. A roadmap to 2050 (2018). The International Renewable Energy Agency (IRENA). https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_Report_GET_2018.pdf; Theme report on energy transition. Towards the achievement of SDG 7 and net-zero emissions (2021). United Nations. https://www.un.org/sites/un2.un.org/files/2021-twg_2-062321.pdf.

level, this is ensured by specific competencies – engineering-economic and engineering-managerial (Table 1). Engineering-economic competencies refer to the ability to use economic knowledge when evaluating the effectiveness of creating new technical and technological systems and their operation. Engineering-managerial competencies encompass the ability to organise an active innovative process, implement necessary organisational changes and a suitable corporate culture, manage the life cycle of technological systems, improve internal and external communications, work with personnel, and determine priorities for resource allocation while considering stakeholders' interests. For convenience, the term 'technical and economic competencies' will be used further in this article to denote the mentioned groups of competencies.

It should be noted that interdisciplinary competencies do not arise solely from a good command of the disciplinary knowledge from all academic courses; important additions are necessary for their mastery:

1) Academic disciplines that elucidate the interconnections between different fields of knowledge and provide tools for their integration and practical application in project tasks;
2) Research experience on interdisciplinary topics and problems that demonstrate the essence and importance of interdisciplinary connections and relationships;
3) Practical application of interdisciplinary knowledge to solve real business problems, through which they are transformed into managerial competencies.

Table 2
Implementation of a multidisciplinary approach to the training of managers

Goals of professional training	**Areas and methods for mastering interdisciplinarity**
Students of management – Mastering basic knowledge – Ability to apply it in non-standard situations	Areas of new scientific and technological achievements, sector-specific technologies, and understanding of changes in the content of managerial activities Organisation of R&D using knowledge from various fields Development of systemic, conceptual, strategic, and value-based thinking Conceptual design Business games and teamwork
Lower-level managers – Understanding managerial tasks and basic management systems – Ability to solve non-standard tasks at their level – Ability to work with people and small groups – Mastering the fundamentals of value-based thinking	Demonstration of the multifaceted and complex nature of management knowledge (for engineering graduates) Learning from best practices through the analysis of specific situations Business games, strategic sessions, and teamwork in solving engineering and management tasks
Middle-level managers – Ability to solve non-standard tasks at their level, analyse problem situations, formulate and solve problems – Development of systemic thinking	Integration of management knowledge into a cohesive system Learning from best practices through the analysis of specific situations Conceptual design of development tasks within one's area of activity Business games, strategic sessions, and teamwork in solving innovative challenges
Top managers – Ability to integrate economic, industrial, environmental, political, and cultural goals and solve complex integrated problems – Identify and develop growth points, build breakthrough teams; organise large-scale transformations	Formation of a vision for the future Methods for generating business ideas Behaviour in extreme situations Development of the ability to change vision, strategy, and task priorities Conceptual design of the future Business games, strategic sessions, and teamwork in addressing strategy development and implementation tasks

The goals and methods of interdisciplinary training for managers at different levels of responsibility vary. For lower-level managers, the most important aspect is understanding the interconnections between management systems and the ability to solve atypical tasks. For top managers, priority lies in forming a comprehensive vision for the future, developing competencies for large-scale transformations, managing human capital, and transforming strategic priorities (see Table 2). As shown in the table, the range of interdisciplinarity increases.

Complex problems cannot be solved by simply breaking them down into tasks and assigning responsibility to those with the necessary professional competencies. Non-linear interactions, variability of the system and external environment, and conflicts of interest among stakeholders often mean that it is not even possible to determine what would be considered a successful solution. To manage unpredictable situations, it is essential to maintain a holistic focus on the problem and evaluate the solution as a whole over the entire lifecycle of the system. This requires in-depth knowledge across various fields. Furthermore, science often lacks answers to emerging challenges, necessitating knowledge gained from practice and the ability to generalise accumulated experience in systemic solutions. Interdisciplinary teams can effectively tackle these difficulties, provided there are effective communications and streamlined interactions among team members.

It is also important to emphasise that there is a growing demand for managers, engineers, economists, IT specialists, and professionals from other fields who can work as part of a cohesive team, which implies having a shared conceptual language, a holistic vision of the area for improvement, and proficiency in the tools and methods of systems analysis. In this regard, all team members should possess engineering and economic competencies, albeit with varying degrees of knowledge in areas such as technology, economics, finance, and investment.

For successful actions, members of an interdisciplinary team require knowledge that extends beyond their professional field. To ensure productive interaction, it is necessary to acquire at least a basic level of understanding in related areas, learn to comprehend colleagues with different perspectives, and possess intellectual flexibility, creativity, and the ability to engage in dialogue and collaboration.

Let's take an example from the energy sector. In general, it can be noted that trends in the evolution of the engineering and economic competencies of specialists in this industry are influenced by several factors:

1) the development of energy markets and increased competition;

2) electrification and the displacement of hydrocarbon fuels (the energy transition);

3) the implementation of smart energy systems;

4) the diversification of business and the development of economic relationships between energy suppliers and consumers.

This involves the strengthening and new forms of technical and economic connections within the 'supplier – consumer' framework, including parameters such as the quality and reliability of energy supply (information exchange, mutual financial responsibility for reliability and quality, new economic methods of managing reliability and production efficiency, particularly various demand management mechanisms). The focus of economic activity, not only in the energy sector but also in many other areas of the economy, is shifting from the production-operational framework to a service-oriented one, where polycentric platform-based interactions between market participants are becoming increasingly important.

As a result, the formation of costs and outcomes will become more multi-faceted, and understanding

Fig. 7. Interdisciplinary solutions bring together managers, engineers and economists

interdisciplinarity will become an essential component of systems literacy. For instance, in the promising field of demand-side energy management, the content of engineering and economic competencies will be defined by the need for the following solutions (Table 3).

In a number of studies [Gitelman et al., 2023a; Gitelman, Kozhevnikov, 2023], we have thoroughly outlined the necessary conditions for the 'reset' of engineering-economic education. These include: the revival of engineering-economic faculties; mandatory mastery of the methodologies and experience of systems engineering as the core of fundamental training; a transition to specialised programmes; and a sharp increase in the volume of practical work within the curriculum of relevant programmes. However, an equally important condition is the radical revision of the forms, principles of organisation, and methods of the educational process [Bogomolov, 2022; Ermolov, 2022]. In this context, advanced training is becoming highly relevant – a technologically organised process of acquiring knowledge and competencies to solve future tasks aligned with global trends and national development programmes. It is worth noting that advanced training is carried out using the latest tools, including digital resources, which enable the flexible design of programmes that enhance the attractiveness of professional activities for young people and engage students in addressing current challenges.

The experience of the Department of Energy and Industrial Enterprise Management at Ural Federal University in implementing advanced engineering-economic education demonstrates the high effectiveness of its technological organisation [Professionals in Competition, 2021]. Among the actively developed

Table 3
Technical and business skills in implementing demand-side management programmes

Type of solution	Examples of solutions	
	At the energy company	At the consumer's
Engineering	Assessment of growth opportunities, manoeuvrability, and capacity of generating equipment Changing the mode of power plant operation in the energy system and the structure of generating capacities (e.g., refusal to commission expensive peaking capacities or increase the capacity utilisation factor of base power plants) Reducing the amount of grid capacity redundancy Introduction of load telecontrol and information technologies in the 'supplier-consumer' loop	Switching units to the 'consumer-controller' mode Forcing the unit's performance in the hours of load drop Changing equipment repair schedules Organisation of night shifts
Economic	Planning and evaluation of energy and capacity savings based on the results of demand management programmes implementation Saving of current costs and capital investments in new capacities, especially peaking ones. Budget and programme efficiency Mechanism of economic motivation of consumers	Cost analysis of changes in power consumption modes Results and efficiency taking into account preferences provided by the energy company related to reduced payments for electricity and capacity
Managerial	Designing programmes for design management Coordination of programme implementation schedule with authorities, energy service companies, equipment suppliers Development of incentives for programme participants	Institutionalisation of participation in demand management programmes (preparation of internal regulatory framework, regulations, responsible persons, adjustment of business processes, etc.)

technologies directly used for mastering the systems approach and systems literacy are:

- a digital database of engineering-economic knowledge, which stimulates self-learning and allows for targeted searches for books, articles, and analytical reports by department lecturers for project-research work (Fig. 8);
- virtual tours of leading industrial enterprises to study the technical aspects of complex systems based on their digital twins;
- conceptual design of innovative transformations using a reference model of organisation and continuous project-research work in collaboration with lecturers and external experts.

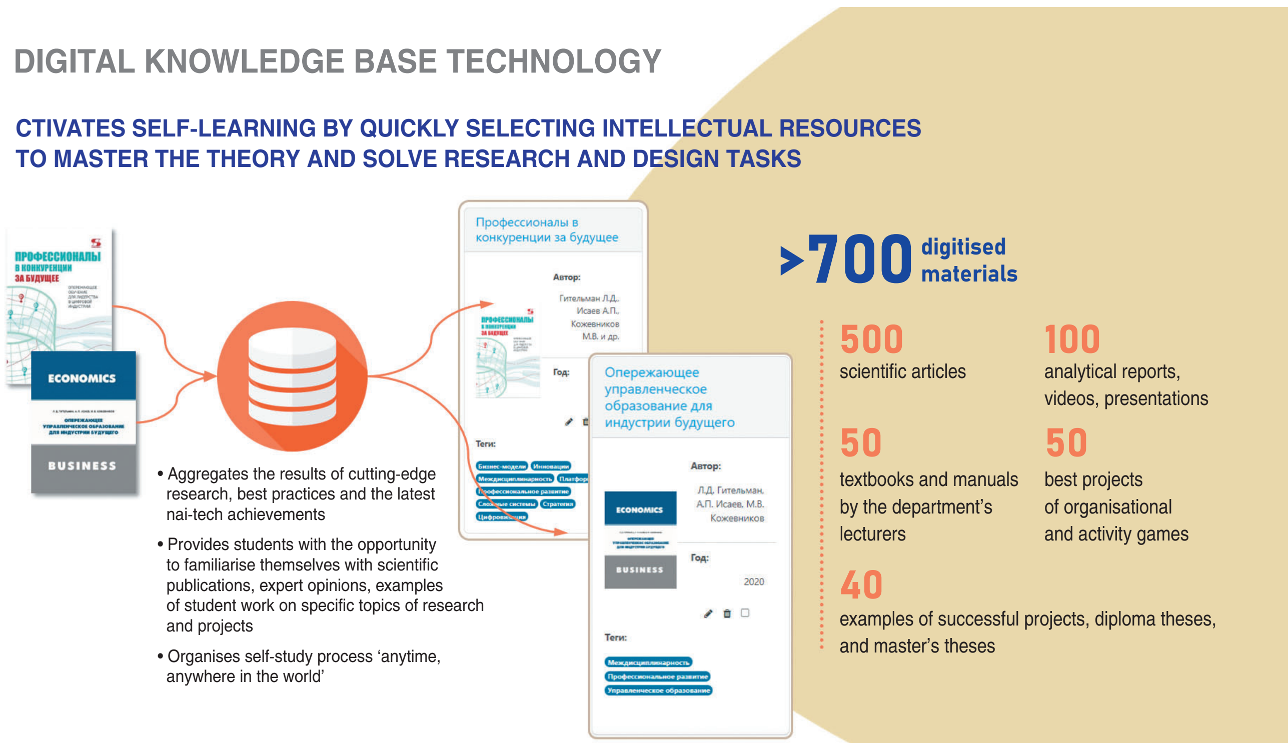
Conclusion

Modern engineering developments represent complex systems and systems of systems, which are based on the interaction of components of various natures and continuously improve throughout design and operation. In the creation of such systems, the interaction between the technical-technological factors of production and the man – their knowledge, skills, and values – is becoming increasingly important, with engineering and humanitarian aspects needing to complement rather than contradict one another. A holistic view of systems, the ability to predict their behaviour under uncertainty, and the organisation of their development and operation in a way that meets the interests of diverse stakeholders – collectively referred to as systems literacy – becomes an essential attribute for managers, engineers, and teams involved in innovative activities.

In the processes of comprehensive modernisation and import substitution, the demand is not only for breakthrough innovations but particularly for their rapid scaling (i.e., organising mass production under resource constraints). The tasks of bringing the latest products and technological solutions to market and energising the innovation process lie within the remit of managers who lead teams and work alongside engineers, economists, and IT specialists. Therefore, in these new realities, systems literacy focuses on understanding interdisciplinary connections and the impact of technologies on the economic, financial, investment, environmental, and social outcomes of enterprises. This significantly highlights the importance of engineering-economic competencies – the ability to evaluate the economic efficiency and market potential of newly developed engineering and technical systems. The issue of accelerated training of personnel with such competencies, under the necessity of achieving technological sovereignty, takes centre stage.

At the same time, systems literacy becomes an integral part of basic engineering-economic training. It enables individuals to perceive systems in the surrounding world (to interpret and evaluate ongoing events through the lens of systematic thinking), to detect and identify patterns

Fig. 8. Visualisation of the Digital Knowledge Database technology



in the dynamics of systems' behaviour, to use acquired knowledge and observations to solve emerging problems and take advantage of arising opportunities, and to learn from experience by adjusting knowledge and actions in line with changes in context and the market environment of the system.

The experience of understanding and developing systems thinking, forming a systemic worldview, and practically applying the systems approach has been accumulated through systems engineering. The tried-and-tested methodologies for overcoming complexity and ensuring adaptability and flexibility in designed systems can be widely used in management, with adjustments for the nature and character of the problems being addressed. Thus, a mandatory condition for the 'reset' of engineering-economic education is the mastery of systems engineering methodologies and experience as the core of fundamental training.

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The article was submitted on 05.04.2024; revised on 21.04.2024 and accepted for publication on 25.04.2024. The authors read and approved the final version of the manuscript.
文章于 05.04.2024 提交给编辑。文章于 21.04.2024 已审稿．之后于 25.04.2024 接受发表。作者已经阅读并批准了手稿的最终版本。

DOI: 10.17747/2618-947X-2024-2-134-151

Decision-making factors for adopting artificial intelligence technologies and transforming sources of sustainable competitive advantage

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Abstract

Technologies based on artificial intelligence are increasingly replacing and augmenting humans in managerial tasks such as decision-making. Modern artificial intelligence (AI) technologies are capable of performing cognitive functions previously associated only with the human mind. According to the company's resource concept (RBV), people's cognitive abilities are a source of non-copyable competitive advantages because they are difficult to simulate, so AI technologies can change the sources of competitive advantages. This study aims to identify the factors that influence the decision of industrial companies to adopt artificial intelligence technologies, as well as to examine the relationship between the adoption of AI technologies with the effects of replacing and/or complementing the cognitive abilities of employees and their impact on the formation of a competitive advantage. The study was conducted on the database of 147 industrial companies, empirically estimating the occurrence of the substitution effect during the introduction of AI technologies. The complementarity effect was estimated using two models: a random effect probit model with random effects (random effect probit) and a fixed effect logit model with fixed effects (fixed effect logit). This made it possible to assess the intra-firm dynamics of resource changes during the implementation of AI technologies in the business process – that is, to trace the effect of resource substitution during the implementation of AI. The results showed that: (1) The decision to invest in AI technologies depends on factors such as the availability of skills to implement AI, the cost of implementing new technologies and the level of current costs in the company as a whole, the expectation of financial and economic impact. (2) The decision to invest in AI is significantly more prevalent among companies that are currently waiting to implement it. The benefits of such investment are manifold. Firstly, it allows for a reduction in the time taken to complete operations. Secondly, it enables a reduction in the number of employees required, due to a reduction in the volume of routine operations. Thirdly, it allows for a reduction in the cost of personnel management. Finally, it facilitates a greater speed of development and promotion of new products. (3) The introduction of AI has the greatest impact on the formation of non-copied competitive advantages, particularly in the following areas: marketing and analytics, development and IT, sales and customer service and the development of new products. (4) The introduction of AI gives rise to both a substitution effect and a complementarity effect, which together result in a shift in the sources of competitive advantages. While the replacement of traditional, domain-specific human cognitive capabilities with numerous computing capabilities of AI leads to the destruction of existing advantages, the complementarity of human and machine capabilities allows for the creation of new, permanent non-copied advantages. The company's resource concept is augmented, and it is shown that heterogeneous unrelated resources, such as human capital and machinery, can also serve as a source of distinctive competitive advantages.

Keywords: machine learning, neural networks, industrial companies, company resource theory, substitution effect, complementarity effect.

For citation:

Trachuk A.V., Linder N.V. (2024). Decision-making factors for adopting artificial intelligence technologies and transforming sources of sustainable competitive advantage. *Strategic Decisions and Risk Management*, 15(2): 134-151. DOI: 10.17747/2618-947X-2024-2-134-151. (In Russ.)

Acknowledgment

The article was prepared on the basis of the results of research carried out at the expense of the budget within the framework of the state mission of Financial
University under the Government of the Russian Federation.

引入人工智能技术的决策因素及其对可持续竞争优势来源的转型

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简介

基于人工智能（AI）的技术在管理任务（如决策制定）中越来越多地替代和补充人类。现代人工智能技术能够执行以前仅与人类思维相关的认知功能。根据资源基础观（RBV），人类的认知能力是难以复制的竞争优势来源，因为它们难以模仿。因此，人工智能技术能够改变竞争优势的来源。

本研究旨在探讨影响工业公司引入人工智能技术决策的因素，以及研究引入人工智能技术与替代和/或补充员工认知能力的效果及其对形成竞争优势的影响之间的关系。本研究基于147家工业公司的数据进行。采用两种模型对引入人工智能技术时出现的替代效应和互补效应进行了实证评估：随机效应Probit模型和固定效应Logit模型。通过这些模型，可以评估公司内部在将人工智能技术引入业务流程时资源变化的动态，从而追踪人工智能引入过程中资源替代的效果。

研究结果表明：(1)决定投资人工智能技术的因素包括：实施人工智能的能力、引入新技术的成本、公司整体的现有成本水平，以及对财务和经济效益的预期。(2) 预期通过人工智能技术减少操作时间、减少员工数量（因为减少了常规操作的工作量）、降低人力资源管理成本，以及加快新产品的开发和推广速度的公司，其投资人工智能的决策和投资强度显著更高。（3） 将人工智能引入市场营销和分析、研发和IT、销售和客户服务以及新产品开发，对形成不可复制的竞争优势影响最大。（4）在引入人工智能的过程中，同时出现了替代效应和互补效应，这改变了竞争优势的来源。虽然用人工智能的计算能力替代传统的行业特定人类认知能力会破坏现有优势，但通过人类和机器能力的互补，能够创建新的、持久的不可复制优势。本研究补充了资源基础观，表明异质的、不相关的资源（如人类和机器）也可以成为独特竞争优势的来源。

关键词：机器学习、神经网络、工业公司、资源基础理论、替代效应、互补效应。

引用文本：

Trachuk A.V., Linder N.V. (2024). 引入人工智能技术的决策因素及其对可持续竞争优势来源的转型.战略决策和风险管理, 15(2): 134–151. DOI: 10.17747/2618-947X-2024-2-134-151.

致谢

该论文是使用财政大学政府任务拨款资助的研究结果编写的。

Introduction

Artificial intelligence (AI) technologies are becoming increasingly important in optimising business processes. According to the consulting company ‘Yakov and Partners’, the Russian AI market in 2022 is estimated at 30-50 billion roubles per year, and is expected to grow to 26-36 trillion roubles by 2028.[1] At the same time, the speed of development of AI technologies is making them increasingly accessible to companies that use AI to solve problems in business functions.

A kind of inflection point in the development of these technologies was passed with the creation of generative AI technology. Modern artificial intelligence technologies are capable of performing cognitive functions previously associated only with the human mind [Rai et al., 2019]. Management researchers have suggested that AI is changing the sources of competitive advantage [Davenport, Kirby, 2016, p. 204; Wilson, Daugherty, 2018, p. 214], but their views on how this change is occurring are contradictory.

[1] Artificial Intelligence in Russia – 2023: Trends and Perspectives. Moscow, 2023. https://yakov.partners/upload/iblock/c5e/c8t1wrkdne5y9a4nqlicderalwny7xh4/20231218_AI_future.pdf?ysclid=lz13ttscls470347383.

A number of studies have shown that AI is replacing human cognitive skills [Balasubramanian et al., 2022] and described how AI technologies are replacing investors [Noonan, 2017], hiring managers [Chamorro-Premuzic et al., 2019] and doctors, including for diagnosis or surgery [Blakely, 2020].

Other studies argue that AI technologies merely complement rather than replace human cognitive abilities [Murray et al., 2021], with investors, managers and doctors using AI to assist with investments, hiring or treatment [Topol, 2019].

According to the resource-based view of the firm (RBV) [Barney, 1991], people's cognitive abilities are a source of non-copyable competitive advantages because they are difficult to imitate. These advantages are a source of competitiveness and allow firms to become leaders due to higher productivity, unique strategies, innovation efficiency and the formation of a better value proposition [Kunc, Morecroft, 2010; Helfat, Peteraf, 2015].

If AI technologies replace human cognitive abilities, then from the perspective of the resource concept, human cognitive abilities cease to be non-copyable competitive advantages because the technologies created and commercialised have low imitation barriers [Brynjolfsson, McAfee, 2014, p. 31]. Conversely, if AI technologies complement human cognitive capabilities, then this will be an added value from an RBV perspective [Argyres, Zenger, 2012], because widely applicable AI technology enables the creation of unique bundles of previously unrelated resources, such as the expertise of doctors and the machine prediction of AI [Agrawal et al., 20-24]. That is, this claim is based on the unique properties of AI technology itself.

Stadler et al [2021] show that when organisations use both familiar and new technologies, a dual effect of resource substitution[2] and complementation occurs[3]. However, in the case of the use of AI technologies, the authors found a substitution effect, but no complementation effect.

However, the results of such studies do not provide answers to questions about the relationships between substitution and complementarity effects, the drivers of these relationships, and possible pathways to new non-copyable advantages.

The article aims to analyse the factors that influence industrial companies' decisions to implement artificial intelligence technologies, the relationship of these technologies with the effects of substitution or complementarity of employees' cognitive abilities, and the impact on sources of competitive advantage.

1. Theoretical review of the literature

Artificial intelligence technologies are systems and services based on machine learning models. Machine learning models have a long history of development, from finding a linear relationship between several factors to using neural network architecture with billions of parameters, which allows them to find complex relationships in data. Today, the following types of models are used in business[4]:

- Predictive AI models are used to predict future events or outcomes based on historical data. They can be used in a variety of fields, including finance, healthcare, marketing and many others. In finance, for example, they are used to predict exchange rates and stock prices or to identify fraudulent transactions; in manufacturing, they are used to predict raw material requirements, prevent breakdowns and plan repairs; in commerce, they are used to predict demand for goods or services;
- AI optimisation models are used to solve optimisation problems or to find the best solution among a number of possible options; they are also widely used in various fields: for example, in medicine – to determine the most effective method of treatment or the best way to perform surgery and prevent complications; in logistics – to optimise routes, predict traffic congestion; in procurement – to reduce costs; in manufacturing – to optimise production processes and reduce costs;
- Generative AI models – models that use the data used for training to create new data of different modalities; in business, they are mainly used to generate text and images;
- Large Language Models (LLMs) – machine learning algorithms that can generate text based on input; used to generate, summarise or modify text;
- Natural Language Processing NLP (Speech, Recommendation and Personalisation) – Technologies that analyse and interpret human language; used in chatbots, customer support, search engines, etc;
- Computer vision CV – an area of AI concerned with the analysis of images and video by computers, including pattern recognition, image segmentation, etc.; used in medicine, robotics, security, etc.

All the models described are based on three types of machine learning models:

1) the model is trained on a database with target response values;
2) the model is trained on data without a target outcome (the model itself looks for patterns in the data);
3) training on feedback based on rules or the trainer's judgement.

Thus, unlike previous technologies, AI technologies enable machines to learn and act autonomously [Balasubramanian et al., 2022], which in turn enables AI to interact with humans in decision making and problem solving [Murray et al., 2021]. As a result, AI has the potential to both replace and augment human cognitive abilities [Raisch, Krakowski, 2021].

Existing literature in the resource-based approach argues that the substitution effect eliminates competitive advantage when new resources with high availability

[2] The substitution effect occurs when the use of one resource leads to a reduction in the use of another (substitute resources).
[3] A complementarity effect occurs when the use of one resource increases the use of another (complementary resources).
[4] Artificial intelligence in Russia… https://yakov.partners/upload/iblock/c5e/c8t1wrkdne5y9a4nqlicderalwny7xh4/20231218_AI_future.pdf?ysclid=lz13ttscls470347383.

replace traditional resources providing the same functionality, while the complementarity effect creates competitive advantage when traditional and new resources are integrated to form new unique resource bundles [Peteraf, Bergen, 2003; Levinthal, Wu, 2010; Polidoro, Toh, 2011; Argyres, Zenger, 2012].

Works [Brynjolfsson, McAfee, 2014; Agrawal et al., 2018; Choudhury et al., 2020; Raisch, Krakowski, 2021] describe AI as a new technological resource of strategic importance that can learn and act independently of humans. Humans and AI differ in the way they process information to generate knowledge, as AI can process much larger amounts of information with greater speed and accuracy, while humans use information processing 'templates' that may introduce potential errors or biases, but also make humans more versatile in complex information environments [Raisch, Krakowski, 2021]. From an RBV perspective, these different characteristics suggest the interplay of substitution and complementarity effects.

Substitution effect in the adoption of AI technologies

The substitution effect in the resource-based concept of RBV is based on the concept of resource substitutability [Peteraf, Bergen, 2003; Polidoro, Toh, 2011], i.e. the ability of resources to replace others that provide the same functionality [Levinthal, Wu, 2010]. Resources with low substitutability are specific or unique, whereas resources with high substitutability can be widely used. At the same time, resources that are highly substitutable can be moved between activities at no additional cost, while resources that are difficult to scale will incur costs for their use in other activities. Thus, general human cognitive abilities have high interchangeability, while cognitive abilities in a narrow, specific domain have low interchangeability and may also be unsuitable for scaling [Helfat, Peteraf, 2015]. This limits the use of their skills in related areas of the company's activities [Wernerfelt, Montgomery, 1988], because their use for substitution in unrelated areas requires additional study and accumulation of experience, with significant economic costs that quickly outweigh any potential benefits [Helfat, Peteraf, 2015].

The introduction of AI technologies can create a substitution effect for cognitive skills. For example, the combination of speech technologies and generative AI makes it possible to write a business letter, suggest ideas for promoting a business in a particular niche, and create personalised offers for customers. In addition, AI is now widely used for forecasting, making strategic decisions, and solving problems that traditionally only humans could do, relying on their cognitive abilities [Shrestha et al., 2019]. Unlike humans, machines have a virtually unlimited capacity to process information and often make better predictions than humans [Raisch, Krakowski, 2021]. For example, AI-powered machines now match or outperform doctors in diagnosing and treating cancer, predicting a candidate's ability to perform in an available position [Chamorro-Premuzic et al., 2019], generating alternative product designs [Verganti et al., 2020], and predicting angel investment opportunities [Blohm et al., 2022]. Thus, the precision and diversity of AI technologies are likely to reduce the traditional value of human resource capabilities as a source of non-copyable competitive advantage, or even render these competitive advantages obsolete [Agrawal et al., 2018, p. 80].

However, there are still open questions in the literature about the substitution effect of AI. To what extent do technical limitations prevent machines from fully making decisions or solving problems [Raisch, Krakowski, 2021]? After all, prediction is only one component of decision making, which also includes tasks such as goal setting, data selection, judgement and action generation [Shrestha et al., 2019]. The nature of substitution may differ when machines replace humans, while previous studies have described the substitution of similar resources (between humans, technologies, etc.) [Peteraf, Bergen, 2003; Levinthal, Wu, 2010]. Therefore, the first question that requires study is whether and how AI replaces human cognitive abilities that form non-copyable competitive advantages?

Complementarity in the implementation of AI technologies

According to the resource-based concept, the complementarity effect creates an uncopiable competitive advantage by forming unique combinations of resources [Newbert, 2007]. Companies that want to create new competitive advantages integrate existing and new resources into resource packages that 'uniquely complement each other' [Argyres, Zenger, 2012, p. 1648]. In [Milgrom, Roberts, 1990] it is emphasised that in order to form a package of unique, complementary resources, they must not only be super-modular, but also unrelated. Such unrelatedness ensures that the resulting resource packages are completely new and capable of creating a sustainable, non-copyable competitive advantage [Argyres, Zenger, 2012].

If we apply this theory to the formation of complementation effects in relation to AI, we can assume that complementation can occur both for different types of tasks [Raisch, Krakowski, 2021] and for the performance of a single task [Agrawal et al., 2018]. For example, the diagnosis of equipment failures is performed by AI, while humans focus on performing the repair or replacement of equipment (different types of tasks). Or humans may use AI to diagnose, but use their contextual understanding to avoid bias. That is, in the case of AI, we can talk about the simultaneous dynamics of substitution and complementarity effects [Brynjolfsson, McAfee, 2014; Raisch, Krakowski, 2021]. However, [Shrestha et al., 2019] note that the combination of human and machine capabilities in the context of AI can lead to negative complementarity effects, as AI learning can occur without human supervision.

In this study, we examine whether and how AI can complement human skills with technological resources, and how such complementation is related to the substitution effect.

2. Research methodology

Since there is little research on the factors that drive the decision to adopt AI technologies and no established theory on how sustainable competitive advantages are generated by adopting AI, we use a survey-based approach [Berry et al., 2021] to compare the substitution and complementarity effects of adopting AI technologies.

2.1. Formation of the research sample

For the analysis, 38 in-depth interviews of about one hour were conducted with senior managers of companies. Questions were then developed for a questionnaire which was sent to around 600 industrial companies with more than 500 employees, with a response rate of 19.3% (116 companies). After excluding questionnaires with missing data for any of the questions, the final sample consisted of 109 enterprises. This brings the total number of industrial companies in the sample to 147. The questionnaire data were supplemented with company performance indicators available from open sources on their websites and in the Amadeus and Ruslana BvD databases as of May 2024.

The companies included in the sample belong to industrial production in three sectors: high, medium and low tech; more than half of the companies surveyed have been operating in the market for more than 15 years; the age of the companies in the sample varies from 2 to 205 years, with an average of 44 years.

The share of international enterprises in the sample presented is 13%, the share of foreign enterprises operating in the Russian market is 7%, the share of Russian enterprises operating in the domestic and foreign markets is 28%, and the share of Russian enterprises operating only in the domestic market is 52%. The characteristics of the sample companies are presented in Table 1.

It should be noted that the expenditures on AI implementation by the companies in the sample are characterised by an extremely wide range: less than 1% of the companies surveyed spend more than 10% of their revenues on AI implementation, 7% of the companies spend 5-10% of their revenues, 16% of the companies – 3-5% of their revenues, the majority of the companies surveyed – 67% – invest 1-3% of their revenues in AI technologies, the remaining 9% – less than 1%.

2.2. Research model

The choice of methods for analysing the drivers of new technology adoption largely depends on the problem under consideration. The authors of [Mairesse, Robin, 2009] use the maximum likelihood method (MLE) to simultaneously analyse all aspects of firms' innovation activities, including investment in new technologies. However, we will use the Tobit II model, which answers two different questions: 'Why do firms invest in AI?' and 'What influences the level of investment in AI?' At the same time, the composition of the factors influencing investments in AI and their size can both differ and coincide.

For the analysis, we use a system of structural equations that allows us to assess the factors of AI technology implementation, their impact on the creation of competitive advantages and, consequently, the competitiveness of industrial companies.

Equation (1) estimates the probability that industrial firms will invest in AI technologies:

$$AI\_doing_{it} = \begin{cases} 1, \text{если } AI\_doing^*_{it} = x_{it} b_{it} + u_{1it} > \tau \\ 0, \text{если } AI\_doing^*_{it} = x_{it} b_{it} + u_{1it} \le \tau \end{cases}. \quad (1)$$

Table 1
Characteristics of the sample companies

	All industries	High-tech industries	Medium-tech industries	Low-tech industries
Number of companies	147	16	82	49
Percentage of sample companies implementing AI in their business processes	0.32	0.94	0.53	0.27
Total cost of technological, marketing and organisational innovations (million roubles)	87 162 000	42 064 000	28 092 000	17 006 000
including the total cost of implementing new technologies (million roubles)	29 278 100	17 354 600	7 318 000	4 605 500
Average cost of AI (million roubles)	5030	10391	2938	2774
Median real expenditure on AI (million roubles)	267	401	232	104

The explanatory variable *AI_doing* takes the value 1 if firm *i* decides to invest in AI technologies at time *t*, and 0 otherwise.

Equation (2) estimates the volume of investment in AI technologies per employee:

$$AI_{it} = \begin{cases} AI^*_{it} = x_{it}\, b_{2t} + u_{2it}, \text{если } AI\_doing_{it} = 1 \\ 0, \text{если } AI\_doing_{it} = 0 \end{cases}. \quad (2)$$

Equations (3) and (4) reflect the results of the formation of non-copyable competitive advantages: profits from the sale of new products with unique characteristics ($P_{new}pr_{it}$) and the number of patents obtained by the firm ($Patents_{it}$):

$$P_{new}\, pr_{it} = AI_{1it}\, \alpha_{r1t} + z_{it} b_{3t} + u_{3it}\,, \quad (3)$$

$$Patents_{it} = AI_{2it}\, \alpha_{r2t} + z_{it}\, b_{4t} + u_{4it}\,. \quad (4)$$

To analyse the occurrence of the substitution effect when implementing AI technologies ($Substitution\ AI_{it}$) and the complementarity effect ($Complementation\ AI_{it}$) we will estimate the equations of the results of the formation of non-copiable competitive advantages using two models: a probit model with random effects (random effect probit) and a logit model with fixed effects (fixed effect logit).

Fixed effect logit models allow us to estimate the intra-firm dynamics of resource changes when implementing AI technologies in a business process, i.e. to track the resource substitution effect when implementing AI. In addition, the substitution effect can influence a change in a firm's decision to invest in AI, as well as identify inter-firm differences – why some firms invest in AI more often and more than others.

When estimating a random effect probit equation, factors with low within-group volatility are excluded from the analysis in order to estimate the complementarity effect.

To account for potential non-normality and heteroskedasticity in the residuals, standard errors in all models are bootstrapped from 150 replications [Efron, 1979].

Equation (5) shows the achievement of leadership by a firm through the formation of non-copyable competitive advantages, expressed as the change in the firm's market share (Q_t) as a function of the firm's investment in AI, the release of new products ($P_{new}pr_{it}$) and the number of patents received by the firm ($Patents_{it}$).

In addition, we analysed the influence of the substitution effect ($Substitution\ AI_{it}$) and the complementarity effect ($Complementation\ AI_{it}$). Since a firm's market share depends not only on the introduction of new technologies, but also on its investment in current operations, the quality of the labour force it uses, etc., we add variables that show the influence of other factors:

$$Q_t = a_{NPt}\, P_{new}pr_{it} + a_{Pt}\, Patents_{it} + a_{R3t}\, AI_{it} + h_{it} b_{5t} + u_{5it}. \quad (5)$$

The variables in this model are described below.

2.3. Research variables

Independent variables for the two-stage Heckman model

In order to analyse different aspects of companies' decision making regarding the implementation of AI, we used the following indicators, the selection of which was based on in-depth interviews and existing research on the implementation of new technologies:

- x_{1t} – company size, measured as the logarithm of the number of employees. It can have both positive and negative effects on decisions to implement new technologies: large companies have better access to resources, including financial resources, and therefore have more opportunities to carry out large and expensive implementations of new technologies, including AI; small companies are more flexible in adapting to market and consumer demands and can make decisions more quickly, ahead of large companies in implementing AI to bring new products to market;
- x_{2t} – age of the company, measured as the logarithm of the number of years the company has been in business. Like size, it can have both positive and negative effects. K. Schumpeter wrote that the age of a company reflects experience and well-established business processes, which facilitates the introduction of new technologies. At the same time, young companies have flexibility, fresh ideas and are able to take a leading position through innovation and the introduction of new technologies;
- x_{3t} – the presence of research on AI and innovative developments, a dummy variable equal to 1 if the company has its own departments and 0 if not. Conducting research develops employees' skills in AI, and the results of successful research stimulate further investment in AI;
- x_{4t} – availability of skills to implement AI, measured as the logarithm of the number of employees with skills to implement AI technologies. The presence of employees with skills to implement AI technologies stimulates it;
- x_{5t} – the total cost of current activities, measured as the logarithm of the volume of current investments. This indicator is related to the financial capacity of the enterprise, which also influences the introduction of new technologies in the enterprise;
- x_{6t} – the cost of acquiring new technologies is measured as the logarithm of the sum of the costs of acquiring new technologies. Acquiring new technologies develops the skills of employees and serves as a source of new knowledge;
- x_{7t} – The quality of the workforce is measured as the logarithm of the number of employees with higher education. The higher the qualifications of employees, the more they are prone to complex intellectual work and creativity, their presence increases the efficiency of innovation and encourages companies to further invest in new technologies;

- x_{8t} – return on sales, measured as the logarithm of pre-tax profit as a percentage of sales in the previous year. Profits are an important source of funding for AI implementation costs and can increase the attractiveness of AI investments for companies;
- x_{9t} – international activity, a dummy variable equal to 1 if the firm has export revenues and 0 otherwise. The studies show a positive impact of a firm's international activity on its innovation activity, which is explained by the high level of competition in international markets and the need to implement new technologies in order to achieve leadership;
- x_{10t} – liquidity constraint, a dummy variable that measures the availability of financial resources to the enterprise to support its operations and finance innovative business initiatives, equal to 1 if the enterprise has access to financial capital and 0 if it faces liquidity constraints. Access to financial capital is particularly important for investments in new technologies, which are characterised by high resource intensity and risk;
- x_{11t} – availability of infrastructure – communication and available capacity of the enterprise, a dummy variable equal to 1 if the enterprise has its own infrastructure and 0 otherwise;
- x_{12t} – assessment of the level of perceived risk in implementing AI, a dummy variable equal to 1 if the company assesses the level of risk as low or moderate, and 0 otherwise. If the firm perceives the risks to be low or moderate, it will be able to start implementing AI;
- x_{13t} – expected financial impact, a dummy variable equal to 1 if the firm expects a financial impact and 0 otherwise. If the firm is confident that the implementation of AI will have a financial impact, this will positively influence its decision to implement AI;
- x_{14t} – regulatory conditions and level of government support for AI investment, a dummy variable equal to 1 if the firm uses government support and 0 otherwise. Regulatory conditions and government support encourage firms to invest in AI;
- potential economic effects, a dummy variable equal to 1 if the firm expects an effect and 0 if it does not. The expectation of economic effects contributes to the firm's decision to adopt AI, and we identify and analyse the types of effects:
  - x_{15t} – reducing the working time required to carry out operations,
  - x_{16t} – reducing the number of employees by reducing the volume of routine operations,
  - x_{17t} – increasing loyalty through personalised responses to users,
  - x_{18t} – reducing costs of the HR function by creating off-the-shelf training, writing interview summaries, analysing interviews,
  - x_{19t} – increasing the speed of information retrieval from corporate knowledge bases,
  - x_{20t} – increasing the speed of development and promotion of new products.

Independent variables used to model the results of creating non-copyrightable competitive advantages

In order to analyse various aspects of the creation of non-copyable competitive advantages during the implementation of AI, we used the following indicators, the selection of which was determined by the in-depth interviews conducted:

- business processes in which the company uses AI. In general, the industrial companies surveyed are implementing AI in the following business processes:
  - z_{1t} – HR management and internal corporate functions,
  - z_{2t} – sales and value proposition building,
  - z_{3t} – marketing and analytics,
  - z_{4t} – development and IT,
  - z_{5t} – customer service and support,
  - z_{6t} – research and development,
  - z_{7t} – operations management and production,
  - z_{8t} – logistics and supply chains,
  - z_{9t} – finance and procurement,
  - z_{10t} – legal support and risk management,
  - z_{11t} – forecasting and strategy formation,
  - z_{12t} – communications and security,
  - z_{13t} – development of new products.

The distribution of companies using AI in different business processes is shown in Figure 1.

- The stage of AI implementation will also influence the creation of non-copyable competitive advantages. For example, in the study of the company 'Yakov and Partners'[5] five stages of implementation of artificial intelligence are distinguished, on the basis of which we introduce the following variables:
  - z_{14t} – initiation – when there is no AI implementation strategy and no internal expertise, the company is just starting to think about the need to implement AI;
  - z_{15t} – study – the stage of targeted exploration of potentially interesting solutions;
  - z_{16t} – study – the stage of targeted exploration of potentially interesting solutions;
  - z_{17t} – formalisation – plans and budgets for implementing and scaling AI have been approved;
  - z_{18t} – scaling – AI development and scaling becomes part of the business strategy; AI implementation has a real impact.

The distribution of companies by level of AI adoption is shown in Figure 2.

- Another factor reflecting the influence of substitution or complementarity effects in the creation of non-copyable competitive advantages is the amount of resources required:

[5] Artificial intelligence in Russia… https://yakov.partners/upload/iblock/c5e/c8t1wrkdne5y9a4nqlicderalwny7xh4/20231218_AI_future.pdf?ysclid=lz13ttscls470347383.

– z_{19t} – If the volume of resources used is increased during the implementation of AI, a complementarity effect is observed; otherwise, a substitution effect is observed.

To analyse human involvement in the execution of a business process, we analysed two types of operations:

– the business process is carried out by a person independently, without the use of AI technologies;
– the business process is performed by a human using AI technologies.

- And another variable – z_{20t} – a factor of the presence and implementation of own developments of AI technologies, a dummy variable equal to 1 if the company implements its own developments of AI and 0 otherwise.

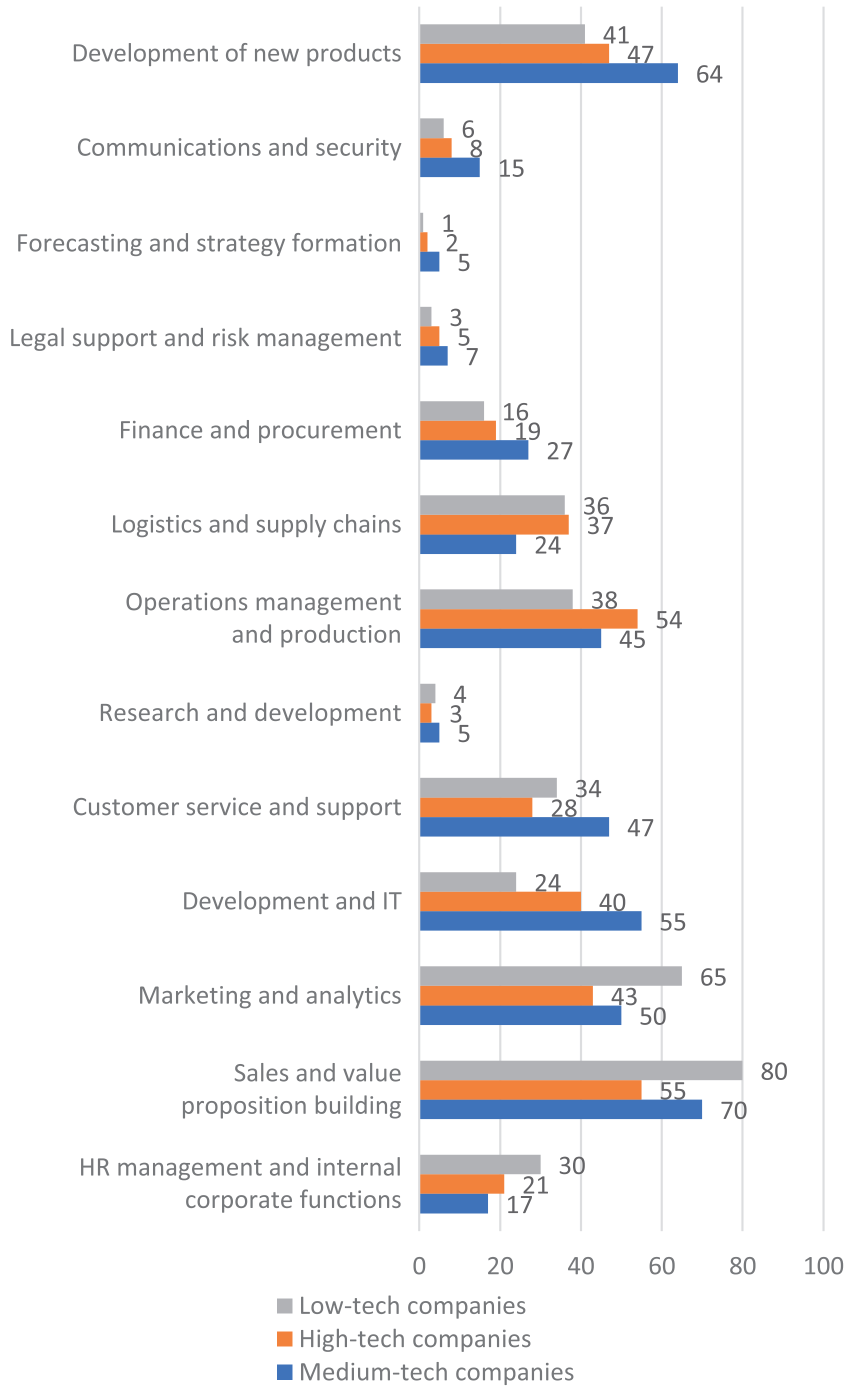
Among the industrial companies that participated in the survey, the share of companies that have and are implementing their own AI developments in the sample was 26%, while the share of companies that only use vendor solutions was 74%.

Control variables

The results of the formation of non-copiable competitive advantages of industrial firms (in our case, market share) may vary depending on the industry and the level of competition in the industry. The following variables were included in the model as control variables.

- The industry in which the company operates. Three main sectors have been identified:
  – High-tech – manufacture of pharmaceuticals, office and computer equipment, electronic components and equipment for radio, television and communications, medical products, aircraft, including spacecraft;
  – Medium high-tech – chemical production, manufacture of machinery and equipment, electrical machinery and equipment, motor vehicles, petroleum products, rubber and plastic products, metallurgical production, manufacture of fabricated metal products;
  – Low-tech – Manufacture of food products, tobacco products, textiles, clothing, wood and wood products, pulp, paper and paper products, publishing and printing, secondary raw materials processing.

Fig. 1. Business processes in which the surveyed companies use AI technologies



- The level of competitive intensity in the $COMP_i$ industry, measured as the combined market share of the three largest competitors in the industry.
- Government participation in the capital of the enterprise is measured as the government's share in the total capital of the enterprise.

The analytical model of the study is shown in Figure 3.

3. Research results

The main model of the first equation of the model is Tobit II, estimated using a two-stage method. In the first stage, the analysis of the sustainable drivers of investment in AI is carried out on data for 2021-2023. In this case, the selection equation is estimated using a random effects probit model.

The coefficient estimates of the equations are very different. The Tobit II investment intensity equation differs significantly from the selection equation ($\chi^2(31) = 1894.28$, $p = 0.000$).

The results of the evaluation of the AI investment decision model for 2021-2023 are presented in Table 2.

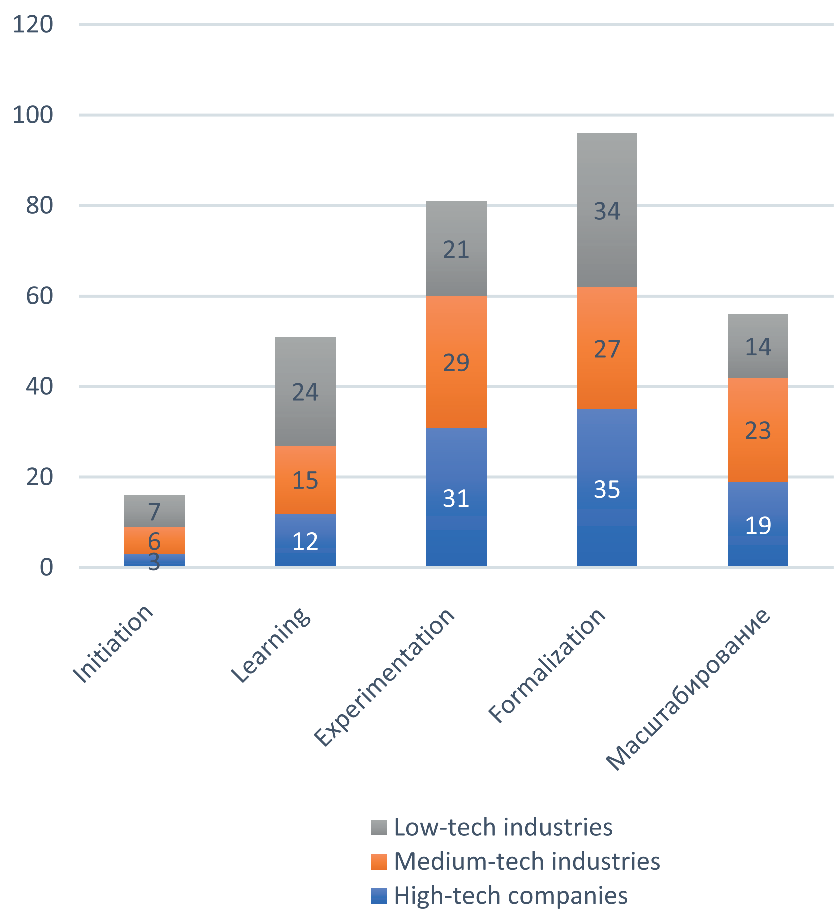
An analysis of the equation assessing the factors influencing the decision to implement AI based on a full random effects model allows us to conclude that, in general, investments in AI technologies are most positively influenced by: the availability of skills to implement AI, the cost of implementing new technologies and the level of current costs in the company as a whole, the expectation of financial effects and the availability of infrastructure.

Company size has a moderate impact, suggesting that larger companies are, on average, more likely to make a positive decision to implement AI in their business processes. However, company size has no impact on the volume of AI investment.

There are also no significant differences in the influence of AI investment factors by industry. In high-tech industries, the intensity of AI investment does not depend on whether the company is an exporter or not. In medium- and low-tech industries, the intensity of AI investment is significantly higher for exporting enterprises than for non-exporters.

The decision to invest in AI is much more often taken by enterprises that expect a potential economic effect from the implementation of AI. For example, the decision to invest in AI and its intensity is much higher for companies that expect to: reduce the time to complete operations; reduce the number of employees due to a reduction in the volume of routine operations; reduce the cost of the HR function; increase the speed of developing and promoting new products.

Fig. 2. Distribution of industrial companies in the sample by levels of adoption of AI technologies



The impact of increasing the speed of information retrieval within corporate knowledge bases does not have a significant impact on the intensity of investment in AI.

Table 3 presents an assessment of the impact of the introduction of AI technologies on the outcomes of the formation of non-copyable competitive advantages, as well as the impact of the effects of substitution (*Substitution* AI_{it}) and complementation (*Complementation* AI_{it}).

When analysing the different versions of the equation for the results of the creation of non-copyable competitive advantages, it should be noted that the fixed effect model has a lower explanatory power due to the weak variation of the factors, although it is not statistically rejected either for the equation of profits from the sale of new products with unique characteristics (χ^2 (19) = 24.89, p = 0.0091), or for the equation of patents received (χ^2 (19) = = 29.23, p = 0.0088).

It can be concluded that both substitution and complementarity effects are occurring simultaneously in the implementation of AI in Russian industrial enterprises. At the same time, the substitution effect is most evident in such functional areas as customer service and support, marketing and analytics, human resources management and internal corporate functions, and communications and security. It should be added that the emergence of the substitution effect is clearly observed only at the stage of scaling AI for industrial companies in all sectors considered.

It should be noted that the introduction of AI technologies has a significant impact both on the creation and sale of new products with unique characteristics and on the registration of patents. At the same time, the adoption of AI has a greater impact on the creation of new products with unique characteristics than on the number of patents registered. The introduction of AI has the greatest impact on the number of patents registered in functions such as development and IT, research and development, forecasting and strategy formulation. The complementarity effect is more important for patent registration in the early stages of implementation, and the substitution effect only in the scaling stage.

The fifth equation for the change in market share is analysed using a short random effects model, which includes only the most important factors, to analyse the influence of

Fig. 3. Analytical research model

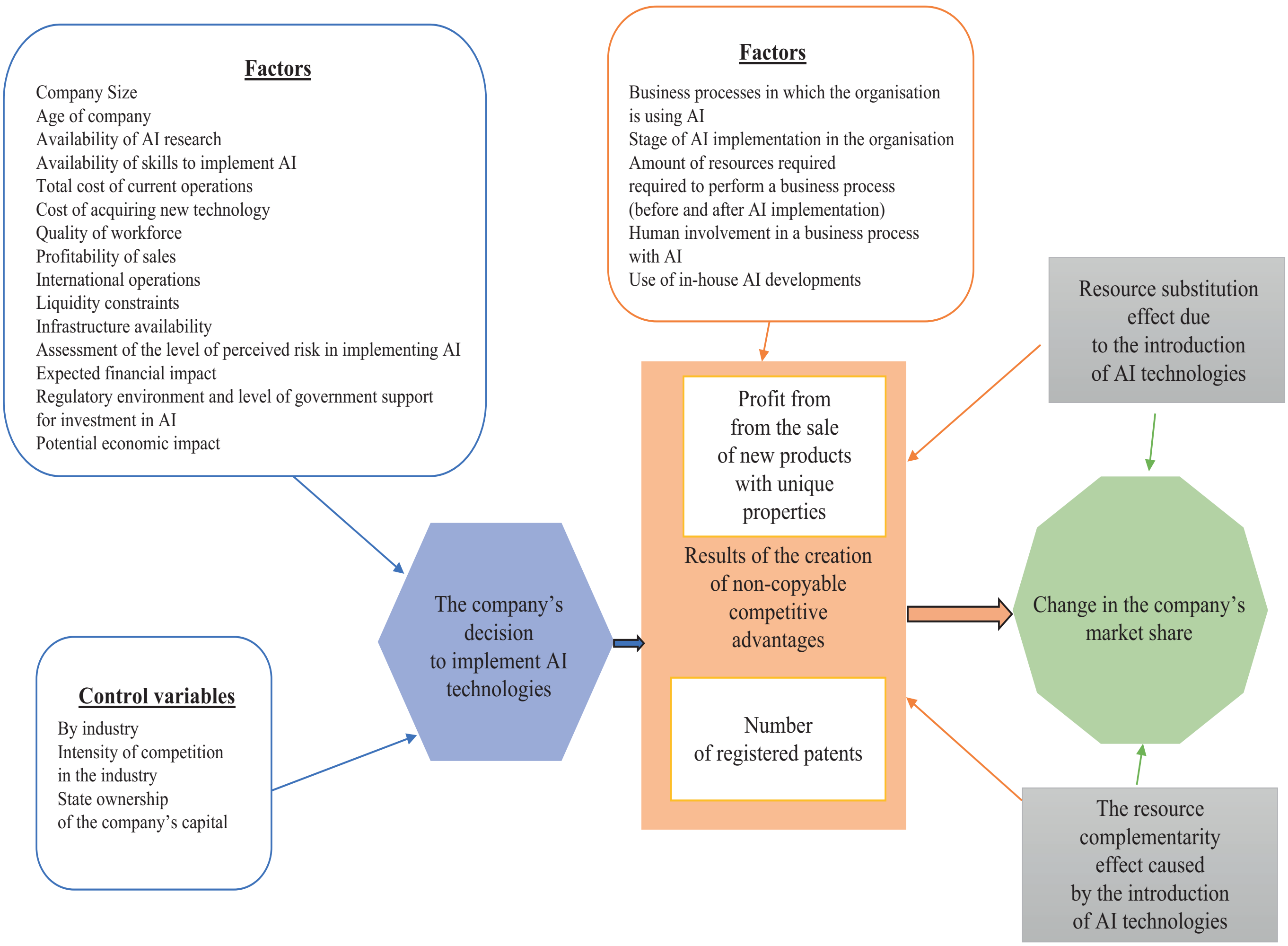


Table 2
Investment decisions based on AI technology (two-stage Heckman model (Tobit II)), 2021–2023

Dependent variable	High-tech industries		Medium-tech industries		Low-tech industries	
Companies' AI investment decisions and investment volumes						
Method of analysis - random effects model	1 Stage	2 Stage	1 Stage	2 Stage	1 Stage	2 Stage
Firm size – x_{1t} (logarithm of average number)	0.187*** (0.007)	0.064* (0.072)	0.142*** (0.081)	0.062* (0.103)	0.145*** (0.111)	0.014** (0.107)
Age of the firm – x_{2t} (logarithm of the average number of years)	0.024*** (0.012)	0.117 (0.037)	0.033*** (0.021)	0.276* (0.043)	0.127*** (0.032)	0.074*** (0.022)
Availability of research on AI and innovative developments – x_{3t} (1 – yes, 0 – no)	0.151*** (0.102)	0.124 (0.112)	0.172** (0.115)	0.177 (0.107)	0.109** (0.134)	0. 171** (0.017)
Availability of skills to implement AI – x_{4t} (1 – yes, 0 – no)	0.216*** (0.046)	0.242 (0.017)	0.361*** (0.029)	0.373* (0.031)	0.309*** (0.033)	0.291*** (0.028)
Total cost of current activities – x_{5t} (log of total cost of current activities)	0.284*** (0.051)	0.297 (0.023)	0.311*** (0.049)	0.304* (0.037)	0.249*** (0.021)	0.264*** (0.012)
Cost of acquiring new technologies – x_{6t}, (logarithm of total cost of acquiring equipment)	0.202** (0.064)	0.219 (0.043)	0.216*** (0.141)	0.274 (0.048)	0.219*** (0.059)	0.174*** (0.106)
Workforce quality – x_{7t} (log of number of employees with tertiary education)	0.134*** (0.009)	0.115*** (0.029)	0.211*** (0.013)	0.118*** (0.104)	0.123*** (0.027)	0. 129*** (0.079)
Profitability of sales – x_{8t} (log of pre-tax profit as a percentage of turnover in the previous year)	0.164*** (0.041)	0.159 (0.139)	0.104*** (0.071)	0.132** (0.298)	0.128** (0.030)	0.076 (0.122)
Availability of export earnings – x_{9t} (1 – yes, 0 – no)	0.093* (0.041)	0.077** (0.088)	0.292*** (0.094)	0.374*** (0.298)	0.152* (0.030)	0.077*** (0.122)
Liquidity constraints – x_{10t} (1 – yes, 0 – no)	0.098 (0.063)	0.084*** (0.032)	0.114*** (0.043)	0.146*** (0.091)	0.131* (0.099)	0.142*** (0.048)
Availability of infrastructure – x_{11t} (1 – yes, 0 – no)	0.203* (0.055)	0.213** (0.065)	0.144* (0.025)	0.158** (0.69)	0.152* (0.030)	0.147*** (0.052)
Assessment of the level of perceived risk in implementing AI – x_{12t} (1 – yes, 0 – no)	0.103 (0.036)	0.157*** (0.042)	0.184*** (0.041)	0.178*** (0.037)	0.157* (0.046)	0.164*** (0.068)
Expected financial impact – x_{13t} (1 – yes, 0 – no)	0.271*** (0.041)	0.269** (0.088)	0.284*** (0.094)	0.293*** (0.298)	0.279* (0.035)	0.276*** (0.112)
Regulatory conditions and level of government support for investment in AI – x_{14t} (1 – yes, 0 – no)	0.065* (0.045)	0.047*** (0.046)	0.016 (0.066)	0.018*** (0.069)	0.014* (0.052)	0.001*** (0.54)
Reduction in working time to carry out activities – x_{15t} (1 – yes, 0 – no)	0.213*** (0.062)	0.246 (0.122)	0.285*** (0.025)	0.219*** (0.094)	0.231* (0.029)	0.292*** (0.047)
Reduction in the number of employees due to a reduction in the volume of routine operations Routine operations – x_{16t} (1 – yes, 0 – no)	0.158*** (0.073)	0.157 (0.097)	0.164*** (0.073)	0.219*** (0.164)	0.148* (0.101)	0.223*** (0.071)
Increase loyalty through personalised responses to users – x_{17t} (1 – yes, 0 – no)	0.094*** (0.059)	0.108 (0.053)	0.123*** (0.066)	0.117*** (0.018)	0.169* (0.051)	0.138*** (0.021)
Reduced costs for the HR function – x_{18t} (1 – yes, 0 – no)	0.183*** (0.081)	0.165 (0.082)	0.178*** (0.072)	0.162*** (0.032)	0.189* (0.046)	0.194*** (0.034)
Increase the speed of searching for information within corporate knowledge bases – x_{19t} (1 – yes, 0 – no)	0.059*** (0.068)	0.026 (0.091)	0.109*** (0.024)	0.101** (0.118)	0.078*** (0.031)	0.038* (0.002)
Increase in speed of new product development and promotion – x_{20t} (1 – yes, 0 – no)	0.238*** (0.092)	0.213 (0.047)	0.183*** (0.062)	0.233** (0.028)	0.265*** (0.044)	0.249** (0.062)
Constant	3.337*** (0.178)	– 2.457 (0.723)	- 6.591*** (0.298)	4.273** (0.524)	- 5.569*** (0.442)	3.845** (0.861)
Pseudo R^2 (%)	39.3	5.17	39.3	5.17	39.3	5.17
Number of observations	16		82		49	

Notes: 1. The figures shown are marginal values. 2. Statistical significance of the coefficients: *** – $p \leq 0.001$; ** – $p \leq 0.01$; * – $p \leq 0.05$. 3. All standard errors (in brackets) are bootstrapped (150 replications).

Table 3
Results of the assessment of the impact of the introduction of AI on the creation of non-copycat competitive advantages

Dependent variable	High-tech industries		Medium-tech industries		Low-tech industries	
Method of analysis: Substitution effect - random effects model Complementarity - fixed effects model	Substitution effect	Complementation effect	Substitution effect	Complementation effect	Substitution effect	Complementation effect
Profit from the sale of products with unique properties						
AI investment intensity – AI_{it}	0.223*** (0.087)	0.214* (0.065)	0.192*** (0.071)	0.174* (0.103)	0.143*** (0.051)	0.166** (0. 071)
Human resources management and internal corporate functions – z_{1t} (1 – yes, 0 – no)	0.254*** (0.032)	0.071* (0.043)	0.242*** (0.064)	0.162* (0.051)	0.245*** (0.041)	0.112** (0.053)
Sales and value proposition formation – z_{2t} (1 – yes, 0 – no)	0.038*** (0.025)	0.062 (0.033)	0.053*** (0.021)	0.057* (0.036)	0.071*** (0.034)	0.067*** (0.031)
Marketing and analytics – z_{3t} (1 – yes, 0 – no)	0.221*** (0.068)	0.254 (0.073)	0.172** (0.061)	0.151 (0.053)	0.179** (0.032)	0. 182** (0.051)
Development and IT – z_{4t} (1 – yes, 0 – no)	0.102*** (0.049)	0.195 (0.054)	0.106*** (0.059)	0.204* (0.068)	0.154*** (0.063)	0.211*** (0.072)
Customer service and support – z_{5t} (1 – yes, 0 – no)	0.402** (0.051)	0.119 (0.048)	0.314*** (0.027)	0.123 (0.032)	0.271*** (0.039)	0.083*** (0.046)
Research and development – z_{6t} (1 – yes, 0 – no)	0.155*** (0.046)	0.129*** (0.034)	0.191*** (0.042)	0.178*** (0.061)	0.203*** (0.062)	0. 179*** (0.049)
Operations and production – z_{7t} (1 – yes, 0 – no)	0.121*** (0.057)	0.159 (0.073)	0.165*** (0.062)	0.179** (0.081)	0.215** (0.053)	0.192 (0.066)
Logistics and supply chain – z_{8t} (1 – yes, 0 – no)	0.162*** (0.056)	0.172 (0.063)	0.211*** (0.058)	0.261*** (0.054)	0.222* (0.068)	0.238*** (0.072)
Finance and procurement – z_{9t} (1 – yes, 0 – no)	0.106*** (0.038)	0.102 (0.059)	0.123*** (0.034)	0.164*** (0.078)	0.152*** (0.041)	0.138* (0.057)
Legal and risk management – z_{10t} (1 – yes, 0 – no)	0.176*** (0.051)	0.181 (0.048)	0.166*** (0.037)	0.178*** (0.049)	0.192*** (0.052)	0.188* (0.047)
Forecasting and strategy development – z_{11t} (1 – yes, 0 – no)	0.102*** (0.046)	0.109 (0.055)	0.093*** (0.035)	0.072*** (0.048)	0.112*** (0.051)	0.118* (0.064)
Communication and security – z_{12t} (1 – yes, 0 – no)	0.224*** (0.064)	0.121 (0.059)	0.263*** (0.052)	0.189*** (0.061)	0.296*** (0.083)	0.179* (0.072)
New product development – z_{13t} (1 – yes, 0 – no)	0.274*** (0.098)	0.252 (0.109)	0.228*** (0.065)	0.264*** (0.153)	0.184*** (0.059)	0.198* (0.085)
Stage of initiation – z_{14t} (1 – yes, 0 – no)	0.106*** (0.058)	0.109 (0.053)	0.129*** (0.037)	0.131*** (0.044)	0.136* (0.053)	0.098*** (0.039)
Trial stage – z_{15t} (1 – yes, 0 – no)	0.154*** (0.063)	0.132 (0.097)	0.138*** (0.052)	0.125*** (0.046)	0.146* (0.041)	0.125*** (0.039)
Stage of experimentation – z_{16t} (1 – yes, 0 – no)	0.062*** (0.031)	0.045 (0.037)	0.082*** (0.053)	0.065*** (0.066)	0.053* (0.031)	0.021*** (0.016)
Formalisation stage – z_{17t} (1 – yes, 0 – no)	0.024*** (0.065)	0.032 (0.078)	0.036*** (0.064)	0.048*** (0.073)	0.055* (0.058)	0.067*** (0.081)
Scaling stage – z_{18t} (1 – yes, 0 – no)	0.458*** (0.065)	0.074 (0.043)	0.387*** (0.062)	0.094*** (0.032)	0.381* (0.046)	0.089*** (0.034)
Change in volume of resources required – z_{19t} (logarithm of total resource costs)	0.069*** (0.053)	0.056 (0.084)	0.069*** (0.073)	0.053** (0.049)	0.035*** (0.051)	0.046* (0.042)

Table 3 *(ending)*

Dependent variable	High-tech industries		Medium-tech industries		Low-tech industries	
Method of analysis: Substitution effect - random effects model Complementarity - fixed effects model	Substitution effect	Complementation effect	Substitution effect	Complementation effect	Substitution effect	Complementation effect
Availability and implementation of own AI developments – z_{20t} (1 – yes, 0 – no)	0.052*** (0.074)	0.101 (0.053)	0.087*** (0.044)	0.063** (0.058)	0.031*** (0.052)	0.029** (0.041)
Constant	4.591*** (0.263)	3.843 (0.539)	–2.379*** (0.335)	–5.121** (0.423)	4.841*** (0.381)	2.129** (0.482)
Within *R* (%)	7.13	6.73	7.13	6.73	7.13	6.73
Between *R* (%)	34.79	33.55	34.79	33.55	34.79	33.55
Overall *R* (%)	29.23	24.18	29.23	24.18	29.23	24.18
Number of observations	16		82		49	
Number of patents registered						
AI investment intensity – AI_{it}	0.173*** (0.054)	0.161* (0.059)	0.174*** (0.053)	0.189* (0.073)	0.033*** (0.041)	0.056** (0. 069)
HR & internal functions – z_{1t} (1 – yes, 0 – no)	0.094*** (0.054)	0.073*** (0.042)	0.115*** (0.048)	0.101*** (0.059)	0.132*** (0.073)	0.128*** (0.066)
Sales & value proposition – z_{2t} (1 – yes, 0 – no)	0.089*** (0.055)	0.071 (0.041)	0.074*** (0.038)	0.072* (0.061)	0.097*** (0.042)	0.083*** (0.061)
Marketing & Analytics – z_{3t} (1 – yes, 0 – no)	0.249*** (0.042)	0.234 (0.038)	0.203** (0.032)	0.179 (0.067)	0.199** (0.032)	0. 173** (0.046)
Development & IT – z_{4t} (1 – yes, 0 – no)	0.261*** (0.032)	0.275 (0.048)	0.291*** (0.053)	0.283* (0.041)	0.109*** (0.039)	0.194*** (0.052)
Customer service & support – z_{5t} (1 – yes, 0 – no)	0.122** (0.037)	0.119 (0.051)	0.163*** (0.057)	0.179 (0.063)	0.159*** (0.048)	0.162*** (0.037)
Research & development – z_{6t} (1 – yes, 0 – no)	0.373*** (0.113)	0.285*** (0.123)	0.354*** (0.094)	0.337*** (0.108)	0.382*** (0.064)	0.359*** (0.082)
Operations & manufacturing – z_{7t} (1 – yes, 0 – no)	0.188*** (0.035)	0.197 (0.047)	0.201*** (0.069)	0.193** (0.091)	0.237** (0.064)	0.192 (0.104)
Logistics & supply chain – z_{8t} (1 – yes, 0 – no)	0.097*** (0.049)	0.112 (0.064)	0.148*** (0.042)	0.134*** (0.053)	0.108* (0.039)	0.097*** (0.072)
Finance & Procurement – z_{9t} (1 – yes, 0 – no)	0.013*** (0.009)	0.022 (0.014)	0.038*** (0.024)	0.047*** (0.035)	0.018* (0.045)	0.036*** (0.053)
Legal & risk management – z^{10t} (1 – yes, 0 – no)	0.092*** (0.037)	0.063 (0.042)	0.019*** (0.046)	0.028*** (0.059)	0.013* (0.068)	0.091*** (0.072)
Forecasting & strategy development – z_{11t} (1 – yes, 0 – no)	0.202*** (0.053)	0.213* (0.054)	0.217** (0.037)	0.228*** (0.044)	0.223* (0.044)	0.241*** (0.039)
Communication and security – z_{12t} (1 – yes, 0 – no)	0.061*** (0.025)	0.013* (0.054)	0.079** (0.037)	0.028*** (0.044)	0.103* (0.044)	0.124*** (0.039)
New product development – z_{13t} (1 – yes, 0 – no)	0.312*** (0.057)	0.293* (0.099)	0.269** (0.125)	0.274*** (0.113)	0.227* (0.098)	0.249*** (0.079)
Stage of initiation – z_{14t} (1 – yes, 0 – no)	0.027*** (0.053)	0.242 (0.031)	0.038*** (0.026)	0.331*** (0.024)	0.044* (0.035)	0.322*** (0.034)
Trial stage – z_{15t} (1 – yes, 0 – no)	0.064*** (0.039)	0.247 (0.025)	0.041*** (0.063)	0.239*** (0.024)	0.045* (0.032)	0.238*** (0.042)
Stage of experimentation – z_{16t} (1 – yes, 0 – no)	0.016*** (0.009)	0.229 (0.013)	0.032*** (0.036)	0.247*** (0.038)	0.034* (0.024)	0.249*** (0.027)
Stage of formalisation – z_{17t} (1 – yes, 0 – no)	0.362*** (0.031)	0.245 (0.037)	0.382*** (0.053)	0.165*** (0.066)	0.353* (0.031)	0.121*** (0.016)
Scaling stage – z_{18t} (1 – yes, 0 – no)	0.309*** (0.072)	0.106 (0.054)	0.348*** (0.033)	0.054** (0.046)	0.334*** (0.019)	0.049* (0.024)
Change in volume of resources required – z_{19t} (logarithm of total resource costs)	0.134*** (0.065)	0.131 (0.039)	0.082*** (0.035)	0.063** (0.044)	0.051*** (0.035)	0.026** (0.031)
Availability and implementation of in-house AI developments – z_{20t} (1 – yes, 0 – no)	0.202*** (0.046)	0.209 (0.055)	0.293*** (0.035)	0.272*** (0.048)	0.212*** (0.051)	0.218* (0.064)
Within *R* (%)	6.69	7.18	6.69	7.18	6.69	7.18
Between *R* (%)	35.16	39.66	35.16	39.66	35.16	39.66
Overall *R* (%)	24.89	29.23	24.89	29.23	24.89	29.23
Number of observations	16		82		49	

Table 4
Results of the analysis of changes in the market share of industrial enterprises

Dependent variable	High-tech industries		Medium-tech industries		Low-tech industries	
Method of analysis: Substitution effect - random effects model Complementarity - fixed effects model	Substitution effect	Complementation effect	Substitution effect	Complementation effect	Substitution effect	Complementation effect
Invest in AI – AI_{it}	0.021*** (0.047)	0.023* (0.054)	0.017*** (0.069)	0.016* (0.101)	0.017*** (0.081)	0.014** (0.067)
Profits from sales of new products with unique features – $P_{new}\,pr_{it}$	0.216*** (0.069)	0.215* (0.077)	0.351*** (0.094)	0.354* (0.088)	0.327*** (0.059)	0.303** (0.074)
Number of patents – $Patents_{it}$	0.344*** (0.047)	0.318* (0.054)	0.203*** (0.069)	0.194* (0.101)	0.201*** (0.081)	0.204** (0.067)
Enterprise size – h_{1t} (log of average number of employees)	0.113*** (0.036)	0.109* (0.084)	0.117*** (0.046)	0.094* (0.073)	0.128*** (0.051)	0.137** (0.048)
Age of the enterprise – h_{2t} (logarithm of the average number of years)	0.067*** (0.048)	0.084 (0.061)	0.089*** (0.042)	0.056* (0.069)	0.093*** (0.074)	0.056*** (0.049)
Presence of research in AI – h_{3t} (1 – yes, 0 – no)	0.168*** (0.067)	0.132 (0.102)	0.172** (0.115)	0.059 (0.066)	0.083** (0.052)	0. 079** (0.048)
Total cost of current activities – h_{5t} (log of total cost of current activities)	0.123*** (0.057)	0.154 (0.049)	0.091*** (0.052)	0.099* (0.064)	0.107*** (0.072)	0.116*** (0.058)
Availability of competences for the implementation of AI – h_{7t} (logarithm of the number of employees with higher education)	0.256*** (0.068)	0.249*** (0.073)	0.243*** (0.052)	0.239*** (0.053)	0.261*** (0.098)	0.258*** (0.042)
Expected financial impact – h_{8t} (logarithm of the sum of the financial impact of implementing AI)	0.193*** (0.049)	0.162 (0.108)	0.204*** (0.069)	0.193** (0.096)	0.129** (0.047)	0.166 (0.055)
Availability of export earnings – h_{9t} (1 – yes, 0 – no)	0.179*** (0.054)	0.206 (0.093)	0.221*** (0.088)	0.233*** (0.073)	0.173* (0.035)	0.128*** (0.052)
Reduction in number of employees due to decrease in volume of routine operations routine operations – h_{11t} (1 – yes, 0 – no)	0.014*** (0.019)	0.013* (0.024)	0.029*** (0.021)	0.037* (0.101)	0.039*** (0.081)	0.024** (0.067)
Reduction in costs of human resources function – h_{12t} (1 – yes, 0 – no)	0.107*** (0.019)	0.105* (0.023)	0.104*** (0.094)	0.103* (0.088)	0.107*** (0.059)	0.103** (0.074)
Reduction in working time for routine tasks – h_{13t} (1 – yes, 0 – no)	0.211*** (0.021)	0.206* (0.022)	0.207*** (0.029)	0.205* (0.011)	0.201*** (0.081)	0.204** (0.067)
Increasing the speed of development and promotion of new products – h_{14t} (1 – yes, 0 – no)	0.213*** (0.022)	0.215* (0.023)	0.212*** (0.022)	0.217* (0.021)	0.219*** (0.008)	0.222** (0.007)
Constant	4.663*** (0.151)	5.351 (0.612)	3.044*** (0.371)	2.974** (0.449)	– 4.318*** (0.529)	2.257** (0.721)
Within R (%)	3.98	4.97	3.98	4.97	3.98	4.97
Between R (%)	29.84	35.72	29.84	35.72	29.84	35.72
Overall R (%)	23.75	26.94	23.75	26.94	23.75	26.94
Number of observations	16		82		49	

the substitution effect, and a fixed effects model to analyse the influence of the complementarity effect. Table 4 shows the marginal effects of the productivity of firms in three industries.

As in the previous equations, the fixed effects model has less explanatory power in the equation for market share change, although it is not statistically rejected (χ^2 (22) = 23.75, p = 0.0088). This means that the complementarity effect is more significant than the substitution effect in the adoption of AI.

In high and medium-high tech industries, the relationship between the intensity of investment in AI, the results of the creation of non-copyable competitive advantages and the increase in market share is confirmed. At the same time, the strongest relationship between the results of the creation of non-copyable competitive advantages and market share is observed in the high-tech sector for the number of registered patents (the elasticity of market share with respect to the number of patents is 0.344), in the medium and low-tech industries – for the creation of new products with unique properties (0.351).

4. Discussion and conclusions

The study shows that there is little difference between companies in different industries in their decisions to implement AI technologies. Similar conclusions have been reached in previous studies [Ruzhanskaya et al., 2023]. At the same time, the decision to invest in AI technologies depends on such factors as the availability of skills for implementing AI, the cost of implementing new technologies and the level of current costs in the company as a whole, and the expectation of financial and economic effects.

It should also be noted that the availability of resources (both financial and infrastructural) is an important factor when deciding on the intensity of investment in AI. Among the economic effects expected from the implementation of AI technologies, the most significant are: reduction in the time needed to perform operations; reduction in the number of employees due to a decrease in the volume of routine operations; reduction in the cost of the human resources function; and an increase in the speed of developing and promoting new products.

Our empirical data show that the marginal effect of investment in AI technologies is in the range of 0.021-0.023 in high-tech industries, 0.016-0.017 in medium-tech industries, and 0.014-0.017 in low-tech industries.

The most popular functions for implementing AI technologies are: marketing and analytics (creating creative materials), development and IT (coding assistants for developers), sales and customer service (operator prompts and voice assistants), and internal corporate functions (generating training, writing texts, verifying documents, etc.).

Most industrial companies are currently in the experimentation phase, where there are no common standards for the implementation of AI and in-house developments or vendor solutions are being tested in various functions, or in the formalisation phase, where plans and budgets for the implementation and scaling of AI have been approved. However, in order to achieve significant financial and economic impact from the implementation of AI technologies, it is necessary to optimise business processes and attract specialists with skills in the field of AI implementation. At the same time, in in-depth interviews, almost all – 98% – top managers cited the lack of specialists capable of implementing and using AI as the main obstacle to its development.

The impact of AI on the results of the creation of non-copyable competitive advantages varies between industries. For example, for high-tech industries, the introduction of AI technologies has a significant impact on patenting and a slightly smaller impact on the creation and sale of new products with unique features. For medium- and low-tech industries, AI technologies have a more significant impact on the creation of new products with unique characteristics than on patenting.

Another issue explored in this study is the influence of substitution and complementarity effects in the creation of non-copyable competitive advantages.

Our study confirmed the dualistic effect of AI adoption, i.e. the simultaneous emergence of both the substitution effect and the complementarity effect, which shifts the sources of competitive advantage: although the replacement of traditional domain-specific human cognitive capabilities by the multiple computational capabilities of AI destroys the existing advantage, new permanent, non-copyable advantages are created based on the complementarity of human and machine capabilities.

In terms of substitution, it is currently taking place in functions such as customer service, human resources and corporate functions. And this trend is likely to continue as the gap between human and machine productivity continues to widen [Davenport, Kirby, 2016].

The results of the in-depth expert interviews also confirm that the availability of modern AI technologies will affect the substitution of some functions performed by humans by machines, and that these functions will no longer represent uncopyable competitive advantages, as they will be easy to imitate. At the same time, the expert survey showed that such a substitution effect has significant limitations related to the technical characteristics of software and hardware systems. For example, there are limitations when there is little data or when constant change makes it impossible to use past decision models to predict future outcomes [Raisch, Krakowski, 2021]. In situations of high uncertainty, companies will continue to rely on human intuition. Thus, the limitations of software and hardware make human capabilities difficult to replicate, and they will continue to serve as a source of non-copyable advantages for the foreseeable future [Murray et al., 2021; Raisch, Krakowski, 2021].

Our work confirms the complementarity effect – the importance of combining human and machine capabilities as a new source of competitive advantage. This conclusion was also confirmed by the results of in-depth interviews: experts associated competitive advantage with the complementarity of human and AI capabilities, especially in functional areas such as research and development, IT, creative ideas, production and social interaction. For example, [Raisch, Krakowski, 2021] describe how perfumers, despite the introduction of AI into their fragrance development processes, still work with experts because machines do not have the human ability to perceive odours and predict the human emotions they evoke. This example shows that AI is likely to replace some – but not all – complex business tasks. And this, in turn, will provide opportunities to combine human skills and AI to create unique competitive advantages based on complementarity.

Our study contributes to the resource-based view of the firm, as most previous studies have focused on the complementarity of only homogeneous or related resources [Peteraf, Bergen, 2003; Levinthal, Wu, 2010; Polidoro, Toh, 2011; Argyres, Zenger, 2012]. Our work shows that heterogeneous, unrelated resources, such as people and machines, can also be a source of unique competitive advantage. Such complementarity of unrelated resources is possible because AI is not narrowly applied and can be used in a variety of domains.

However, this study has limitations, mainly related to the sample size of companies. Further field studies are needed to more fully describe the impact of AI technologies and provide insights into the division of labour between humans and AI at the organisational level, as well as to identify related sources of sustainable competitive advantage.

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The article was submitted on 16.04.2024; revised on 15.05.2024 and accepted for publication on 20.05.2024. The authors read and approved the final version of the manuscript.
文章于 16.04.2024 提交给编辑。文章于 15.05.2024 已审稿．之后于 20.05.2024 接受发表。作者已经阅读并批准了手稿的最终版本。

DOI: 10.17747/2618-947X-2024-2-152-163

Marketing strategy formation under sanction: Utilizing Balanced Scorecard and Hoshin Kanri models in the Iran Khodro Company's regional passenger car markets

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Abstract

There is a sufficient amount of research to confirm that economic sanctions can cause significant damage both to the economic growth of a country and to companies operating in a sanctioned country. In response to multilateral economic sanctions, the sanctioned country develops a number of strategic programmes aimed at easing the sanctions and supporting its economy. Companies also develop strategies to survive and make sustainable profits.

The study aims to examine the strategies that enable companies not only to survive, but also to thrive in international markets; the functional strategies that companies use to increase the efficiency of their activities.

The Iranian automotive industry served as the empirical basis for the study. The case study is of Iran Khodro, one of the two leading companies in the Iranian automotive industry, which accounts for more than 50% of the automotive market in Iran, is given. Using data from companies in the automotive industry, we found that among the functional strategies, marketing strategy is the most important for its effectiveness.

In addition, the management of financial, customer and operational indicators based on the MTSP (Balanced Scorecard) is positively associated with the entry of companies into foreign markets. Finally, this study has showed that for companies in the automotive industry, access to new technologies, financial resources, a strategic plan and an export orientation are key to working successfully under sanctions.

Keywords: Iran Khodro, sanctions, strategic marketing, auto industry, Balanced Scorecard model, Hoshin Kanri model.

For citation:

Rezaeinejad I. (2024). Marketing strategy formation under sanction: Utilizing Balanced Scorecard and Hoshin Kanri models in the Iran Khodro Company's regional passenger car markets. *Strategic Decisions and Risk Management,* 15(2): 152-163. DOI: 10.17747/2618-947X-2024-2-152-163.

在制裁条件下制定营销战略：在伊朗霍德罗汽车公司（Iran Khodro）乘用车区域市场使用平衡计分卡和方针管理模型

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简介
有大量研究表明，经济制裁可以对国家的经济增长和在受制裁国家运营的公司造成重大损害。面对多边经济制裁，受制裁国家制定了一系列战略计划，以减轻制裁影响并支持其商业发展。公司也相应地制定了旨在生存和实现稳定利润的策略。
本研究的目的是探讨能够使公司不仅在制裁环境中生存，而且在国际市场上取得成功的策略。本研究以伊朗汽车工业为实证基础。案例研究对象为伊朗汽车工业的两大领军企业之一伊朗霍德罗汽车公司（Iran Khodro），其市场份额占伊朗汽车市场的50%以上。
利用汽车工业公司的数据，作者得出结论，在各种职能战略中，营销战略对其有效性具有最大意义。此外，基于平衡计分卡的财务、客户和运营指标管理与公司进入国际市场之间存在正相关关系。最后，本研究表明，对于汽车工业公司而言，获得新技术、金融资源、拥有战略计划以及注重出口是成功应对制裁条件的关键。
关键词： 伊朗霍德罗汽车公司，Iran Khodro, 制裁、战略营销、汽车工业、平衡计分卡模型、方针管理模型。

引用文本：
Rezaeinejad I. (2024). 在制裁条件下制定营销战略：在伊朗霍德罗汽车公司（Iran Khodro）乘用车区域市场使用平衡计分卡和方针管理模型。战略决策和风险管理, 15(2): 152–163. DOI: 10.17747/2618-947X-2024-2-152-163.

Introduction

Professors R.S. Kaplan and D.P. Norton introduced a Balanced Scorecard (BSc) method. Many organisations use it to translate the organisation's vision and mission into a strategy [Kaplan, Norton, 1996]. They expressed these goals and objectives in four perspectives: financial, customer, internal business process, learning and growth. This approach covers financial and non-financial aspects of an organisation's performance and balances the performance outcomes of the past and future performance drivers [Kaplan, Norton, 2000]. The financial dimension focuses on spending money on financial resources. In the Balanced Scorecard model, attention to the customer is essential, gaining customer satisfaction through efficient distribution and improving the quality of goods. The third dimension of the Balanced Scorecard is because of the 'internal processes of the organisation' that will strengthen the previous two sizes. Then, 'growth and learning' focuses on the improvement of team members, the quality of organisation's information system, the tools, layout and equipment to achieve goals [Kaplan et al., 2004].

Hoshin Kanri is a planning system for implementing and disseminating the the organisation's objectives and macro strategies to different levels [Zairi, Erskine, 2011]. The Hoshin Kanri planning method extends and shares the goals, directions, and approaches of senior management to the level of the organisation's employees. This enables each organisational unit to plan and manage its activities accordingly [Tennant, Roberts, 2001]. The results are then evaluated and reviewed, and through Deming's circle (PDCA cycle), the aim is to continuously improve the organisation's performance. For this purpose, all organisations are always doing different actions at the assessment rate and monitoring their life status [Freyssenet, 2010].

The following are some of the key reasons for strategic planning; these reasons show that the absence of such a system poses challenges and risks to the organisation:

1) Monitoring and controlling organisational performance at the micro and macro levels [Arnold, Quelch, 1998];
2) Providing an appropriate basis for management decisions [Lee et al., 2022];
3) Creating the possibility of diagnosing and troubleshooting organisational disorders [Cameron, Green, 2019];
4) Controlling performance indicators, effectiveness, productivity, and profitability [Peridy, Abedini, 2008];
5) Establishing a basis for appropriate and effective sanctions;
6) Establishing a viable option to achieve the organisation's strategic objectives;
7) Creating an appropriate space for performance improvement at all levels of the organization [Tennant et al., 2002];
8) Establishing appropriate organisational performance management structures [Piplai, 2001];
9) It is possible to compare the company with competitors, identify strengths and weaknesses, and environmental opportunities and threats to help develop strategies tailored to its environment and capabilities [Pavlínek, Ženka, 2010];
10) The review of past investments and the decision on new investments are based on rankings and performance evaluations [Kotler et al., 2019].

As can be seen from above statements, strategic planning ensures growth and success in terms of various aspects of the organisation, a comprehensive system, and proper functioning [Cavusgil, Nevin, 1981].

Iran Khodro is one of the two giant automotive poles of the Iranian automotive industry, with more than 50% of the car market share in Iran. Realisation of percentage of market share in Iran showed their success in the domestic market by more than 50%. Iran Khodro's cooperation with several global mechanisms has been traced to realise the strategy of selecting new builders. Given this, the company has failed to reach the international market [Rezaeinejad, 2021a; 2021b]. Only 2% of Iran Khodro's output has been exported; therefore, the successful presence of the Iranian company in the global market has been considered a strategic issue. In response, the main issue and the critical question for the management of the agent and vice-export is the translation of this current strategy in Iran Khodro Company. The implementation of such a strategy requires the participation and alignment of many organisational levels. Therefore, two Balanced Scorecard perspectives and Hoshin Kanri were targeted as the required tools.

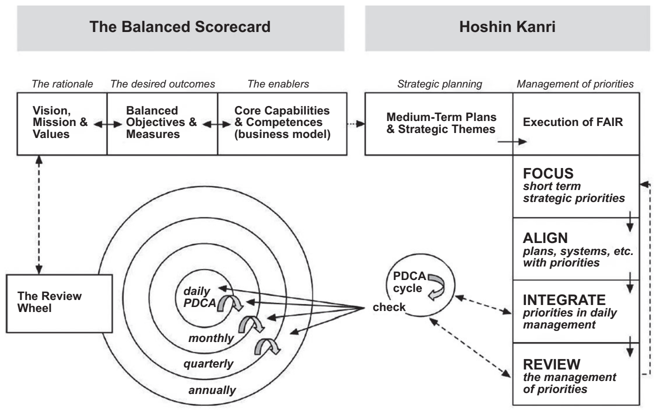
1. Literature review

In recent years, various academics and marketers have found that strategic planning is an effective tool to differentiate and gain a competitive advantage in the market [Clarke, Flaherty, 2003]. These strategic programmes have remained in the market for decades, maintaining their superior position through continuous innovation [Mottaghi, 2019]. Thus, strategic plans have also paid attention to both companies and customers [Humphrey, 2003]. A strategic foresight programme is a tool for measuring an organisation's competitiveness, which since the formation of this concept has been studied mainly through two approaches: financial and non-financial measures [Malina, Selto, 2001]. The topic discussed in this field is whether strategic planning should be considered with the marketing or financial approache [Paul, 2019]. As we will see, most studies have been concerned with these two views. There have also been attempts to combine these two views into a comprehensive model using the Balanced Scorecard and Hoshin Kanri models. By referring to each of these perspectives, this study has attempted to present a model that combines the two perspectives to create a more comprehensive approach to codifying strategic planning [Fernandes et al., 2006].

The integration of the Balanced Scorecard and Hoshin Kanri as a strategic management system is a new theory that has been studied in recent years. It was first proposed by B.J. Witcher and V.S. Chau in 2007. However, attempts have been made to use two models simultaneously rather than as a single model.

As stated, the first example of integrating the two models was presented in 2007 by Witcher and Chau, who gave a Balanced Scorecard and Hoshin Kanri for the strategic management process in the organization's success in achieving its goals should be integrated into an integrated model and complement each other. As shown in Figure 1, the above figure indicates the Balanced Scorecard and Hoshin Kanri as complementary capabilities. The Balanced Scorecard is a long-term strategy. Hoshin Kanri has been stated in the short term [Witcher, Chau, 2007].

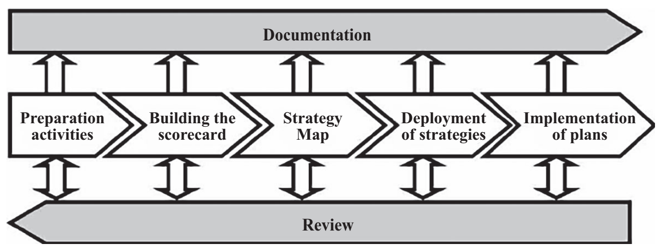
Fig. 1. Integrated model presented by Witcher & Chau



Source: [Witcher, Chau, 2007].

Another example of integrating two models came in the same year, but with a different approach, from Ş. Serdar Asan and M. Tanyaş. In their view, the Balanced Scorecard is a function-oriented and objective model, whereas Hoshin Kanri is process-oriented. They believe that by presenting an integrated model of strategy implementation, weaknesses in setting strategic objectives and placing them in a specific framework can be overcome and better synergy effects can be achieved. The proposed process is shown in Figure 2.

Fig. 2. Integrated model presented by Serdar Asan & Tanyas



Source: presented by [Serdar Asan, Tanyas, 2007].

This stage reviews the literature on strategic management and the use of the Balanced Scorecard and Hoshin Kanri used in companies and organisations.

1. 'Lessons from implementing the Balanced Scorecard in a small and medium-sized manufacturing organisation'were done by [Fernandes et al., 2006].

The UK manufacturing sector is facing massive challenges to survive in today's global and volatile marketplace. Companies are adopting newer management systems to clarify and translate their vision and strategy and translate them into action to meet these challenges. The Balanced Scorecard (BSC) is one such approach that is gaining considerable interest, especiallyin small and medium-sized enterprises (SMEs). This paper uses a case study of an SME to show how BSC can be successfully implemented using a systematic and structured methodology. This paper presents the experimental results of the proposed deployment methodology and highlights the experiences, successes, and lessons learned during the implementation process. In conclusion, this research confirms the validity and usefulness of the proposed methodology and offers managerial insights and guidelines for similar implementations.

The project initiation phase is the most critical step in the entire implementation process, as it defines the planning and forcasting of the actions required to complete the implementation process. Then, by defining the criteria and indicators, they are examined in the four dimensions of the Balanced Scorecard and are characterised by essential criteria. It builds a clear view of the organisation's movement towards its ultimate goal. It functions to move it to employees at different levels, moving them towards their ultimate goal.

2 .'Balanced Scorecard implementation in Jordan: an initial analysis' was conducted by [Al Sawalqa et al., 2011].

This paper analyses the state of implementation of the Balanced Scorecard (BSC) in Jordanian industrial companies. From an economic perspective, Jordan is an example of an advanced developing country in the Middle East region. The paper is a more comprehensive investigation into the diversity of performance measurement techniques developed in the West in the Jordanian context. A quantitative survey of 168 companies provided insight into the implementation, diffusion, and purpose of the BSC approach in medium and large industrial companies. The results showed that 35.1% of the companies surveyed used the BSC approach. The results also indicated that approximately 30% of the respondents were considering or implementing the BSC approach. The results showed some inconsistency in the types and number of BSC perspectives used. Companies implementing the BSC used different perspectives in their BSC, focusing on the original four perspectives suggested by the original authors of Kaplan and Norton.

The Balanced Scorecard has spread across industrial sectors and increased with the size of the organisation. The study revealed that Jordanian industrial companies use a Balanced Scorecard for various purposes, such as assessing organisational performance, observing legal cases evaluating management performance, and enhancing business process development [Xia, Tang, 2011]. Other objectives include a better understanding of cause-and-effect relationships, the relevance of organisational strategy, the management of productivity, reward, performance, and decision making.

3. 'The Successes in Long-Term Implementation of Balanced Scorecard: A Healthcare Organisation Study' was conducted by [Chang et al., 2010].

Measuring organisational success is an ongoing challenge for both academics and practitioners. Although studies support the widespread use of the Balanced Scorecard (BSC) in many organisations, few reports have identified critical success factors that can maximise the benefits and overcome certain critical predicaments faced at different stages of BSC implementation in the long term. The purpose of this study is to reflect on the successive phases in the evolution of BSC implementation for the most prominent Presbyterian hospital system in Taiwan. We discuss four phases of BSC implementation from 2001 to 2008 and examine the proposed phases and the activities carried out in each phase. Four stages can be distinguished: (1) planning and design; (2) weighting and evaluating the strategic performance measures; (3) aligning the strategic business units and strategic support units; and (4) achieving long-term performance and cultural change. Their study also elaborates on the experiences and results of monitoring and managing organisational performance towards a long-term dynamic realisation of an overall goal from the perspective of health care executives ,while exploring managerial guidance for similar implementations. These findings can be generalised for other organisations adopting or considering adopting the BSC.

4. Implementation of Balanced Scorecard: example of the Ministry of Youth and Sport of the Republic of Turkey by [Ekmekçi, 2014].

In this article, the Balanced Scorecard approach has emerged as a selection method through multiple performance measures that meets many of the challenges faced by public institutions. The adoption of what are considered to be private sector management styles and techniques is now becoming commonplace. The Balanced Scorecard methodology enables institutions to measure tangible and intangible assets. These measurements are made in four dimensions: financial perspective, customer perspective, internal process perspective, and learning and growth perspective. In modern management, sport must be controlled autonomously as developed countries. Turkey is one of the three countries where sport is managed by the government. Sport is a state institution, but it is a widespread sector with profit and non-profit organisations in Turkey. For this reason, the Balanced Scorecard method is applied to the Ministry of Youth and Sports as a strategic management tool in this study.

2. Methodology

Methods such as interviews, questionnaires, document review, analysis, and objective observation are used to gather information and evidence in research. However, the following methods will be used in this study: examination of books, articles, and general references related to the field of Balanced Scorecard and Hoshin Kanri, study and analysis of strategic planning document of Iran Khodro Company, questionnaire, the statistical population in this study consists of 15 persons of experts related to the case.

The executive model for research stages is divided into seven phases, which are:

Phase 1: Defining the vision, mission, and values: the mission and vision of the organisation is a document that distinguishes an organisation from other similar organisations, defines values and priorities, specific competitive capabilities and the scope of the organisation's activities in terms of product, customer and market.

Phase 2: Identifying critical success factors and key performance indicators: the critical success factors include an organisation's resources, capabilities and characteristics in the industry and are necessary for success in the marketplace. Key performance indicators help organisations define and measure the achievement of organisational goals. Once an organisation has analysed its mission, all stakeholders are identified, and objectives are defined to measure the degree of access to these objectives. Then, the critical indicators of the tool's performance are provided.

Phase 3: TheSWOT analysis and the determination of the evaluation matrix of the internal factors and external factors and dimensions of the competition and competitor' analysis is an effective tool to identify the environmental conditions and the internal capabilities of the organisation. Understanding the surrounding environment is the basis of this effective strategic management and marketing tool. The first step is to identify internal factors and external factors. After identifying all the strengths and weaknesses, threats, and opportunities, the internal factors evaluation matrix (IFE) is formed from the external factors evaluation matrix (EFE). Next, the internal strengths and weaknesses of the matrix are analysed, and the opportunities and threats of the external factors are examined.

Phase 4: Defining the strategy and creating a quantitative decision matrix: After identifying and scoring internal and external factors in Phase 3, these factors are grouped in the matrix. Then, using the matrix, the strategies are counted, and the priority of implementation is determined.

Phase 5: Defining strategic objectives using the Hoshin Kanri model: after completing the strategic objectives of the export area, the strategic objectives qualitatevly define the outcome of all the organisation's activities and emphasise the long-term (20-year horizon) based on the medium-term goals and the strategies necessary to achieve these goals.

Phase 6: Defining the strategy map and creating a Balanced Scorecard model: to build this model, the organisation's strategy must be translated into the dimensions and objectives of several levels (according to the original model to four levels of financial, customer, internal processes, and growth learning) and then, for each of the objectives set in these levels, one or more standard targets are defined to measure the achievement of the objectives. The final step is to define number of plans and action steps to meet the standards set for each indicator.

3. Findings and Discussion

3.1. Case Study: Iran Khodro

Iran Khodro (Persian: ایرانخودرو), branded as IKCO, is an Iranian automobile manufacturer based in Tehran. Founded in 1962 by the Khayami brothers, Iran National Company (the first name of Iran Khodro Company) began its operations by assembling L.P. or 321 buses with its parts supplied from Germany. To meet Iranian society's demand for automobile suitable car, the company's founders held talks with the British car manufacturer Talbot to obtain the production certificate to assemble the Hunter Hileman without any localisation. The cooperation with the British manufacturer resulted in various models of the Hunter Hileman or Paykan in 1967. Paykan was assembled into various primary, deluxe, sports, station wagon and pick-up models. In addition to Paykan, Iran National also produced and assembled heavy vehicles [Holweg et al., 2009].

Given the progress made in the production strategy of the national vehicles, Iran Khodro took another long step in designing and developing more sophisticated auto parts and technical sets of subsystems [Esfahani, Pesaran, 2009]. The company has achieved self-sufficiency due to its lack of trust in foreign suppliers and its all-out efforts to achieve the necessary capacities to produce all models of national vehicles [Rezaeinejad, 2021a; 2021b].

Over the years, IKCO has developed its capabilities to become the most influential industrial group in Iran engaged in industrial activities and services in the automotive sector for both passenger and commercial vehicles. Determined to become a world-class car manufacturer, IKCO established its R&D, engine development and testing centres, along with the latest technology of production machinery, equipment, and facilities in cooperation with leading European countries in the automotive industry, including Germany and France [Klier, Rubenstein, 2010].

Since 2003, IKCO has exported passenger cars to more than 40 countries, mainly in the CIS, the Middle East, North Africa, and Eastern Europe [Kuboniwa, 2009]. IKCO cars have been sold in Belarus, Syria, Turkey, Iraq, Venezuela, Azerbaijan, etc. The export of car parts and castings is one of IKCO's main overseas activities. The developing of export is a strategic perspective for IKCO, which is another sign of its movement towards internationalisation and its promotion as a regional company and even an international company.

3.2. Iran Khodro SWOT matrix

After analysing the SWOT matrix, it is clear that the main focus is on organisational processes, followed by the growth and learning perspective. The principle is that these two aspects of the organisation are designed to achieve strategic goals.

Table 1
Strengths and Weaknesses

Weaknesses (W)	Strengths (S)
W1) Lack of allocation unit in the field of international affairs	S1) Modern and advanced machinery and equipment
W2) High logistics and distribution costs	S2) Establishment of the quality management system
W3) Lack of a coherent mechanism in measuring customer satisfaction and agencies	S3) Existence of personnel with knowledge and belief in system thinking
W4) Long time to issue documents	S4) Government attention to export and credit for production
W5) Weakness in the knowledge of managing agencies and lack of appropriate training programme for them	S5) Customer complaint management
W6) Lack of staff in the markets and lack of foreign offices	S6) Having appropriate and efficient marketing capabilities
W7) Lack of comprehensive and up-to-date documentation	S7) Being one of the top exporters
W8) Weakness in effective monitoring of product presentation in the markets	S8) Customer-oriented spirit of the staff
W9) Lack of standards for most activities	S9) Identification of customer expectations
W10) Unclear monitoring of after-sales service performance	S10) Having excellent experience at international level
W11) Weakness in promotion strategy in the market	
W12) Lack of specialised personnel	

Table 2
Opportunities and threats

Threats (T)	Opportunities (O)
T1) Lack of promotion in foreign markets	O1) Consumer dissatisfaction with the quality of Chinese products
T2) Lack of updated product	O2) Exploitation of common political and religious issues
T3) Inadequate government support for exports compared to competitors	O3) Ability to use financial resources and export credit sales
T4) The presence of competitors in the area of economical vehicles such as China and India	O4) Cheap price of spare parts
T5) Increasing speed of competitors offering diverse and quality products	O5) Sales growth in global markets
T6) Low mental image of Iran Khodro brand compared to competitors	O6) Demand for small and economical cars
T7) Increasing the variety of competitors' products	O7) Government attention to exports
T8) Risk of bankruptcy	O8) Transformation of a car from an investement vehicle to a luxury vehicle
T9) Absence of Iran in trade and economic associations	O9) Demand for economy cars in high risk areas
T10) Macroeconomic indicators such as inflation and exchange rate stability	O10) Active and experienced workforce
T11) Lack of flexibility in the production line	
T12) Comprehensive sanctions	
T13) Lack of transport infrastructure and banking communication	
T14) Quality and options	
T15) Lack of an information structure in customer affairs	

3.3. Definition of the strategy and creation of a Quantitative Strategic Planning matrix

Table 3
The internal and external matrix

Conservative strategy	Aggressive strategy
Defensive strategy	↘ Competitive strategy IFE=2/63 EFE=2/57

According to the Quantitative Strategic Planning matrix, the author has prepared some strategies.

1) innovation strategy in the process of export marketing and sales research;
2) information, organizational, and human capital management strategy;
3) market share maintenance and expansion plan;
4) export process operations excellence strategy (international affairs, logistics, finance and commerce);
5) external database management strategy;
6) brand development strategy;
7) agency management strategy and agency satisfaction;
8) productivity strategy;
9) growth and profitability strategy;
10) export customer satisfaction strategy.

According to the Quantitative Strategic Planning matrix, we have prioritised strategies using expert opinion in Table 4.

Table 4
Quantitative Strategic Planning matrix

Priority	Strategies
66/6	Strategy 4 = Export process operations excellence strategy (international affairs, logistics, finance and commerce)
62/5	Strategy 1 = Innovation strategy in the process of export marketing and sales research
38/5	Strategy 5 = External database management strategy
35/5	Strategy 7 = Agency management strategy and agency satisfaction
3/5	Strategy 2 = Information, organisational, human capital management strategy
51/4	Strategy 3 = Strategy to maintain and grow market share
01/4	Strategy 10 = Export customer satisfaction strategy
91/3	Strategy 6 = Brand development strategy
44/3	Strategy 9 = Growth and profitability strategy
32/3	Strategy 8 = Productivity strategy

3.4. Defining strategic goals by the Hoshin Kanri model

After analysing the SWOT analysis and studying the mission and vision of the organisation, the strategic objectives of the company were prepared according to Hoshin Kanri objectives as follows:

1. Employing experts in the field of export.
2. Institutionalising individual and organisational export knowledge.
3. Using modelling of top organisations.
4. Fostering export culture in the organization.
5. Optimising the export organisation structure.
6. Development of export customer database.
7. Development of customer communication systems and agency network.
8. Information systems development and integration.
9. Improving the knowledge and skills of export personnel.
10. Deepening and expanding market studies.
11. Improving the market research mechanism.
12. Demand management of export customers.
13. Developing new marketing methods.
14. Quantitative and qualitative improvement of participation in international exhibitions.
15. Developing interaction with agents and customers.
16. Brand development.
17. Simplifying the logistics process and product distribution.
18. Simplifying document issuing processes.
19. Enhancing the capabilities of the dealer network.
20. Expanding dealer network.
21. Developing network monitoring and evaluation.

22. Agent business development.
23. Developing agency standardization.
24. Product export development.
25. Development of new marketing and sales methods.

3.5. Preparation of a balanced scorecard and definition of the strategic plan

In the end, the integrated model of the Balanced Scorecard and Hoshin Kanri provided for Iran Khodro's export division in Tables 5–8. Tables 5–8 prepare a Balanced Scorecard model for Iran Khodro in four aspects.

4. Conclusions and proposals

In the strategic planning of Iran Khodro's export division, attention has been paid to the cause-and-effect relationships and the Balanced Scorecard. Based on the objectives derived from the strategy, indicators and measurement criteria have been defined based on the Hoshin Kanri, considering that Iran Khodro Company operates as one of the two major car manufacturing hubs in the country with more than 50% share of the passenger car market in Iran. Therefore, based on the Hoshin Kanri model and the Balanced Scorecard model, it was examined whether the Balanced Scorecard framework could be designed to meet the needs for effective translation, implementation, and alignment of

Table 5
The Balanced Scorecard model from a customer perspective

Target value	Measurement unit	Related measures	Strategic objectives
70	Percent	Customer satisfaction with product price	Economic price
85	Percent	Customer satisfaction with after-sales service	Competitive after-sales service
75	Percent	Agent satisfaction with after-sales service	
75	Percent	Agent satisfaction with sales services	Competitive sales service
90	Percent	Agent satisfaction with product quality	Modelling of top organisations
90	Percent	Customer satisfaction with product quality	
85	Percent	Agent satisfaction with product comformity with the order	Product conformity with the order
85	Percent	Agent and customer satisfaction with timely delivery	Timely delivery
60	Percent	Agent satisfaction with product prices	Information systems integration
35	Percent	Market share of Iran Khodro products in export markets	Maintaining and growing of market share
73	Percent	Satisfaction of export sales network agents	Export customer satisfaction
35	Percent	Iran Khodro brand awareness	Well-known brand
73	Percent	Satisfaction of export sales network agents	Developing and updating system documentation standards
35	Percent	Customer satisfaction with the free service portfolio	Complementary service portfolio
75	Percent	Agent satisfaction with the economic situation of the sales agents' business	Economisation of representative units

Table 6
The Balanced Scorecard model in financial-aspect

Target value	Measurement unit	Related measures	Strategic goals
2000	Device	Number of CBUs issued	Increase exports of current products
2700	Device	Number of CKDs issued	
50	Percent	Export rates to production	
9	Number	Number of CBU markets	
500	Thousand dollar	Export value of production equipment and technical and engineering services	
153 486	Thousand dollars	Exported CKD value	
65	Percent	The ratio of the number of new products exported to total exports	Export new products
158 486	Thousand dollars	Export value of new products	
30	Percent	The ratio of sales to investment	Information systems integration
5	Percent	Per capita advertising cost per car in the target market	Increase marketing cost efficiency / Sales
110 000	Thousand dollars	The amount of savings in marketing costs	
150 000	Thousand dollars	The amount of logistics costs saved per year	Reduce logistics and distribution costs
35	Percent	The ratio of absorbed export credits to export value	

Table 7
The Balanced Scorecard model in growth & learning-aspect

Target value	Measurement unit	Related measures	Strategic goals
50	Number	Number of registered sciences	Institutionalisation of individual and organisational export knowledge
34	Number	Number of databases	Development of customer database /product / market
34	Number	Number of records and database fields	
45	Hour	Specialised export training per capita per year	Improving the knowledge and professional skills of export staff
5	Number	Number of Modelling activities carried out and reported (organizations, exhibitions, seminars, research, etc.)	Modelling of top organisations
80	Percent	Implementation of export culture promotion in the organisation	Fostering an export culture in the organisation
8	Number	Number of methods used to promote export culture in the organisation	
75	Percent	The degree of alignment of the organisational structure with export strategies	Optimisation of the export organisational
60	Percent	The degree of integration of information systems	Integration of information systems
15	Number	Number of new information systems	
75	Percent	Percentage of implementation of customer relationship and agency system	Development of customer communication systems, dealer networks and overseas production sites
11	Number	Number of documents created	Developing and updating system documentation standards
11	Number	Number of documents updated	

Table 8
The Balanced Scorecard model in internal processes-aspect

Target value	Measurement unit	Related measures	Strategic goals
65	Percent	Percentage of coverage of market studies with standard criteria	Improving and expanding market research
25	Number	Number of market research reports	
25	Number	Number of markets studied	
20	Number	Export market portfolio implementation rate	Portfolio management maintaining and influencing target markets
8	Number	Number of complementary services provided per dealership	Top organisation modelling
8	Number	Number of complimentary services provided by agencies	
4	Number	Number of sales promotion methods	Developing new marketing and sales promotion methods
4	Number	Number of advertising methods per market	Increasing promotional methods
5	Number	Number of visits to trade fairs as a percentage of total number of visits per year	
8	Number	Number of delegations received and sent	Encouraging interaction with agents, customers and domestic and foreign institutions
6	Number	Number of conferences per year	
3	Number	Number of brand development programmes	Creating a well-known brand
35	Percent	Reduction of CBU container shipping costs	Agility of supply and preparation processes
3	Day	Average time of logistics process to export products	
55	Percent	Ratio of documents required for duty drawback to documents delivered	Agility of financial and business processes
2	Day	Average time to issue documents	
75	Percent	Percentage of needs met by export customers	Managing the strategic needs of foreign production sites

Table 8 *(ending)*

Target value	Measurement unit	Related measures	Strategic goals
75	Percent	Percentage of product location added to products - production sites	Optimising the business structure of foreign production sites
7	Number	Number of markets with a production site	
18	Number	Number of monitoring systems	Systematisation of monitoring systems of foreign production sites
18	Scores	Score of representatives in each market	Development of standardisation and capacity of agencies
14	Scores	Acceptable score obtained by representatives in evaluations	
7	Number	Number of agencies	Expansion of the network of agencies
4	Number	The number of representatives evaluated	Development of network monitoring and evaluation

macro-strategies and strategic issues at different levels of the organisation, so that each level can understand its role and position in the realisation of strategic issues and gain more value from the use of this tool.

Evaluation of Iran Khodro's strategic plan using key components of the Balanced Scorecard:

A. Financial aspect

1. Increasing the current products exported

'Increase in exports of current products' is calculated using three key indicators: 'number of vehicle parts exported,' 'value of spare parts exported,' 'export value of production equipment and engineering and licensing services,' to the number of CBU export markets. The situation indicates a weakness and the need to work on improving this area. Therefore, the author suggested that Iran Khodro Company strengthen sales by holding monthly planning meetings with all relevant units, implementing the export reporting system, consolidating existing distributed systems, and concluding and renewing contracts with customers and contractors. It is important to act with the necessary capacity and flexibility and to continue to increase capacity through the programme. Furthermore, should a group undertake the sales and installation of production facilities in a simultaneous manner, the average installation time of projects will be reduced, thereby facilitating the expeditious realisation of support revenues.

2. Exporting new products

The calculated value for the export of new products through the two key indicators, number of new product sites and number of markets studied for the construction of the production line, is in close proximity to the set goal and exibits minimal discrepancy from the set goal. In accordance with the devised plan, the calculated actual values are evaluated in relation to the set goals. The defined indicators are deemed sufficient and appropriate for evaluating the company's financial performance.

B. Customer aspect

1. Export customer satisfaction

The export customer satisfaction indicator is comprised of two key metrics: the number of markets in which the end-customer survey was conducted and the number of markets in which the representative survey was conducted. According to the pre-established goals, these metrics indicate areas of weakness and a need to implement strategies to enhance this aspect of the process. Therefore, the researcher recommended that Iran Khodro Company a more comprehebsive approach to the planning of surveys and evaluations to be conducted in designated markets. For this goal, the company may consider conducting surveys in other potential markets, includinf Syria, Venezuela, Iraq.

2. Product compliance with the order

The critical indicator of product compliance with the order, namely the export fulfillment rate, serves to highlight the necessity for improvement in this particular area. It was therefore recommended by the researcher that Iran Khodro Company implement more rigorous performance monitoring and comparison with the plan, submit reports to the production, supply, and logistics headquarters, and accurately reflect customer orders to Iran Khodro planning. Furthermore, it was suggested that weekly meetings be held with relevant units, and that orders be packaged on time.

According to the resulting planning in each metric, it is possible to calculate the actual values and compare them with the set goals. The defined indicators to evaluate customer performance are efficient and effective.

C. Internal processes aspect

1. Improving and expanding market studies

Improving and expanding market studies through four key indicators: market study standardisation, improving export market prioritisation methods, improving survey methods and identifying appropriate sources for purchasing information according to the set goals. The result of efforts in this field is presented. It is therefore recommended that Iran Khodro Company implement a comprehensive plan to address the shortage of human resources, which is likely to become increasingly acute in the context of the planned expansion in activities in the field of advertising and international affairs. In order to prioritise markets and select several models, it is necessary to:

2. Implement effective control and penetration management strategies within target markets

The management of protection and influence in target markets is indicated by five key factors, which also demonstrate the relative weakness of some sectors and the necessity for efforts to improve these sectors. It was thus recommended that Iran Khodro Company appoint a resident representative of Iran Khodro in the Iraqi market and a representative in the African markets. Furthermore, the implementation sales development plans in four markets, namely Iraqi, Azerbaijanian, Syrian and Egyptian was advised, as was the expansion into five markets in Ukraine, Russia, Belarus, Nigeria, and Algeria. Finally, the pursuit of an increase in the warranty ceiling for export vehicles was also recommended. In order to facilitate the preparation of a business plan and its approval by the board, the company will pursue the adoption of the Euro 4 standard for all export products by engineering, marketing and presenting prototype vehicles in African markets. Furthermore, the company will market and offer a model car in markets in Asia and Europe. In addition, the company will participate in car exhibitions in Africa and Latin America, Asia, and Europe.

3. Develop innovative marketing techniques and sales promotions

The attainment of the set goals demonstrates a notable deficiency, threby underscoring the necessity for improvement. Therefore, the researcher proposed that Iran Khodro Company undertake the compltion and implementation of the seven markets in Syria, Iraq, Venezuela, Algeria, Azerbaijan, Egypt, and Sudan.

4. Provide quantitative and qualitative development of advertising mechanisms

The number of markets for which export advertising information has been provided shows the effectiveness of the programmes in this area. Therefore, the researcher said that Iran Khodro Company should improve its advertising and provide more useful tools in eleven countries (Egypt, Nigeria, Algeria, Iraq, Syria, Ukraine, Belarus, Azerbaijan, Sudan, Senegal, and Venezuela) .

5. Promote interaction with representatives and customers and institutions

The objective is to enhance the interaction with representatives, customers and domestic and foreign institutions. This will be achieved by pursuing the creation of an export website, which is a key indicator of success in this sector. The efficiency and effectiveness of the programmes in this sector are demonstrated by the attainment of the set goals. It was therefore recommended by the researcher that Iran Khodro Company persevere in its efforts to establish an export website, with the preparation of web pages in languages other than English representing a key component of this strategy.

6. Introduce brand promotion in global markets

The term ‘brand promotion in global markets’ is defined by three key indicators, the performance of which indicates a slight weakness in relation to the set goals. This area therefore requires improvement. In light of these considerations, the researcher proposed that Iran Khodro Company delineate and assemble an advertising campaign in six Asian and three African markets, while concurrently identifying potential avenues for expansion in regions such as Syria, where prevailing political circumstances present a challenge.

7. Make agencies more standardised and capable

The researcher recommended that Iran Khodro Company should create a standard for overseas agencies, develop software software for active markets, and create training packages for agencies.

8. Expand the network of agencies

The expansion of the network of agencies can be gauged by the key indicator of the number of selected regional agencies. This indicator demonstrates the effectiveness of the programmes in this sector in achieving the set goal. In light of the aforementioned considerations, the researcher proposed that Iran Khodro Company delineate and operationalise a network development plan in the Syrian and Iraqi markets. This entailed formulating a plan to visit the markets,applicants and agencies, with the objective of selecting five regional agencies in Syria and two agencies in Iraq.

9. Monitor and evaluate networks

The researcher proposed that Iran Khodro Company devise a checklist to assess the standardisation of agencies and oversee and monitor agencies’ standards. The calculation of actual values and comparison with set goals is made possible by the resulting planning in each metric. The defined indicators for evaluating customer performance are sufficiently efficient and evaluative.

D. Consider learning and growth aspects

1. Develop customer, product and market database

The development of a customer, product and market database is contingent upon the creation of a comprehensive export database. This indicator demonstrates the current deficiencies in this sector and underscores the necessity for more rigorous implementation of programmes and criteria. Consequently, the researcher proposed that the Iran Khodro Company assume a coordinating and monitoring role in the field of database design across various stages, facilitating the exchange of information regarding the export unit’s requirements.

2. Develop and update system documentation standards

The development and updating of system documentation standards, as indicated by the critical factor (number of documents finalised, reviewed and compiled), in accordance with the established goals, demonstrates a relatively high level of effectiveness and efficiency of programmes in this area. It is therefore recommended that the Iran Khodro Company maintain and reinforce the number of finalised, revised, and compiled documents. In order to achieve this objective, it is essential to give due consideration to the review of the executive method of commercial services.

As can be observed, an analysis of the results obtained in each of the measures indicates that, at least in the short term, some indicators should be adjusted or a suitable mechanism should be designed to respond to and calculate them.

Finally, considering the consensus on these indicators, the potential for calculating actual values and comparing them with the established goals for the two indicators, and the aforementioned explanation, it can be concluded that these indicators, in terms of learning and growth, represent a valuable tool for evaluation and performance assessment in the strategic planning domain of Iran Khodro Company.

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The article was submitted on 05.05.2024; revised on 31.05.2024 and accepted for publication on 10.06.2024. The author read and approved the final version of the manuscript.
文章于 05.05.2024 提交给编辑。文章于 31.05.2024 已审稿．之后于 10.06.2024 接受发表。作者已经阅读并批准了手稿的最终版本。

DOI: 10.17747/2618-947X-2024-2-164-175

Management decision making in public administration information systems in South Africa: The role of the Auditor General of South Africa in improving effectiveness

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Abstract

The Auditor General of South Africa (AGSA), a statutory body that evaluates public sector information systems, is the main corporate governance instrument in the study. The different methods of corporate governance are explained in this article. The article examines the barriers to improving public sector information systems. Our analysis will focus on the efficiency of information systems in the public sector, closely linked to South Africa's National Development Plan 2030 and the Medium Term Strategic Framework, critical measures to achieve success. The study uses Atlas.ti 7 for qualitative textual analysis. This software analyses textual data from the 2017–2021 AGSA reports.

This thematic study highlights the micro and macro challenges faced by South Africa's public sector governance institutions. The problems stem from deficiencies in the information system, changes in the leadership, and a lack of transparency and access to information. We also face smaller issues such as a lack of executive accountability for their decisions, inadequate technology skills, ineffective project management, no disaster recovery procedures, declining IT governance and delays in filling key IT positions.

The study suggests promoting a transformative mindset to raise awareness of the critical role of information technology in public sector management. It also highlights the need to identify South African corporate governance practices that hinder information systems. The paper aims to improve the corporate governance framework for information systems in order to maximise the efficiency of the public sector.

Keywords: information systems (IS), public sector governance, audit reports, corporate governance, South Africa, strategic decisions, risk management, auditor general of South Africa (AGSA), economic impact.

For citation:

Latchu A., Singh S. (2024). Management decision making in public administration information systems in South Africa: The role of the Auditor General of South Africa in improving effectiveness. *Strategic Decisions and Risk Management,* 15(2): 164-175. DOI: 10.17747/2618-947X-2024-2-164-175.

南非公共行政信息系统的管理决策：南非总审计长在提高效率中的作用

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简介

南非总审计长是评估公共部门信息系统的机构，是本研究中考虑的主要公司治理工具。本文解释了各种公司治理方法；探讨了与南非2030年国家发展计划和中期战略计划密切相关的公共部门信息系统改进的主要障碍，这些计划对于取得成功至关重要。 本研究使用Atlas.ti 7进行质性文本分析。该软件分析了2017年至2021年间南非总审计长的报告中的文本数据。本文探讨了南非公共部门管理机构面临的微观和宏观问题。问题的产生源于信息系统的缺陷、管理层更替、以及缺乏透明度和信息获取。此外，还有一些较轻微的问题，如领导者对其决策缺乏责任心、技术技能不匹配、项目管理效率低下、缺乏应急恢复计划、信息技术领域的公司治理恶化以及关键IT职位的替换不及时。 本研究建议推动创新思维，以提高对信息技术在公共部门管理中关键作用的认识。同时，强调了识别南非公司治理实践中阻碍信息系统发展的必要性。其主要目标是改进信息系统的公司治理结构，以最大限度地提高公共部门的效率。

关键词：信息系统、公共部门管理、审计报告、公司治理、南非、战略决策、风险管理、南非总审计长、经济影响。

引用文本：

Latchu A., Singh S. (2024). 南非公共行政信息系统的管理决策：南非总审计长在提高效率中的作用。战略决策和风险管理, 15(2): 164–175. DOI: 10.17747/2618-947X-2024-2-164-175.

Introduction

The concept of 'governance', derived from the Latin word 'gubernare', meaning 'to rule' or 'to steer', is particularly relevant in the field of corporate governance, which is concerned with the management and oversight of corporations [Singh, Singla, 2022]. Corporate governance has evolved due to the need for accountability after business failures and the adoption of rules by organisations such as the OECD [Otman, 2022]. Corporate governance techniques address issues such as internal controls, board operations, disclosure, transparency, and stakeholder trust [Kiranmai, Mishra, 2022]. This development is a global phenomenon, affecting countries at different economic stages [Gutterman, 2023]. Corporate governance establishes a relationship between shareholders (principals) and management (agents) in which managers are tasked with achieving the organisation's objectives. Conflicts arise due to divergent interests between principals and agents, and governance systems are needed to manage these issues [Lazarides, Drimpetas, 2008; Lazarides et al., 2008; Papazafeiropoulou, Spanaki, 2016]. Research shows that high quality corporate governance reduces conflicts between directors and management, who often have superior information, leading to discrepancies in information management [Lazarides, Drimpetas, 2008; Salim et al., 2022].

[Kay, Silberston, 1995] describes traditional corporate governance as the accountability of managers to shareholders, a complex concept influenced by a number of factors. [Wild, 1994] emphasises the role of audit committees in enhancing accountability. In both governmental and organisational contexts, information systems (IS) are critical for efficiently managing the collection, processing, and distribution of information, thereby avoiding data saturation [Zvyagin, 2022]. [Gaines et al., 2012] notes the evolution of IS from a support role to a strategic partner, and [Almazán et al., 2017] discusses the impact of IS on organisational performance, both highlighting the role of IS in gaining competitive advantage and improving outcomes. Effective corporate governance ensures that IS provides essential information to controlling shareholders, or citizens in public institutions [Mehta, Chandani, 2020]. High quality information frameworks are crucial for improving decision making in governance [Água, Correia, 2021]. Transparent and reliable financial information is essential for governance and the protection of shareholder interests, especially in public companies where citizens are stakeholders. Timely and accurate information prevents data misuse and breaches [Bushman, Smith, 2003; Lazarides, Drimpetas, 2008; Fung, 2014; Chen et al., 2019].

In the area of overseeing individuals and their representative groups, a comprehensive framework of established norms, rules, legal statutes, and regulatory measures ensures the achievement of corporate governance [Lazarides, Drimpetas, 2008; Lazarides et al., 2008]. Although the implementation of robust corporate governance frameworks is costly, it significantly enhances organisational functionality and performance by ensuring efficient operation, stability and minimised principal-agent conflicts in information systems (IS) [Lazarides, Drimpetas, 2008; Ali, Green, 2012; Papazafeiropoulou, Spanaki, 2016]. Effective information systems (IS) performance is defined by attributes such as regulation, interaction, information distribution, adaptability, data retention, and cybersecurity [Lazarides, Drimpetas, 2008; Chen et al., 2019]. Issues such as IT downsizing, IT budget cuts, and misinformation can undermine corporate governance [Ali, Green, 2012].

Effective IT governance, which includes top management participation, regulatory compliance, and efficient communication systems, is crucial for organisational success and preventing project failures [Ali, Green, 2012; Asgarkhani et al., 2017]. A well-designed IT governance framework is essential for achieving long-term viability, aligning the strategic interests of executive management with those of shareholders through established structures and mechanisms [Achim, Borlea, 2014; Jarboui et al., 2014; Locke, Duppati, 2014]. Corporate governance, shaped by organisations such as the Institute of Directors in South Africa (IODSA), provides the guidance and control necessary to ensure that organisations achieve their set goals and objectives [Gstraunthaler, 2010].

The performance of public sector organisations depends on their adherence to strategic and national objectives under government supervision. Theimplementation of strategic management is crucial for improving the efficiency of the public sector and achieving good governance [Locke, Duppati, 2014; Vasyunina et al., 2022]. Effective corporate governance systems, characterised by fairness, transparency, and value-enhancing activities, contribute to the optimal allocation of resources and improved business performance. These systems are critical to the success of public sector enterprises [Mohamad, Muhamad Sori, 2011; Locke, Duppati, 2014; Yapa, 2014; Ali Asghar et al., 2021].

A robust corporate governance framework can deter fraud and abuse of authority while enhancing public confidence in the management of economic resources [Matei, Drumaşu, 2014]. [Alnaser et al., 2014] asserts that effective corporate governance in public companies increases investor confidence and positively affects market performance. This concern is particularly important in developing countries, where fraud and abuse of authority tend to be more widespread [Ponduri et al., 2014]. To enhance accountability in the public sector, corporate governance practices have been adapted to better manage and steer organisations in line with government objectives [Papazafeiropoulou, Spanaki, 2016]. Corporate governance emerged in response to widespread embezzlement and financial misconduct in developed economies such as the US and the UK [Ali, Green, 2012; Matei, Drumaşu, 2015]. This need for governance has become a global concern, affecting all stages of the economy [Gutterman, 2023]. Notable incidents such as the Watergate scandal in the US in the 1970s, involving the illegal use of funds for political purposes, and abrupt corporate failures in the UK in the 1980s and 1990s, highlighted the need for a clearer distinction between shareholder and managerial powers [Matei, Drumaşu, 2015]. The creation of the Cadbury, Greenbury, Hampel, and Combined Codes in the UK was a response to the separation of ownership and control in organisations, and these codes have played a crucial role in shaping corporate governance standards both at home and abroad [Walsh, Seward, 1990; MacNeil, Esser, 2022]. Corporate governance encompasses elements such as principal-agent interactions, performance and accountability, regulatory frameworks, and external audits. It sets out a structure of rules, customs and processes that shape how a company is organised and what it aims to achieve [Elamer et al., 2022].

Information systems (IS) facilitate the integration of accounting, finance, human resources, supply chain management, and production, improving data consolidation and the sharing of critical information [Lee, Whang, 2000; Bernstein, Haas, 2008; Carr, 2016; Chen et al., 2019; Fakhimuddin et al., 2021]. Studies show that IS integration with corporate governance improves information handling and overall performance [Ravichandran et al., 2005; Gorla et al., 2010; Lipaj, Davidavičienė, 2013; Almazán et al., 2017; Chen et al., 2019]. Effective IS planning and senior management support are critical to improving business performance [Raghunathan, King, 1988; Ragu-Nathan et al., 2004].

Assesstments of public sector effectiveness in IS and corporate governance reveal a complex relationship between governance and performance [Coles et al., 2001; Larcker et al., 2007]. Appropriate governance frameworks, including competent audit committees and internal audit, are essential [Dzomira, 2020; Oprea et al., 2023]. Effective IT governance is also critical to public sector performance, addressing challenges and improving governance standards [Ako-Nai, Singh, 2019; Chigudu, 2020; Cuadrado-Ballesteros, 2020].

Information processing theories suggest that effective IS should integrate business processes, provide comprehensive and accurate information, and facilitate timely decision making, directly impacting organisational operations [Habba et al., 2017; Pereira, Sá, 2017; Ricciardi et al., 2018; Amin, 2019; Chen et al., 2019; Quan, 2019; Stoilov, 2019; Susanto, Bong, 2019; Fatieieva, 2020]. Effective IS reduces the cost of decision making and improves the quality and timeliness of information [Chen et al., 2019]. In the public sector, political decisions and conflicts can affect management priorities, often leading to poor governance [Chen et al., 2019].

In South Africa, corporate governance often fails to meet the needs of the public, resulting in numerous investigations and leadership changes [Masegare, Ngoepe, 2018]. Effective governance should involve a multifaceted approach that includes legal, political, and social dialogue, continuous evaluation, and stakeholder engagement, as highlighted in the King Code and Batho Pele guidelines [Masegare, Ngoepe, 2018]. Risk-based systems of an audit mechanism can increase the effectiveness of public administration sector entities in addressing sustainability and strategic challenges more robustly [Masegare, Ngoepe, 2018].

In South Africa, the public administration and state-owned entities operate under specific corporate governance systems and frameworks to ensure fairness and impartiality in the discharge of their responsibilities. Despite the challenges it faces, the public sector plays an important role. It contributes around 10% of global output and is an important economic consideration [Daiser et al., 2017]. To address transparency issues and improve public sector governance, the South African government has introduced several measures. These measures aim to improve accountability, operational efficiency, and the alignment of public organisations with national objectives:

1.CGICT Framework: South Africa's Department of Public Service and Administration (DPSA) has developed the CGICT Framework, which provides guidelines for ICT governance in government organisations. This framework aims to align corporate ICT governance practices across state bodies and public enterprises and supports the auditing activities of the Auditor General of South Africa (AGSA) [Public service corporate.., 2012; Mawson, 2017].

2. Public Finance Management Act (PFMA): The PFMA is critical to updating financial management practices and ensuring transparency, accountability and collaboration in the budgeting process in South Africa. It sets out criteria for financial management at national and provincial levels to improve financial accountability and openness [Madue, 2007; Siswana, 2007].

3.King IV Code: This code governs corporate governance in South Africa, emphasising sustainability, corporate social responsibility, and detailed reporting. Influenced by African values such as Ubuntu, it adapts to changing socio-economic and political conditions to promote connectivity and humanity [Gstraunthaler, 2010; Dube, 2016].

4. ISO 38500 Standard: ISO 38500 outlines key principles to guide the wise and effective use of information technology in organisational contexts. This standard provides as a framework for corporate governance of IT, ensuring that IT supports and enhances the overall business objectives and strategy. It is essential for IT governance in the South African public sector, providing a framework for assessing IT governance and suggesting improvements for inter-organisational IT systems [Campbell et al., 2011; Public service corporate.., 2012].

5. COBIT 5 Framework: Designed to assess and manage the governance of information systems and technology, COBIT 5 provides a systematic approach to the challenges of information governance and management. It helps organisations achieve their goals by balancing benefits, risks, and resource utilisation [COBIT 5.., 2013; De Haes et al., 2013; Kozina, Sekovanic, 2015; Mora Aristega et al., 2017].

6. Auditor General of South Africa (AGSA): The AGSA is an independent body responsible for auditing public sector organisations to uphold constitutional democracy and good governance. Mandated by Chapter 9 of the Constitution and the Public Audit Act, the AGSA oversees the allocation of public funds and enhances public confidence through audits that focus on material irregularities. Enforceable corrective measures, such as debt certificates, are issued for non-compliance to recover lost funds [Hatchard, 2018][1] .

The discussion of specific regulations and their impact on corporate behaviour and results is often inadequate in many publications. The public sector benefits from establishing corporate governance in a number of ways, including reduced costs, higher quality services, more flexible IT systems, greater information security and more effective risk management. [Oprea et al., 2023; Singh, 2023]. Values such as honesty, transparency, and accountability in corporate governance help public institutions achieve their goals and meet public needs [Yohana, 2022]. For all organisations, particularly in the public sector, effective corporate governance is essential for sustainable resource management and operational longevity, and have a significant impact on performance [Latchu, Singh, 2022]. In the public sector, corporate governance principles can significantly reduce fraud and financial distress. In addition, the adoption of corporate governance adresses issues related to the configuration of information systems, increases managerial accountability, strengthens IT capabilities and promotes efficient project and information management in the South African public sector. Poor corporate governance can lead to an inefficient and unresponsive economic infrastructure, ultimately hindering the achievement of strategic government goals [Gichoya, 2005]. Effective IT governance is essential for aligning IT initiatives with business objectives and includes strategies such as senior management involvement, adherence to ethical practices, and effective corporate communications [Ali, Green, 2012]. The lack of strong corporate and IT governance in the South African public sector poses a major obstacle to achieving the goals of the National Development Plan 2030 (NDP) and the Medium-Term Strategic Framework (MTSF) [Mathase et al., 2019]. These frameworks are key components of South Africa's development strategy, aligning national priorities with global sustainable development goals [Fourie, 2018]. The Sustainable Development Goals (SDGs), comprising 17 interconnected targets, aim to address critical global issues such as poverty, inequality, and climate change. These goals are underpinned by the concept of sustainable development, which balances meeting the demands of the present with ensuring that future generations can meet their own needs [Clark, Wu, 2016; Pedersen, 2018].

1. Literature review

The performance of information systems (IS) performance is a key aspect of major government-led public sector reforms aimed at improving the accessibility of public bodies, promoting collaboration, openness, and the availability of information [Trotta et al., 2011; Castelo, Gomes, 2023]. IS contribute to transparency in public sector organisations by enabling resource monitoring and facilitating optimal decision making [Trotta et al., 2011; Yesimov, Bondarenko, 2018]. Despite this, information systems (IS) operations are influenced by the pressures for process standardisation within public administration [Trotta et al., 2011]. For change in the public sector to be successful, information systems (IS) need to improve organisational performance to achieve strategic goals and foster citizen engagement, thereby reducing bureaucratic barriers to critical decision-making [Trotta et al., 2011]. Challenges in IS procurement, such as miscommunication between vendors and procurement agencies, hinder the achievement of intended goals [Riihimäki, Pekkola, 2021]. While IS are essential to the ability of public sector organisations to innovate and create value [Senyo et al., 2021], their impact is more thoroughly documented in the commercial sector than in the public sector of developing countries [Senyo et al., 2021]. Reforms that exclude IS lead to misalignment and failure to achieve objectives [Senyo et al., 2021].

[1] Integrated annual report 2020–2021 (2021). AGSA. www.groundup.org.za/topic/sassa/.

There is a growing interest in using IS to improve and streamline public sector service delivery [Kassen, 2022]. IS not only collect, store, process, and deliver reliable information to citizens and government agencies, but also offer flexibility in managing and processing public sector information, subject to accurate implementation and an appropriate performance environment [Kassen, 2022]. Corporate governance in state-owned organisations is a key driver of economic governance and has a significant impact on public service accountability, business performance, and operational efficiency [Mahadeo, Soobaroyen, 2012; Goel, 2015; Heo, 2018].

South Africa's public sector faces significant challenges related to IS security breaches. The uptake and application of information systems in Africa's public sectors, including South Africa, is particularly limited [Akande, Van Belle, 2013]. Notably, South Africa has the highest rate of ransomware incidents and business email breaches on the continent, revealing critical IS weaknesses [Devanny, Buchan, 2024]. In the South African public sector, examples of IS breaches include:

1. October 2019: Shadowy Hackers infiltrated Johannesburg's municipal website and billing system, demanding a ransom of four bitcoins (about $ 30,000) to prevent the release of data [Daniel et al., 2023].

2. May 2020: Unintentional changes to the UIF website led to a data leak exposing personal information of UIF claimants; a security researcher identified and reported problem, which was subsequently resolved by the UIF [Pieterse, 2021].

3. September 2021: The Department of Justice and Constitutional Development suffered a ransomware attack that compromised its IT systems. The Information Regulator fined the department ZAR 5 million ($ 279,000) for breaching POPIA, issued through an infringement notice [Dugas, 2022].

Public sector organisations experienced significant downtime due to information system failures attributed to corporate governance weaknesses [Pieterse, 2021; Daniel et al., 2023]. However, there is limited literature addressing corporate governance challenges specific to information systems (IS) and their role in improving public sector effectiveness in the context of reform [Kassen, 2022]. The purpose of this research was to identify the primary operational barriers affecting information systems (IS) in the South African public sector that operate within a robust corporate governance framework, whether mandated by law or established by regulation. The research question was, 'What are the barriers to IS in the South African public sector with a comprehensive corporate governance system in place?

2. Description of the research methodology

This document presents an auditor's analysis of the barriers to information systems (IS) in the South African public sector. We approached the governance questions using a constructivist philosophical framework, which emphasises the construction of knowledge about the world through subjective understandings informed by experiences and participants' perspectives. The research is based on a qualitative methodology that focuses on understanding phenomena by examining real and historical events in their actual contexts [Leedy, Ormrod, 2023]. We are investigating the Auditor General of South Africa (AGSA) to obtain a thorough understanding of the challenges facing the information systems (IS) function in the public sector. The study focuses on the unique characteristics of the South African public sector that contribute to understanding and identifying difficulties that affect the functionality of information systems (IS) in this context [Leedy, Ormrod, 2023]. Documentary data taken from the AGSA's annual integrated and general reports for the years 2016 to 2020 serve as the study's unit of analysis. The AGSA website provided the annual integrated and general reports. Documents are essential tools that substantiate and illustrate how individuals manifest and record their roles within society. They serve as both a method and a medium through which societal and organisational dynamics are understood and experienced [Flick, 2013]. The data relevant to the research inquiry is characterised by its qualitative aspects.

In order to fully understand the obstacles faced by the information systems (IS) function within the public sector, this research adopts the Auditor General of South Africa (AGSA) as a focal case study. The research focuses on the unique characteristics of the South African public sector, which helps to identify and understand the barriers to IS functionality in this environment [Leedy, Ormrod, 2023]. The analysis focuses on documentary data from the AGSA's annual integrated and general reports, which coverthe years 2016 to 2020 and are available on the AGSA website. These documents act as evidence of how entities articulate and document their social roles and actions, and serve as a medium for capturing and experiencing social and organisational behaviour [Flick, 2013]. The study is qualitative in nature, using thematic analysis to uncover the corporate governance challenges associated with information systems. Thematic analysis involves organising the data into fundamental themes that explain the core phenomena in the dataset [Flick, 2013]. This analysis is carried out using Atlas.ti 7 software.

3. Findings and discussion

A thorough examination of the annual and general reports for the five years to 2020 has led to conclusions about the challenges facing information systems (IS). This analysis involved distinct codes and 60 quotations. Figure 1 provides a comprehensive overview of these challenges as assessed by the Auditor General of South Africa (AGSA).

Figure 1 provides a comprehensive picture of these challenges as assessed by the Auditor General of South Africa (AGSA).

3.1. Macro issues affecting the functioning of information systems (IS)

From a broader perspective, the effectiveness of information systems within the public sector is significantly influenced by the overarching framework of corporate governance, the variability of economic conditions, changes in political leadership, and the persistent deficit of trustworthy information available to the public, which hampers accountability and transparency. Changes in government leadership complicate the implementation and resolution of issues highlighted in audit findings. In addition, economic downturns continue to challenge the operational efficiency of information systems, as reported by the Auditor General of South Africa (AGSA):

- The year 2017–2018 was characterised by a weakening economy and lower credit ratings, which placed fiscal constraints on the provision of public services and the generation of money.

Government bodies in the public sector are accountable to the taxpayer, who is the representative of the citizenry. The information they release to the public is critical to establishing the checks and balances necessary for accountability, in line with the findings of the AGSA:

- The lack of accurate and timely progress reports from government institutions is problematic, as it undermines the public's ability to hold officials accountable for meeting strategic goals.

3.2. Micro-issues affecting the functioning of information systems (IS)

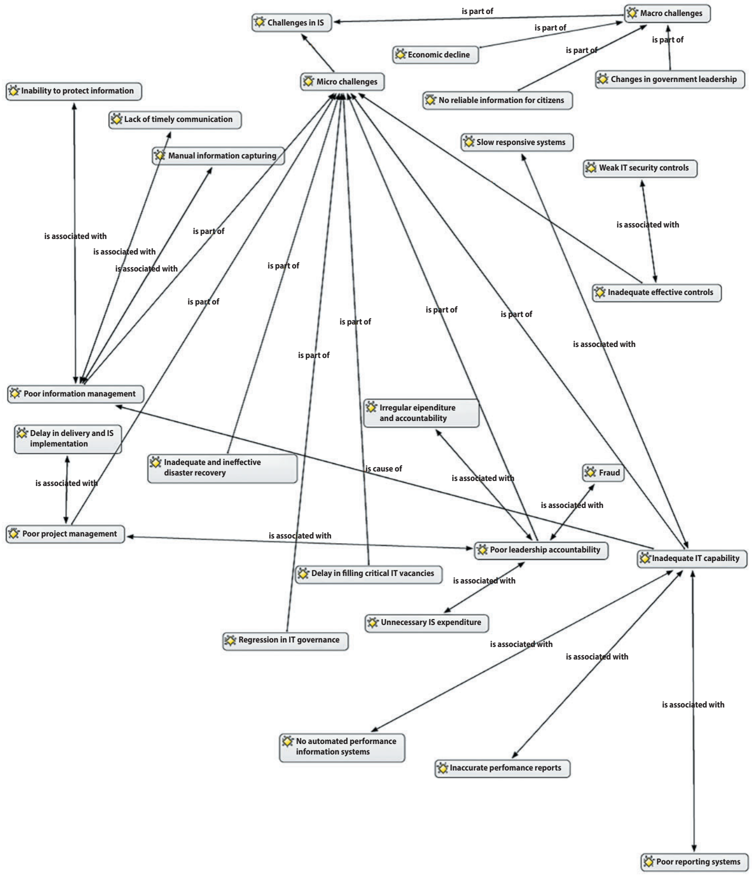
Micro-level barriers to the effective operation of information systems in public sector organisations, such as inadequate IT security measures, limited technological capabilities, lack of leadership accountability, project management deficiencies, ineffective information handling, inadequate disaster recovery plans, gaps in IT governance, and delays in hiring IT staff , represent critical organisational management challenges. Inadequate IT controls, combined with the absence of strong and effective safeguards, ultimately hamper the functioning of these systems. The AGSA highlights these issues as follows:

- The continuing shortage of IT security expertise, coupled with inadequate funding, remains a major concern.
- The public sector has been hampered by inadequate funding for defence measures and outdated IT systems.
- Despite significant government investment in advanced technology to streamline operations, the data generated by these systems is unreliable, creating opportunities for fraud and misuse.
- Government agencies have had their systems compromised by hackers, resulting in the inability to provide essential services. In some cases, hackers have demanded ransoms to restore systems.
- Inadequate support from service providers for outdated systems meant that necessary security updates could not be applied, resulting in significant IT security vulnerabilities.

Furthermore, in addition to the deficiencies in IT controls, there is a significant gap in the controls needed to maintain and improve the functionality of the information system. The AGSA highlighted significant observations as follows:

- Government organisations are concerned about the IT environment, as they struggle to establish effective security and user control policies. The implementation of automated control systems that maintain organisational continuity should be prioritised.
- The IT security has not changed because management has been unable to recruit IT professionals with the essential skills required to maintain the current IT infrastructure.

Fig. 1. Challenges in functioning of IS



Source: compiled by the authors.

- Inadequate controls for secure information processing have led to a significant decline in the effectiveness of IT governance.
- Control concerns remained prevalent, particularly in the areas of security and user control, due to the limited capabilities of the systems.
- Those responsible for IT management and compliance, including the implementation of governance systems, are often reluctant to monitor and address existing weaknesses in IT control mechanisms.
- There is a lack of assurance that IT service providers are meeting agreed performance standards due to inadequate monitoring of contracts.In the public sector, managers have often focused on symptom management rather than improving the efficiency and effectiveness of information systems.
- Inadequate funding hinders the procurement of modern IT infrastructure and improved internet connectivity.

Inadequate recovery processes within public sector entities have been shown to have a negative impact on revenue collection and service delivery. The Auditor General of South Africa (AGSA) highlights deficiencies in information technology (IT) capabilities as evidenced by slow and unresponsive systems, poor reporting systems, erroneous performance reports, and the absence of an automated performance information system. These

IT deficiencies affect the operational efficiency of information systems, according to the AGSA:

- The oversight of public sector organisations was considered insufficient to adequately address the IT control weaknesses identified in the audit findings.
- The lack of attention paid by leaders to holding public sector management accountable and addressing the underlying causes of information system inefficiency leads to an increase in the intensity of slow response..

Public bodies in South Africa's provinces encountered deficiencies in their reporting systems, as highlighted in the following perspective:

- There is a lack of guidance at national level to address the difficulties associated with reporting systems. Effective reporting systems help public organisations to allocate resources efficiently throughout the planning and budgeting process.

The lack of control mechanisms has a direct impact on the quality of information generated for decision making. The Auditor General of South Africa (AGSA) has attributed this problem to both accounting staff and IT:

- The lack of effective accountability in monitoring and evaluation units, together with the instability of information systems, makes it difficult to obtain reliable data, which is essential for enabling well-informed and high-quality decision-making in public sector bodies.

The extensive reliance on manual processes was a significant challenge for many public sector organisations, hindering the rapid implementation of critical decisions. The AGSA found that:

- In the absence of advanced automated tracking tools, public sector organisations have relied on Microsoft Excel, which is vulnerable to potential manipulation. Evaluating the delivery of services to citizens in the public sector is critical, so monitoring performance is essential. As a result, the spread of inaccurate data weakens governments' efforts to meet their commitments to citizens.

Ensuring the accuracy and availability of recorded data is essential for accurate reporting. Despite the ambitious goals and priorities set out in the Strategic Plan, the lack of adequate information systems posed a significant challenge to their effective implementation. This shortfall reflects a wider issue of poor leadership, which has hindered the successful delivery of strategic information systems objectives. Inadequate management accountability is evidenced by cases of irregular expenditure, lack of accountability, wasteful expenditure on information systems and fraudulent activities. Irregular spending and lack of accountability have a negative impact on the performance of information systems. The following observations have been made:

- Weak accountability within governance structures has severely hampered service delivery in vital areas such as essential infrastructure, education, and public health.
- Public officials and managers were found to have been involved in the decision-making processes that led to expenditure that deviated from standard norms, such as irregular expenditure. They were unwilling to address these issues and instead chose to write off the expenses.

Inefficient allocation of resources, as evidenced by wasteful expenditure on information systems, hampers the functioning of the IS. This disclosure was made by the Auditor General of South Africa (AGSA), who made the following observation:

- The inefficient use of IT resources within public sector organisations is demonstrated by the procurement of non-essential software.

The AGSA has reported fraud trends in supply chain contracts that have impacted on the functionality of the IS:

- A review of of 259 audit findings in the public sector revealed investigations into contracts with fraud risks, research into fraud detection methods and assessments of high-risk contractual in the supply chain.

The main obstacle facing information systems (IS), due to poor project management, is manifested in delays in IS deployment and integration. This concern was underlined by the AGSA, which highlighted specific project management challenges:

- Sub-optimal implementation of information technology (IT) initiatives has resulted in the inefficient allocation of resources to avoidable expenditure. In addition, the systems supporting IT initiatives do not meet the expected standards.

Inadequate information management was associated with failure to secure information, lack of timely communication and manual recording of information. The inability to secure information was expressed as follows:

- Public sector organisations sometimes face delays in providing valuable data for compliance and governance due to a lack of readily available information.
- There is a lack of accountability on the part of public sector leaders, who have been seen pressuring the AGSA (Auditor General of South Africa) to withhold providing substantive evidence.
- The review indentified deficiencies in information security protocols were discerned. Decisions based on information are crucial and require reliability, credibility and high standards of information integrity. In addition, information security is essential to prevent vulnerabilities and reduce the risk of unauthorised manipulation.

The delay in correspondence was attributed to shortcomings such as unfinished preparatory documents, inadequate documentation, particularly in the context of meetings, delayed correspondence and the late addition of supplementary documentation close to the end of the audit.

The performance of information systems (IS) has been hampered by the manual processing of information in the following ways:

- Manually entered data has the potential to contain errors, making it diffficult to use for decision making. In addition, the reliance on handwritten information is a significant barrier to planning and monitoring business activities.

The lack of sufficient and effective disaster recovery measures challenges the effectiveness of information systems by putting pressure on their efficiency. This pressure manifests itself in the following ways:

- More than 60% of inspected public sector organisations surveyed lacked a recovery strategy to ensure business continuity in the event of technology disruption, leaving them vulnerable to disaster.

- The lack of attention to risk management in the IT environment has rendered current procedures ineffective.
- A common disaster that disrupts the functioning of IS is the breakdown of the recovery link and systems, resulting in the unavailability of services and adversely affecting public sector activities.

The regression of information technology governance is a major concern that contributes to the ineffectiveness of public sector information systems, a sentiment echoed by the AGSA:

- IT governance was identified as a significant challenge in the administration of government bodies, requiring attention and focus. In several cases, the establishment of governance mechanisms was completely absent.
- The lack of monitoring of IT investments has hampered the ability to determine the return on investment achieved by IT-informed expenditure.
- IT committees lack the necessary tools to adequately surveil their performance against strategic objectives and mandates.
- The achievement of strategic objectives faces significant challenges,both in the immediate and longer term, exacerbated by deficiencies in the existing IT infrastructure that inhibit conditions conducive to the growth of the public sector.

Progress in implementing IT controls has been hampered by delays in filling IT posts. The position is articulated in the subsequent AGSA opinions:

- Key IT personnel were not recruited, resulting in a failure to effectively monitor IT controls and address audit-related issues.
- The decision to stop recruiting IT staff meant that key areas of information systems were neglected for long periods, exacerbating IT control issues
- The field of information technology (IT) is constantly changing, and it has been found that the existing management skills are not able to keep up with the emerging issues. As a result, IT problems have remained unresolved.

4. Conclusion and recommendations

An efficient information system has the capacity to streamline key decision-making processes in the public administration, government operations and for the citizens. The results of the study reveal several areas for improvement in the public sector's use of information systems. Challenges have been identified, including limited public access to reliable information, inadequate information technology security safeguards, ineffective leadership, inadequate in disaster recovery infrastructure, understaffing of critical personnel, and deficiencies in IT governance have been identified. The findings of this research have multiple implications for individuals, government agencies, and public sector stakeholders. While it may be impracticle to to fully address the inherent constraints that hinder the effectiveness information systems (IS) in the public sector, stakeholders express significant concerns that require a thorough examination of these barriers:

- How can information systems (IS) be used to provide accurate and timely information for critical decision making?
- What methods can be used to improve the effectiveness of IT cybersecurity protocols in mitigating security breaches?
- How might one assess the effectiveness of leadership in ensuring the smooth operation of information systems (IS)?
- What strategies can be implemented to improve the information systems governance process?

A significant limitation of this research is that it focuses exclusively on the AGSA's view of the challenges affecting the operational effectiveness of information systems (IS) in the public sector, neglecting the input of auditees. There is a noticeable lack of academic discourse on corporate governance issues relating to the functionality and effectiveness of information systems within South African governmendepartments. The report advocates for further research to gain a deeper understanding of the auditees, particularly public sector IT management, who have ultimate accountability and oversight responsibilities in the audited areas.

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The article was submitted on 28.04.2024; revised on 02.06.2024 and accepted for publication on 10.06.2024. The authors read and approved the final version of the manuscript.
文章于 28.04.2024 提交给编辑。文章于 02.06.2024 已审稿．之后于 10.06.2024 接受发表。作者已经阅读并批准了手稿的最终版本。

DOI: 10.17747/2618-947X-2024-2-176-185
UDC 334.7+339.94
JEL L11, L22, L23

B2C and B2B platform model-based determinants of Russian industrial companies' strategy choices for entering foreign markets

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Abstract

The article presents an overview of a number of parameters and factors influencing the choice and formation of strategies for the entry of Russian industrial enterprises into international markets based on platform models of interaction in the B2C and B2B segments. This focus makes it possible to define and specify in more detail the mechanisms, formats, opportunities and limitations in the development of strategies for the entry of Russian industrial enterprises into international markets, supported by platform models of interaction. In the context of building international platforms for industrial companies, aspects of the specifics of platform interaction have been identified. A list of twelve determinants is proposed, how to choose a strategy of entering foreign markets by Russian industrial enterprises based on the mechanisms of platform interactions. The fact is that in the current conditions of the platform economy, value creation is the result of a new combination of information, physical products and services of various types, as well as new ways of configuring transactions and reconfiguring resources, relationships between suppliers, partners and customers. For Russian industrial enterprises, methodological developments in this area can be particularly useful in the context of increasing the internationalisation of business activities using international B2C and B2B platforms. At the same time, a major difficulty in determining the parameters and priorities of platform interaction between industrial companies, especially in the B2B segment (including in the framework of industrial asset sharing models), is the fact that this type of interaction is still a frontier today in many industrial sectors at the national level, and even more so at the international level. As best practices and success stories of Russian industrial companies entering international platforms emerge, and as the platforms themselves evolve, it will be possible to talk about greater operationalisation and measurability of the determinants of Russian industrial companies' strategy choices. At the current stage of development of international manufacturing platforms, greater awareness of the productivity drivers and determinants of industrial enterprises' strategic choices will enable platform complementors and the platforms themselves to better find common ground and ensure faster growth of network effects.

Keywords: platforms, ecosystems, network effects, Fourth Industrial Revolution, industry 4.0, smart manufacturing, industry, digital technologies, digital transformation, sharing of industrial assets, equipment as a service, marketplaces.

For citation:

Ilkevich S.V. (2024). B2C and B2B platform model-based determinants of Russian industrial companies' strategy choices for entering foreign markets. *Strategic Decisions and Risk Management*, 15(2): 176-185. DOI: 10.17747/2618-947X-2024-2-176-185. (In Russ.)

基于B2C和B2B平台模型的俄罗斯工业企业选择出口战略的决定因素

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简介

本文讨论了影响俄罗斯工业企业基于B2C和B2B平台互动模型选择和制定出口市场策略的多种参数和因素。这种聚焦视角有助于更详细地确定和具体化俄罗斯工业企业基于B2C和B2B平台互动模型开发出口市场策略时的机制、格式、机会和限制。在建立工业公司国际平台的背景下，揭示了平台互动特定方面的特点。提出了一个在构成和考虑方面相对综合的十二个决定因素列表，用于基于平台互动机制选择出口市场策略的俄罗斯工业企业。在当前的平台经济条件下，价值创造是信息、物理产品和各种类型互补产品的新组合的结果，以及新的交易配置和资源重构的新机会，涉及供应商、合作伙伴和买家之间的关系。对于俄罗斯工业企业，在提升经济活动国际化方面，特别是通过国际B2C和B2B平台，这些方法论开发在这一领域可能尤为有益。同时，确定工业公司平台互动参数和优先级的难度相当大，特别是在B2B领域（包括工业资产共享模式），不仅在国家层面，甚至在国际层面，这类互动在当前许多工业领域仍然处于前沿地位。 随着俄罗斯工业公司进入国际平台的最佳实践和成功案例的形成，以及平台本身的演变，我们将能够更加具体和可衡量地讨论俄罗斯工业公司选择战略的决定因素。当前国际生产平台发展阶段，提升对生产力因素和工业企业战略选择决定因素的认识，将有助于平台的补充组件和平台本身更好地找到接触点，并促进网络效应的更快增长。

关键词：平台、生态系统、网络效应、第四次工业革命、工业4.0、智能制造、工业、数字技术、数字转型、工业资产共享、设备即服务、市场平台。

引用文本：

Ilkevich S.V. (2024). 基于B2C和B2B平台模型的俄罗斯工业企业选择出口战略的决定因素。战略决策和风险管理, 15(2): 176–185. DOI: 10.17747/2618-947X-2024-2-176-185. (俄文)

Introduction

Over the past 15 years, there has been a notable uptake of advanced digital technologies in the industrial sector. This has led to changes in internal processes and, subsequently, an increase in operational efficiency and modernisation of production facilities for many enterprises. It is also important to consider the significant impact that digital technologies have on a company's competitiveness, including the effect of network effects. The adoption of digital technologies has the potential to bring about significant changes to the business environment, thereby enhancing competitiveness for all enterprises within the industry. The deployment of digital technologies allows the creation of premium products with advanced features. The pace of digital transformation is accelerating, with all stakeholders in industrial transformation and digitalisation engaged in broader ecosystems and platforms. For industrial companies, the fundamental principle remains consistent with that observed in well-known B2C platforms and ecosystems: the larger the pool of participants (complementers), the higher the network effects, under similar circumstances. However, the transition to cross-border platforms for industrial enterprises is challenging due to a number of factors. The formation of international industrial ecosystems and platforms is not so much constrained by legal issues as it is by a number of internal contradictions inherent in the platforms and ecosystems themselves. These relate to the balance of interests of the parties involved and the distribution of benefits along the value chain.

In order to develop effective strategies for entering foreign markets, Russian industrial enterprises must first gain a comprehensive understanding of the current and prospective mechanisms of partnership and ecosystem interaction in platform models of business internationalisation. The current literature, both domestic and international, has extensively and comprehensively studied general and conventional instruments for supporting exports, including non-resource non-energy goods in new markets [Morozhenkova, 2019]. However, the potential of building platforms and ecosystems has only recently begun to be partially addressed. Despite this, an increasing number of sectors and industries are turning to platforms and ecosystems as a new form of industrial organisation. It is important to consider ecosystems when the multilateral relations underlying a value proposition cannot be decomposed into multiple bilateral relations. In such cases, viewing the situation as a series of bilateral relations may result in the observer missing crucial aspects of the situation [Adner, 2017]. Platform manufacturing represents a significant shift in the way production is planned and executed.

It is becoming increasingly challenging for companies to ascertain the identity of the parties responsible for manufacturing their components. Similarly, it is not always the case that the manufacturers of these components have the necessary equipment. Furthermore, there is an increasing trend towards the transfer of knowledge and decision-making authority across organisational boundaries [Tolio et al., 2023].

However, the research direction in the field of mechanisms and advantages of ecosystems and platforms for interaction between industrial enterprises at the international level is even more multifaceted and multiparametric, and also involves a larger number of interdependent entities. The research in this area is relatively new and tends to focus on specific topics. For instance, there is a growing body of work examining the potential for ecosystems and platforms to optimize the balance of total costs and carbon footprint in the production, storage and distribution of products in an international regulatory environment that includes emission restrictions and trade policy [Mishra & Singh, 2019]. Despite the critical importance of these specific issues, researchers have not yet fully explored the potential for a more comprehensive understanding of how ecosystems and platforms are transforming into a fundamentally new form of industrial organization for industrial enterprises and, accordingly, what prospects for business development arise in this regard from the point of view in terms of principles of interaction and restructuring of business models.

Separate layers of research highlight the importance of ecosystem coordination and ownership, as well as the presence of competing participants and formats for involving various types of complementors, in the international context. These findings are particularly pertinent at the ecosystem level. The productivity of interaction between platform owners and complementors [Uzunca et al., 2022], data ownership and open exchange, and the relationship between various operators at the ecosystem level [Kokkonen et al., 2023] are becoming especially important at the ecosystem level.

Another promising avenue of research is the study of how value is created in the digital interactions of transnational corporations (MNCs) when combining the global reach of MNCs, the power of platform business models and digitalisation. It is particularly interesting to observe how production chains integrate digital technologies into the global manufacturing business of MNCs in order to achieve the combinatorial synergies of Industry 4.0 and platform ecosystems [Das, Dey, 2021; Veile et al., 2022]. For instance, there has been a shift in the focus of value creation through industrial digital twins from internal use by individual enterprises to ecosystem-level use (Rantala et al., 2023). The implementation of Industry 4.0 concepts is typically based on core technologies that integrate diverse hardware and software to streamline operations within and beyond the company. However, in recent years, there has been a growing recognition that Industry 4.0 technologies can collectively function as platforms, forming the bedrock of technology integration on the path of digital transformation [Benitez et al., 2023].

However, the question of what the mechanisms of partnership (bilateral) and ecosystem (multilateral) interaction should be here is more complex than in the situation of just B2C platforms, which are widely known and more intuitively understood by the example of such companies as *Amazon, Alibaba, Wildberries* and *Ozon*. It is evident that Russian and international B2C platforms offer Russian industrial companies in the FMCG sector substantial opportunities to boost revenue. It is important to note that the output structure of Russian industrial companies is dominated by products of low or intermediate (medium) processing, which are not intended for final consumers. Consequently, the opportunities presented by foreign e-commerce platforms in the B2C segment are relevant for a relatively smaller share of Russian businesses than would be the case for Italian industrial companies and conglomerates. It is nevertheless worthwhile to consider the potential, constraints and strategies for exporting Russian industrial FMCG companies (including those in the fast-moving consumer goods or high-frequency purchase categories, as well as everyday goods) via Russian and foreign B2C platforms.

1. The prospects and problems of FMCG sector exports through B2C platforms

In the context of sanctions and restrictions, the potential for international expansion of leading Russian B2C platforms (*Wildberries, Ozon, Yandex* and *Sbermarket*) has been significantly constrained. Following the expansion of Russian platform businesses into Eastern Europe at the end of 2021 (Poland[1], the Czech Republic and Hungary), Belarus represents the only remaining potential target for Russian platforms in the west. This is demonstrated by the active promotion of *Ozon* and *Wildberries*[2] in this country [Kalenik, 2023]. However, the 'turn to the East' for Russian

[1] Matveev D. Poland introduced sanctions against Wildberries and Tatyana Bakalchuk. VC.ru. 2022. February 26. https://vc.ru/trade/410699-polsha-vvela-sankcii-protiv-wildberries-i-tatyany-bakalchuk.

[2] Kalenik D. Ozon will launch an installment plan for Belarusians and increase the number of order delivery points by 3 times. MYFIN.by. 2023. September 25. https://myfin.by/stati/view/ozon-zapustit-rassrocku-dla-belorusov-i-v-3-raza-uvelicit-kolicestvo-punktov-vydaci-zakazov.

Internet economy giants, unlike in some other industries, does not offer any realistic prospects or alternatives. This is because Chinese platforms (especially *Alibaba, JD, Vipshop, Tenscent*) are too strong and dominant not only the Chinese market, but also attract complementors from Central Asia with their 'economic gravity' (in the words of P. Krugman). In the current business environment, it would be more beneficial for Russian industrial companies in the FMCG sector to expand their presence on Chinese digital platforms. This has its own rationale in the evolving geo-economic landscape, but it also presents a set of challenges and strategic constraints. There are four main areas of concern that are interrelated.

The first issue facing Russian FMCG industrial companies is their reliance on a single country's digital platforms. This also has implications for the long-term stability and compatibility of Russian-Chinese relations. It is of greater importance to consider China's approach to regulating digital platforms, including online commerce. Over the past two decades, the PRC has developed a significant platform economy. However, since the beginning of 2021, the Chinese government has implemented a series of new measures, commonly referred to as 'strict regulations', with the aim of addressing issues with 'misbehaving' platforms and enhancing market efficiency. The policy has had a negative impact on the short-term dynamics of the platform economy, including employee layoffs, reduced investment, and a sharp decline in the market value of e-commerce companies [Huang, 2022]. This case study is of significant interest in considering the many aspects of the digital economy, including the response of a strong state like China to the evolution of platform companies from providers of various online services into the core infrastructure of the economy and society. In certain cases, these companies have posed a potential threat to the government's core objectives and priorities [McKnight et al., 2023]. The tumultuous events surrounding digital platforms in China in 2021-2023 have shown that the Chinese government can intervene significantly in the online commerce sector, including for reasons of maintaining the highest possible level of competition among vendors and equal access to all major platforms for all vendors (no exclusive terms and contracts). From a public interest perspective, this regulatory approach is understandable and justified. Initially, international investors in China's leading platforms reacted strongly to the government's intervention, but even this stakeholder group has since become more accepting. However, the share of the stock market represented by "new economy" companies at the end of 2023 has not yet recovered from the significant regulatory changes.

It is also important to consider the role of Russian players in China's digital economy from a strategic perspective, including in the context of the US-China experience with digital regulatory relations. In the early stages of its development, China's thriving platform economy was relatively open, competitive and market-oriented, benefiting from US capital and the entry of US companies. Since 2009, both countries have gradually restricted access to each other's domestic markets for information services. In both cases, the main official justification has been national security rather than trade concerns. Drawing on international political economy theory, some researchers have proposed the concept of digital neo-mercantilism to describe the model of interaction between the US and China [Mueller, Farhat, 2022]. Digital neo-mercantilism is a concept that combines the power and security of the nation-state with the goal of economic development in the digital economy. In the context of domestic political discourse, politicians often emphasise the importance of information flows and digital technologies for the security and power of the state. As a result, states implement a range of industrial policies, data localisation initiatives, trade protectionism, and even exclude foreign companies from certain segments of the digital economy. Both the United States and China are pursuing such policies.

In the natural and Chinese government-induced processes of intensifying competition in the Chinese e-commerce market, it is necessary to understand the place of Russian suppliers in terms of the prospects of ensuring sufficiently high profitability. The 'ecological niche' for many Russian industrial companies may prove to be a competitive 'red ocean', where companies will seek to reduce costs, compete on price and imitate each other's products. It is possible that within certain industries, such as confectionery, the products of Krasny Oktyabr ('Red October') or Belevskaya Pastila may be able to survive due to the authenticity of the product or, to some extent, the protection of the geographical origin of certain items in the product nomenclature, as well as the stability of quality and the popularity of the brand. However, such cases may prove to be exceptions to the general rule.

The second issue with the use of Chinese platforms is that they provide a carrot-and-stick incentive for all vendors (including Russian ones) to operate at the deepest possible discounts in order to continually expand the ecosystem. This model has two long-term and sustainable beneficiaries: the consumer and the platform itself. It is essential to dispel illusions and grasp the realities of how platforms view their vendors. Vendors are, metaphorically speaking, fuel for growth; consumables whose business margins the platform is, at best, indifferent about. If they are interested in margins, it is only out of concern for the loss of sales volumes for the platform itself that have not been built up through deeper discounts.

In fact, there is no great specificity of Chinese platforms in this regard (it would be wrong to ascribe to them a particular ruthlessness towards vendors) – similar manifestations take place in Russia as well. Both Ozon and, in particular, Wildberries regularly urge vendors to support promotions with the deepest possible discounts during the promotional and sales periods, including the threat that their products will not be listed in customers' search queries during the promotional period if the level of discount on the products relative to the average price over the last few months does not reach a certain set level, such as 35%. This has a significant impact on the profitability of vendors on the platforms. They must decide whether to maintain higher prices for some products for a month or two before the sale, allowing them to offer deeper discounts, or to accept temporary "delisting" from the platform as a lesser evil, or still to accept the fact that they will have to work for a week or two with increased sales and a small negative profitability in the name of a "bright future" (and most likely not their own future, but that of the platform).

The third challenge for Russian FMCG industrial companies looking to enter the Chinese market is that they will have to navigate the Chinese business landscape, where Chinese entrepreneurs are known for their global expertise in imitation, product adaptation, rapid implementation, and maximising production scale and efficiency in the so-called unit economy.

The fourth challenge is the influx of complementors and vendors from third countries entering China's online commerce ecosystems. Based on current trends, it is reasonable to assume that this will include Kazakh, Kyrgyz, and Uzbek industrial companies, which may prove to be more competitive (in terms of product mix quality, production costs and logistics chains) and more successful in attracting Chinese investment, particularly in the food industry. Following meetings between representatives of the Kazakhstani government, Kazakhstani businesses and leading Chinese platforms (in particular, JD), there has been a notable increase in the presence of Kazakhstani industrial enterprises on Chinese platforms, with a wide range of food products now available, including sunflower and rapeseed oil, confectionery, alcoholic and non-alcoholic beverages and snacks[3].

2. Mechanisms of international collaboration in the sharing of industrial assets based on B2B platform

There is an increasing tendency among sectors and industries to share equipment and production facilities. It is also worth noting that China is implementing the 'Made in China 2025' programme as part of its national innovation and industrial policy. 'Made in China 2025' is China's version of Industry 4.0. The goal is to enhance the country's manufacturing capabilities and establish over two dozen shared manufacturing platforms with robust innovation capabilities and significant influence in industries projected to become pivotal drivers of quality growth by 2025 [Wang et al., 2020]. The sharing of production capabilities, including equipment, robots, tools, intellectual resources, logistics and warehousing, will be the primary focus.

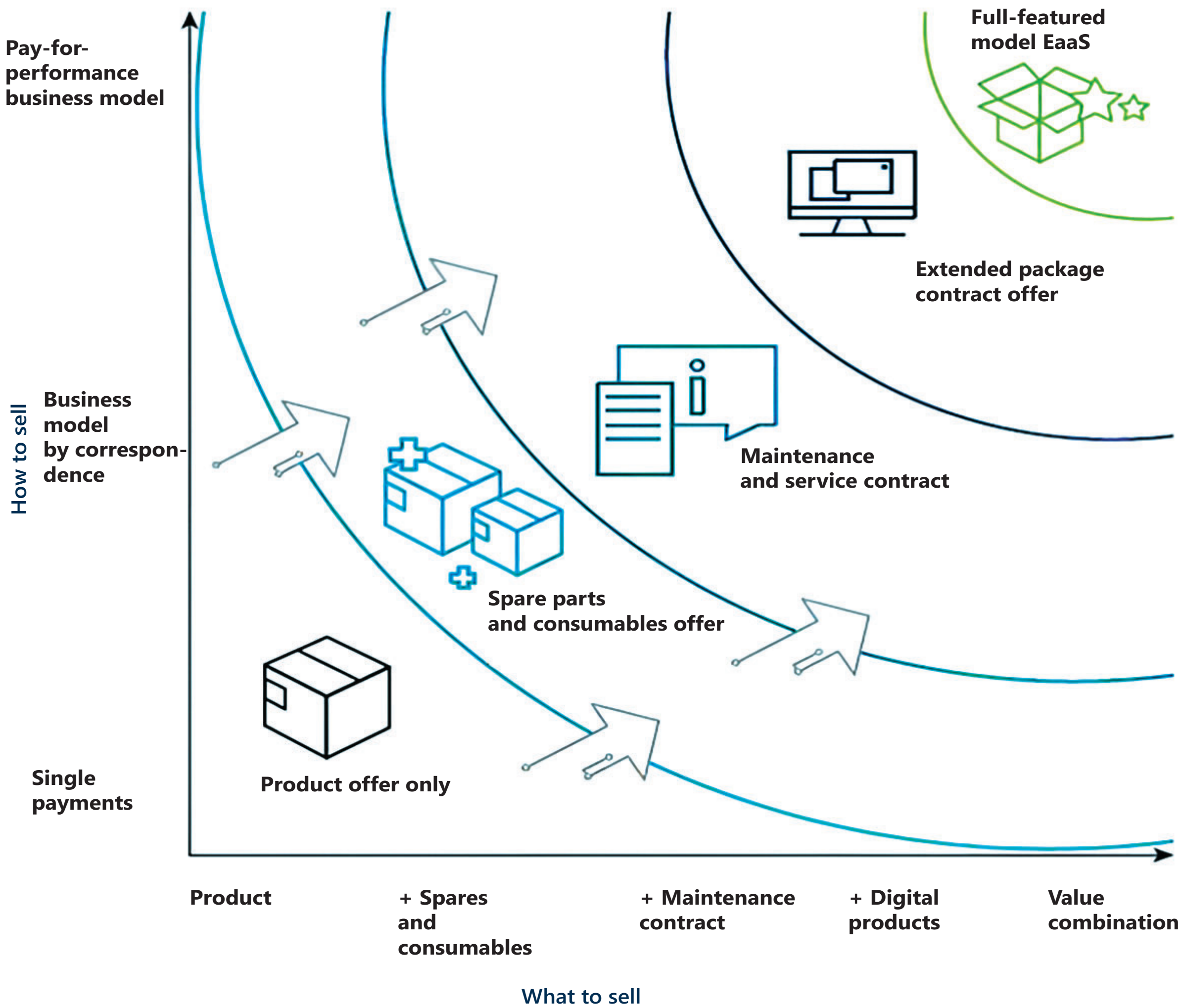
In its most general interpretation, this model is referred to as Equipment-as-a-Service (EaaS), with the focus being on the service and sharing components. It can be viewed as part of the broader manufacturing servitisation trend, which has been accelerated by the advent of digital technologies (Paschou et al., 2020). Industrial managers must consider a range of internal and external factors to ensure strategic, environmental and organisational alignment with the new model [Feng et al., 2021]. The general evolution of this kind of system and the expanded definition of 'hardware as a service' based on combining aspects of the expansion of servitisation and the deployment of platform and ecosystem business models are illustrated in Fig. 1.

It is widely acknowledged within the industrial goods sector that a significant portion of profits is no longer derived from the sale of new equipment. Indeed, aftermarket service offerings that are an organic extension of the core product, such as spare parts or technical support, have emerged as the primary source of profit. In light of the growing prevalence of lower margins on new equipment, an increasing number of OEMs have identified EaaS models as a reliable source of stable revenue streams with high profit margins. Furthermore, there is a clear trend among buyers to shift some of their product usage or capacity into a sharing format. This is driven by fluctuations in demand from their end-users (or other high-end process customers), which are often seasonal or opportunistic in nature. Consequently, customers are opting to purchase fewer machines, typically three or four instead of five, while utilising the remaining one or two as required.

The concept of 'equipment as a service' (EaaS) is already well established among industrial equipment manufacturers. The transition from one-time sales of capital goods (CapEx) to recurring revenue streams based on equipment utilisation or performance (OpEx) has been a standard practice in certain industries for over a decade. The key benefit of this solution is that it enables industrial companies to transition from a high CapEx procurement model to multi-year service agreements with integrated operating cost management. The specific model will be determined based on the customer's requirements. The customer may pay on a per-hour, per-unit, or overall equipment efficiency basis. One prominent example is the Rolls-Royce model, which has been widely publicised and has revolutionised the company's approach to selling

[3] Another Chinese marketplace has opened for Kazakh goods. Kazakh entrepreneurs will sell their products on one of China's largest online platforms. Forbes Kazakhstan. 2023. April 17. https://forbes.kz/economy/business/kitayskiy_marketpleys_jdcom_stanet_dostupnyim_dlya_kazahstanskih_tovarov/.

Fig. 1. An expanded definition of 'Equipment as a Service' based on combining aspects of expanding servitisation and deploying platform and ecosystem business models



Source: Equipment-as-a-Service: From capex to opex – New business models for the machinery industry. Deloitte. 2021. https://www2.deloitte.com/content/dam/Deloitte/de/Documents/energy-resources/Deloitte_Equipment-as-a-Service.pdf.

turbines. The capacity per hour pricing model is based on a cost-per-use basis, with customers only charged for the actual hours of use[4]. There is an increasing awareness among businesses that they are not only original equipment manufacturers (OEMs), but also providers of cyber-physical equipment as a service (CPE-aaS) [Sanchez et al., 2022].

The emphasis on long-term equipment maintenance is critical to the evolution of industrial equipment, as it facilitates the identification of common interests between OEMs and customers, provides a stable revenue stream, and enables OEMs to cultivate a more reliable relationship with customers through real-time data analysis. The ability for multiple industrial customers to share homogeneous production equipment is particularly important in a rapidly changing market environment and technological landscape. The introduction of complex, innovative equipment is often cost prohibitive for companies, especially small and medium-sized enterprises. Access to expensive machines allows industrial companies to test them and understand their capabilities in the context of their specific tasks. This in turn makes the adoption of new technologies more informed, timely and inclusive in terms of building the capabilities and competencies of enterprises [Kimita et al., 2022].

A particularly noteworthy aspect concerns the allocation of access costs to a cohort of tenants. Emerging practice shows that the technologies of the

[4] Nor Lines and Rolls-Royce sign landmark Power-by-the-hour service agreement. Rolls-Royce Press Release. 2017. 24 May. https://www.rolls-royce.com/media/press-releases/2017/24-05-2017-nor-lines-and-rr-sign-landmark-power-by-the-hour-service-agreement.aspx.

Fourth Industrial Revolution make it possible to allocate costs not only according to the duration of access, but also according to the amount of capacity used, or in a combined way where this more accurately reflects the nature of consumption and recovery of industrial assets, based on the analysis of the total (full) cost of ownership. Equipment as a service is one of the most prominent examples of innovation in proprietary business models in industry. It is an innovative business model that combines both the product and the services required to maintain and operate the equipment into a single offering, with a revenue model based on the actual value received [Rösler, Friedli, 2021]. It is vital to gain a deeper understanding of the rationale behind the shift towards sharing-based business models among industrial companies [Stojkovski et al., 2021]. It is essential to emphasise the interconnection between diverse technological domains and the selection of tailored business models by industrial enterprises [Trachuk et al., 2018]. The success of an industrial enterprise is contingent upon the degree of complementarity between a set of digital technologies and a business model. Inconsistencies between these two elements will impact the sustainability and performance of individual business processes and the overall strategy.

At present, the engineering centres in the Russian Federation, both general and specialised in additive technologies, provide technically sound, though limited, opportunities to study and test various technical devices in terms of commercialisation potential and cost-effectiveness. Many enterprises require a more comprehensive offering. It would be advantageous to implement comprehensive digital platforms based on engineering centres, offering equipment rental and leasing, technical support, and the short- and medium-term engagement of rare and highly qualified specialists. This will provide a valuable opportunity to test technologies in real-world business conditions without the need to invest in expensive equipment. In particular, this may facilitate the more effective inclusion of Russian industrial enterprises in international platforms and ecosystems.

Ensuring effective shearing of industrial assets on an international scale presents an even greater challenge. When exploring potential solutions for international industrial asset shearing, Russian industrial companies must consider a number of additional challenges, including the configuration of usage-based business models, currency revaluation of both industrial asset value and industrial subscription payments (industrial subscription), as well as the use of digital financial assets as a means of payment, credit and investment instruments.

3. Proposals on the determinants of the choice of strategies for entering foreign markets

The following list outlines the key factors influencing the choice of strategies for entering foreign markets by Russian industrial enterprises. It is based on the mechanisms of ecosystem interaction and takes into account the current conditions of the platform economy. In this environment, value creation is the result of a new combination of information, physical products and services, a new configuration of transactions and a reconfiguration of resources, capabilities and relationships between suppliers, partners and buyers. The twelve determinants outlined below cover the key aspects of value creation in international production collaboration in a platform configuration:

- the potential for overall platform efficiency based on the reduction of transaction costs in the preparation and execution of export-import transactions of Russian industrial enterprises;
- the potential for complementarity in terms of interdependence with other complementors and counterparts of the platform (both in terms of vertical technological processes and horizontal and unrelated technological interaction);
- the productivity and balance of interests of participants in platforms and ecosystems in terms of the mechanisms and structure of governance and coordination of complementors;
- the potential of international industrial asset shearing for Russian industrial enterprises;
- the potential to improve the operational efficiency of a Russian industrial company, including the possibility of optimising business processes and lead times;
- the potential to increase supply chain transparency;
- the potential to increase the production and logistics flexibility of Russian industrial enterprises;
- opportunities for joint and cross-distribution within inter-enterprise ecosystems of production orders and contracts;
- opportunities to expand product offerings, taking into account interactions with other platform complementors;
- opportunities to 'lock-in' customers;
- opportunities to enhance the innovative nature of activities, including within the context of developing a system of open innovation within the ecosystem of sponsors, complementors, partners and contributors to the platform;
- opportunities to manage the profitability of Russian industrial enterprises in the context of their interdependence with the platform and other complementors of the platform.

It is debatable whether it is appropriate to introduce the possibility of developing new business models as a factor within the proposed list of factors influencing the formation of strategies for entering foreign markets by Russian industrial enterprises based on platform interaction mechanisms. It is crucial to refrain from conflating two discrete areas of focus when examining the involvement of companies, including industrial enterprises, in platforms: strategy and business models. Although there is a clear relationship between business strategies and business models, there are also notable differences in their methodological approaches. It is evident that internationalisation as a business strategy and participation in platforms frequently result in a modification of the company's business model. In some instances, this may even entail a radical transformation or even the creation of an entirely new business model. However, these kinds of developments are often unplanned and derivative, emerging from the evolution of a company's strategy as it becomes integrated into a platform context, including an international one.

Conclusion

In conclusion, a significant challenge in determining the parameters and priorities of platform interaction between industrial companies in the B2B segment (including within the framework of industrial asset sharing models) is the fact that, at both the national and international levels, this kind of interaction is still in its infancy in many sectors. Methodological developments in this area are of particular relevance to Russian industrial enterprises at the present time, as it is essential to identify the preliminary contours of productive interaction in digital platforms. As an increasing number of success stories emerge of Russian industrial companies entering international platforms and as the platforms themselves evolve, it will become possible to discuss in greater depth how Russian industrial companies are selecting their strategies and how these choices can be evaluated. Nevertheless, even at this nascent stage of international production platform development, enhanced awareness of the factors influencing enterprise strategy and productivity will enable platform complementors and the platforms themselves to identify common ground more effectively and facilitate accelerated growth of network effects.

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The article was submitted on 12.05.2024; revised on 04.06.2024 and accepted for publication on 10.06.2024. The author read and approved the final version of the manuscript.
文章于 12.05.2024 提交给编辑。文章于 04.06.2024 已审稿. 之后于 10.06.2024 接受发表。作者已经阅读并批准了手稿的最终版本。

DOI: 10.17747/2618-947X-2024-2-186-199

Decision-making in the field of improving digital services based on customer experience (UX): The impact of using artificial intelligence technology

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Abstract

By conducting UX research, you can reduce user churn in digital services, identify areas of growth, and offer solutions to improve the user experience and retention. The main benefit of UX research is to understand the needs and expectations of users. UX research helps you analyse user's behavior, preferences and problems of users, as well as determine which features and capabilities of the application are important. The introduction of artificial intelligence (AI) has sparked a discussion about how to improve the design processes associated with UX design, leading to the emergence of the concepts of 'artificial design intelligence (ADI)' and 'intelligent design'.

In this article, the author's approach to conducting UX/UI research using AI technology is developed. The current customer path of the banking section in the bank's mobile application is compiled and modelled. In-depth interviews were conducted with 20 respondents, in which respondents compared screen forms with and without the use of AI technology. UI/UX studies are described based on the in-depth interviews conducted, followed by a justification of the need to implement AI technology to personalise the user path in a mobile application.

In addition, the results of the UI/UX study confirmed the hypothesis that the introduction of a personalised user experience using AI technology (photorealistic images of cars) in the bank's mobile application will lead to improved customer satisfaction and increased engagement, which in turn will increase the bank's profitability and competitiveness.

The proposed recommendations will optimise the user experience in the mobile application and improve the NPS and MAU metrics by a factor of 2, according to the experts.

Keywords: UX/UI research, mobile application, consumer preferences, digital technologies.

For citation:

Myagkova K.G. (2024). Decision-making in the field of improving digital services based on customer experience (UX): The impact of using artificial intelligence technology. *Strategic Decisions and Risk Management*, 15(2): 186-199. DOI: 10.17747/2618-947X-2024-2-186-199. (In Russ.)

基于UI/UX研究的数字服务改进决策：人工智能技术的影响

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简介

进行UX研究可以减少数字服务用户的流失，发现增长点，并提出改善用户体验和提高用户留存率的解决方案。 UX研究的主要优势在于了解用户的需求和期望。 UX研究可以分析用户的行为、偏好和问题，并确定哪些功能和应用程序的特性是重要的。 人工智能（AI）的引入引发了关于如何改进与用户体验（UX）设计相关的设计流程的讨论，并催生了人工智能设计（ADI）和智能设计（Intelligent Design）等概念。

本文开发了一种使用AI技术进行UX/UI研究的独特方法；构建并模拟了银行移动应用程序中银行部分的当前客户旅程； 进行了20位受访者的深度访谈，在访谈中他们比较了使用和未使用AI技术的界面设计；基于深度访谈进行了UI/UX研究，并论证了在移动应用中引入AI技术以实现用户路径个性化的必要性。

此外，UI/UX研究的结果证实了以下假设：在银行移动应用中使用AI技术（如照片级真实感的汽车图片）实现个性化用户体验将提高客户满意度和参与度，从而提升银行的盈利能力和竞争力。

提出的建议将优化移动应用中的用户体验，并据专家评估，提高NPS（净推荐值）和MAU（月活跃用户数）指标，提升幅度可达两倍。

关键词：移动应用，客户体验，消费者偏好，数字技术。

引用文本：

Myagkova K.G. (2024). 基于UI/UX研究的数字服务改进决策：人工智能技术的影响。战略决策和风险管理，15(2)：186–199. DOI：10.17747/2618-947X-2024-2-186-199. (俄文)

Introduction

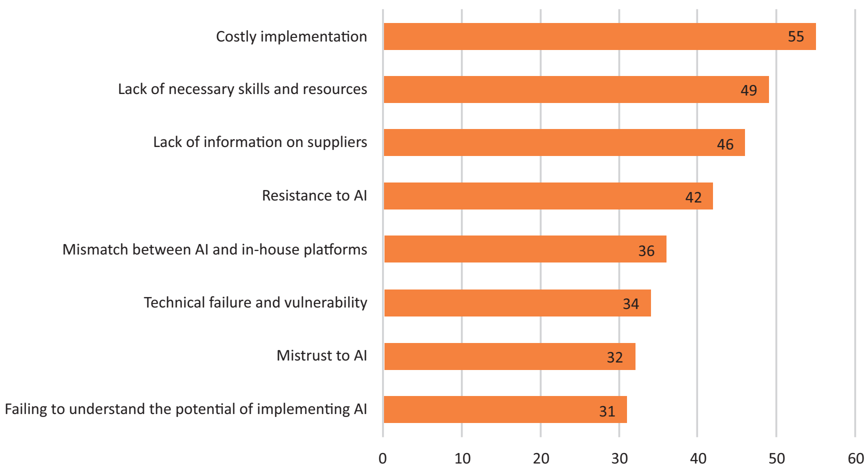
In recent years, Russian companies have been actively implementing the latest technologies and developing their own digital solutions to ensure the convenience and comfort of their customers. The level of digitalisation of Russian companies continues to grow, making financial services more accessible and innovative. Artificial intelligence as an innovative solution is in demand in various industries. More and more companies are deciding to implement this technology in their business processes: from facial and voice recognition to determining customer behaviour [Lew, Schumacher, 2020].

According to the Bank of Russia[1], вleading companies in the Russian market have adapted artificial intelligence mechanisms to their needs, created teams of development experts, designed data processing and gained experience in using advanced processing technologies in their processes.

According to the results of the VTsIOM survey[2], 55% of respondents said they were not using artificial intelligence because of the high initial investment. Some 49% of respondents cited the lack of necessary skills and a development team among staff as a barrier to implementing AI technology. Of those surveyed, 34% cited a technical failure and vulnerability of the technology as a barrier to implementing AI.

Respondents are likely to be concerned that the new technology could lead to data leakage, subsequent breaches of privacy rights and a loss of trust among users.

Fig. 1. Barriers to adoption of AI technology

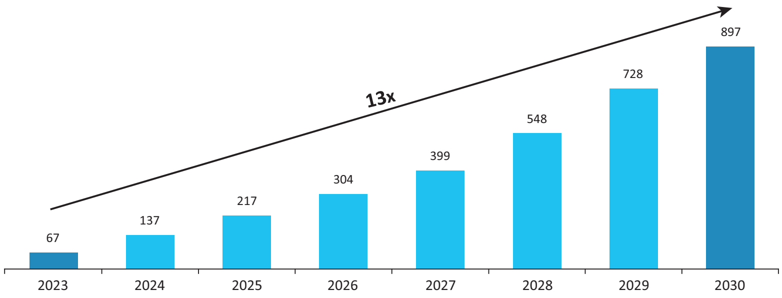


Source: Prospects and problems of using artificial intelligence technologies in the regions of the Russian Federation. tse64fmdsetwhhpd6e57a3wjtsud6mdx.pdf (csr.ru).

[1] Application of artificial intelligence in the financial market. Report for public consultations. Bank of Russia, 2023. https://cbr.ru/Content/Document/File/156061/Consultation_Paper_03112023.pdf.

[2] Artificial intelligence: A blessing or a threat? https://wciom.ru/analytical-reviews/analiticheskii-obzor/iskusstvennyi-intellekt-blago-ili-ugroza.

Fig. 2. Artificial intelligence market growth



Source: Application of artificial intelligence in the financial market. Bank of Russia, 2023. https://cbr.ru/Content/Document/File/156061/Consultation_Paper_03112023.pdf.

Therefore, an IT department or project team with experts in the field of artificial intelligence is needed to implement and support AI technology.

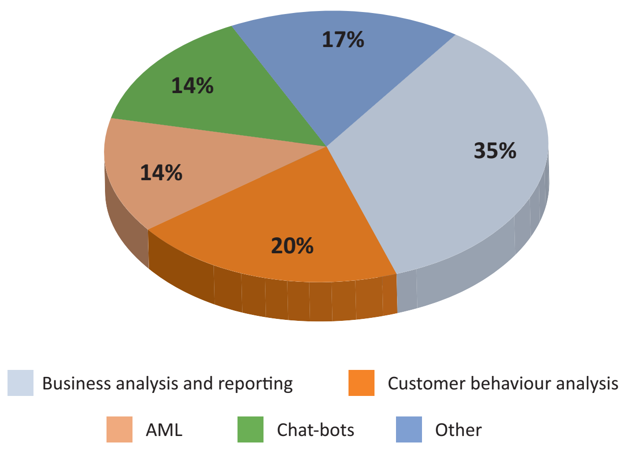
According to the results of the All-Russian Public Opinion Research Centre, 48% of respondents are interested in artificial intelligence as a new technology, and 31% are neutral. The study showed that the majority of Russians have a positive interest in the use of AI technology.

Based on the research conducted[3] it can be concluded that the global market for IT solutions using AI technology will grow 13-fold between 2023 and 2030 – from $67 billion to $897 billion (Figure 2).

Artificial intelligence and machine learning[4] technologies are actively used by Russian companies to collect data and analyse customer information. Figure 3 shows the main applications of artificial intelligence.

Approximately 35% of Russian banks perform business analysis and report generation – with the help of AI technology, banks can quickly process large amounts of data and build financial forecasts[5]. User behaviour analysis accounts for 20% – artificial intelligence enables us to identify human emotions using advanced facial and voice recognition technologies. With AI-powered mobile apps, transactions can be faster and more secure, and banks and financial institutions can recognise human behaviour and offer personalised services through the app[6].

Fig. 3. Areas of application of AI technology in Russian companies



Source: Prospects and problems of use... tse64fmdsetwhhpd6e57a3 wjtsud6mdx.pdf (csr.ru).

AI-enabled products are becoming more customer-centric as the number of users loyal to the technology grows. In the future, AI products will continue to evolve due to their deep understanding of human behaviour. Given the constant development of the technology itself, it is almost certain that most banks will implement it to remain competitive and provide better customer service. The combination of AI technology and UX design offers great opportunities in the future [Stige et al., 2023].

The purpose of this article is to consider how AI technologies can be implemented in the process of developing a digital service, and to assess the impact of implementing AI technology in UX design on an organisation's effectiveness.

1. Literature review

When developing a digital service, designers need to conduct user experience (UX) research that meets the requirements and expectations of the end user [Chen et al., 2018]. Conducting UX research helps to reduce user churn and identify growth points that can lead to an influx of users, as well as offer solutions to improve the experience and retain users. For example, to determine which elements of the application design and functionality evoke emotions and provide a positive user experience, and which, on the contrary, require changes.

The main benefit of UI research is to understand the needs and expectations of users. Research allows you to analyse user behaviour, preferences and problems, as well as determine which features and capabilities of the application are important. For example, what emotions does AI technology evoke in a mobile application [Wiberg,

[3] Artificial intelligence: benefit or threat? https://wciom.ru/analytical-reviews/analiticheskii-obzor/iskusstvennyi-intellekt-blago-ili-ugroza.

[4] The application of artificial intelligence in the financial market... https://cbr.ru/Content/Document/File/156061/Consultation_Paper_03112023.pdf.

[5] Id.

[6] Id.

Stolterman Bergqvist, 2023]. As a result, such research helps you to improve the user experience.

In addition, it should be noted that UI research provides an emotional interaction between the user and the application. By analysing users' emotions and reactions, it is possible to create an interface and content that can evoke positive emotions and increase user engagement, leading to an improved user experience [Li et al., 2024].

An important benefit is the increase in usability, as the main goal of UI research is to create a user-friendly and intuitive interface in a mobile application. Thanks to research, it is possible to identify difficulties that affect the conversion of sales through a mobile application. Therefore, research also allows you to identify the reasons why users may not complete a purchase or skip important steps, and to optimise the elements that affect conversion and sales in a mobile application.

There are numerous examples in the literature where poorly understood customer experience has led to end users abandoning a service due to technostress, fatigue and misuse [Hart, Sutcliffe, 2019; Nisafani et al., 2020]. End users of digital solutions have high demands on applications or services, and the success of digital technologies is often linked to how well developers manage to understand user requirements and translate them into appropriate solutions in terms of functionality and aesthetics [Silva-Rodríguez et al., 2021]. The work [Oulasvirta et al., 2020] shows that creating user-friendly and innovative solutions requires user-centred design with qualities such as creativity, problem solving, reflection and empathy.

In [Verganti et al., 2020], design is defined as a part of the innovation process aimed at making decisions in the area of generating new ideas and solving user problems. The authors define design as a process consisting of a set of stages, methods, tools or collaborative practices, and as a design object that describes new solutions for creating a product, service or process.

In recent years, the UX design process has become a subject of special study in the research literature. For example, the authors of [Verhulsdonck et al., 2021] define UX design as 'the process of supporting user behaviour by providing usability, usefulness and desirability through interactions with a product'. An important part of UX design is to follow a predefined and established process, the key elements of which are piloting, testing and refining [Tokkonen, Saariluoma, 2013].

Currently, one of the most commonly used UX design methods for digital solutions is the so-called user-centred design, i.e. a design that places the user of the product at the centre of the design [Pandian, Suleri, 2020].

With this design method, each phase of the process can be linked to different UX activities, which allows for more detailed information about how such a process changes with the introduction of artificial intelligence [Park et al., 2013]. The authors of the study [Preece et al., 2015] define user-centred design as a design process that involves identifying user needs and requirements, generating ideas, and evaluating them to meet those needs and requirements. A key element of user-centred design is that it is iterative, as steps can be repeated if the result does not meet the user's needs after each iteration. The user-centred design process promotes dynamic interactions between the user and the designer, allowing UX designers to conceptualise, communicate and evaluate their design before creating the final version [Pandian, Suleri, 2020].

However, the design process still takes a lot of time and requires relevant experience and resources. The task of designers becomes increasingly complex as they are required to simultaneously understand what needs to be created (problem setting) and develop an appropriate solution (problem solving) [Yang, 2017]. To understand the task at hand, developers need to gather information about how the solution they are developing is being used by analysing data from the users who interact with the system. However, in many cases this data is missing, which further complicates the task.

The recent introduction of artificial intelligence (AI) has sparked a debate about how to improve the design processes associated with UX design by providing designers with tools that enable them to create higher quality digital services in less time and at lower cost [Oh et al., 2018].

In recent years, the number of practical applications and research in AI for UX has grown rapidly. Using datasets containing, for example, user data or graphical interface elements, AI applications can automate design tasks and facilitate the creation of adaptive interfaces that evolve dynamically according to user requirements [Johnston et al., 2019]. Thus, AI-enabled UX is fundamentally changing the process of digital service development.

The introduction of artificial intelligence has already led to fundamental changes in the UX design process, so it is important to understand how such technologies can be developed and integrated into the design process. In a recent literature review, [Abbas et al., 2022] presented a description of the challenges UX designers face when implementing machine learning (ML) in the design process. In their conclusions, the authors propose several tools, algorithms and techniques that can be used to overcome the emerging challenges. In essence, the study [Abbas et al., 2022] represents another approach that aims to identify the main challenges faced by UX designers. However, their work pays less attention to how AI can be used at different stages of the UX design process.

Other studies have mixed opinions on the use of AI, with some studies citing negative aspects of its use. For example, [Gaffney, 2017] notes potential negative and unintended consequences, and also argues that the use of AI in the UX design process is a potential risk factor associated with a lack of control and autonomy, inconsistency in UX design, decreased productivity, and increased stress and frustration among designers due to fear of losing their jobs [Gaffney, 2017].

[Koch, 2017] emphasise that it is important to view UX design as a holistic process, and that for AI to be a useful tool in the UX design process, both technical capabilities and human needs need to be understood throughout the design process.

The authors of the review [Enholm et al., 2021] consider various definitions of AI and argue that 'there is general agreement that artificial intelligence means endowing a computer with human-like capabilities, meaning that computers are capable of performing tasks that would normally require human intelligence'. Therefore, AI can provide the ability to fine-tune and analyse the use of digital solutions, as well as assist designers in the creative process [Oh et al., 2018].

As the use of artificial intelligence for design purposes has expanded, so have the concepts used to describe this phenomenon. One such concept is artificial design intelligence (ADI): it refers to AI that has developed design knowledge by using ML to predict design trends and generate designs [Li, 2020]. Another example is computational creativity, an area of AI in which systems exhibit behaviours that would be considered creative in humans [Feldman, 2017].

Another area is the interaction of AI with artistic design – the concept of intelligent design. This area includes, among others, AI-assisted automated design, intelligent artificial design system, AI-assisted user experience design for products, and AI-assisted product management [Li, 2020].

However, research into the use of AI in the design process remains fragmented.

Based on the review, the author hypothesises that the implementation of AI technology in a mobile application will personalise the user experience, increase customer satisfaction and their level of engagement, which will ultimately increase the company's profitability and competitiveness in the market.

2. Methodology for studying the impact of AI technology on user experience

In order to conduct this study, the following research questions were formulated:

- How can the implementation of AI technology help at different stages of the development of a mobile banking application redesign?
- Can the implementation of AI technology improve the personalisation of the user experience?
- Can the implementation of AI technology improve customer satisfaction and engagement, thereby impacting the bank's profitability and competitiveness?

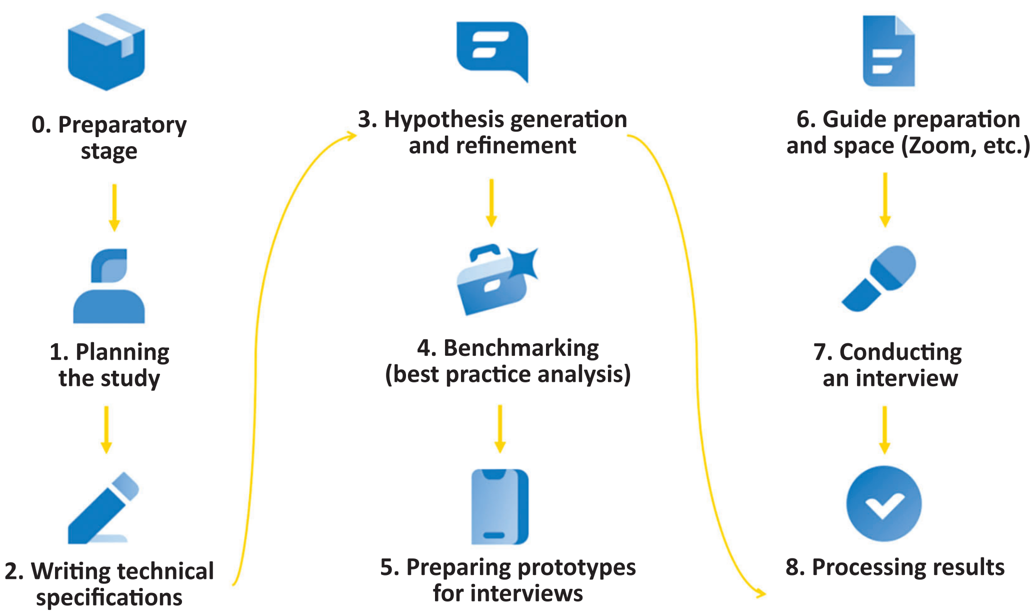
A research methodology was developed to answer the questions posed:

- developed our own approach to conducting UX/UI research;
- captured and modelled the current banking customer journey in the bank's mobile application;
- conducted in-depth interviews with 20 respondents comparing screens with and without the use of AI technology;
- described the UI/UX research based on the in-depth interviews conducted, with subsequent justification of the need to implement AI technology to personalise the user journey in the mobile application.

In the first stage, a methodology for conducting UI research was developed, consisting of nine steps, as shown in Fig. 4.

Preparatory stage: a Customer Journey Map (CJM) was created and modelled in the context of banking scenarios in a mobile application based on the BPMN notation. The advantage of this notation is that it allows to identify

Fig. 4. Stages of UI research



Источник: разработано автором.

growth points in the context of the business and technical aspects of the mobile application. The business side is the user path, the interfaces that the user sees in the mobile application when going through a particular scenario. The technical side includes a description of the microservices of the mobile application.

Planning the study: The research objectives and key participants were defined, key questions for in-depth interviews were formulated based on the previously studied user journey, and a research plan was agreed.

At the technical specification stage. All the requirements were formulated in the form of a research project passport. Then, based on a theoretical review of the literature, hypotheses were defined and refined based on the analysis of the first phase of the study.

The fourth stage involved *benchmarking* (analysis of best practice). Competitors in the market or practices of other successful applications in the industry were analysed to identify strengths and possible areas for improvement. This stage is not mandatory – it allows you to compare the application with competitors, identify similar functionality or radical differences, and gather additional information to create a set of questions for further interviews.

In *preparing prototypes for interviews,* prototypes were created from design layouts to be shown to respondents during interviews.

Preparing the guide and room for conducting the interviews: At this stage, instructions were written describing the scenarios and questions needed to conduct interviews with respondents. A guide is a set of instructions containing a list of questions designed to obtain information from respondents in order to confirm or refute a hypothesis. A group of respondents was also identified at this stage.

The seventh step is *to conduct interviews*. According to the developed scenario, 20 qualitative studies were conducted – in-depth interviews lasting 90 minutes with all answers and emotions recorded.

The final stage is *to process the findings*. All interview recordings were transcribed to create a list of problems and ideas. This allowed us to quantitatively and qualitatively analyse the list of hypotheses and draw conclusions.

3. Research results

3.1 Conducting UI research in a bank's mobile application

The ecosystem in the banking industry, as a trend of digital transformation of business, allows companies to improve the wide range of banking and non-financial services provided to customers. Therefore, we will consider conducting UX/UI research on the 'Auto' section of a mobile banking application.

To determine the current level of the UX concept of the bank's 'Auto' section, as part of the UX/UI research, a customer journey (CJM) was compiled for the scenario of adding a car to the bank's mobile application (Fig. 5).

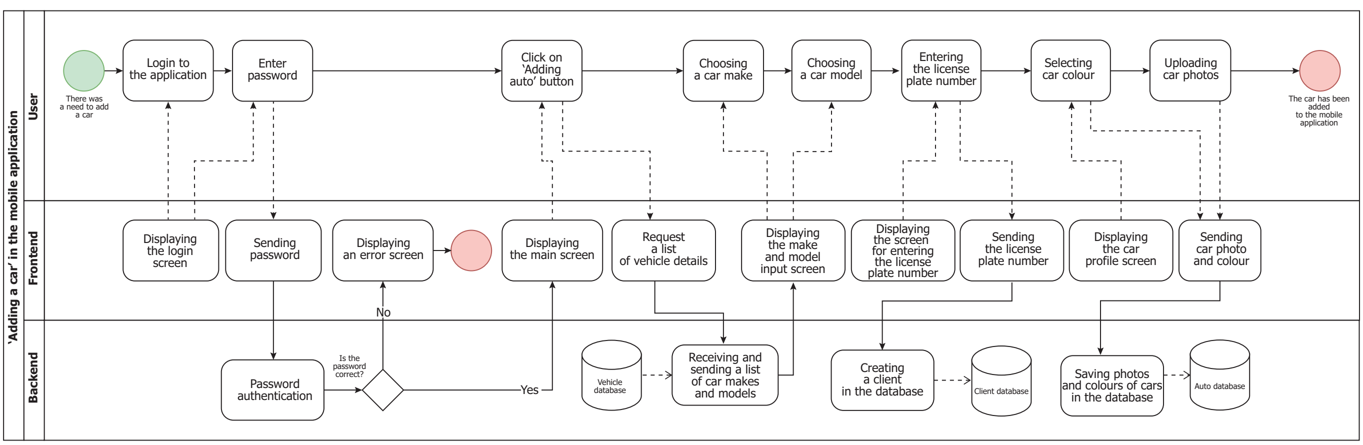
Let's look at the simulated CJM of the current 'Adding auto' scenario in the mobile application. The user starts his journey from the authorisation zone in the mobile application. After receiving the debit card from the bank, he has to enter the pre-set password. If the user is not a bank customer, he will not be able to access the authorised area of the mobile application. This means that the Bank's products and the full functionality of the entire mobile application will not be available to him. If the password is entered correctly, the user will be taken to the main screen of the mobile application.

The main screen of the mobile application contains the bank's main products: banners, account, support chat, profile, stories (news feed), etc.

The main screen serves as an entry point for various scenarios: paying for housing and municipal services, searching for tickets, viewing an invoice, making a payment, including adding a customer's car.

Next the Client must click on the 'Adding auto' button. The customer is taken to the 'Adding auto' scenario. The customer must select the make of their car from the drop down list of models or enter it in the search bar to search.

Fig. 5. User path 'Adding auto' in the mobile application



The search is done by reference to the bank's database. The database is updated and supplemented by integrations with car suppliers or other car services.

Next, the customer must select the car model from the drop-down list of models or enter it in the search bar, as in the previous step. The next step is to specify the year of manufacture of the car and then enter the country registration number.

Further on in the interface, it is possible to edit and change the information: choose the colour, the shape of the discs, upload photos.

After saving the necessary data, the customer completes the process of adding a vehicle in the mobile application. The application will display a notification of successful addition.

A tool like CJM allowed us to gain a deeper understanding of the customer experience and identify potential bottlenecks for further improvement, to create an optimised path for the bank's loyal motorist customers, increasing their satisfaction and improving their experience.

The current 'Adding auto' scenario has several shortcomings in its interface in terms of UX requirements, as shown in Table 1.

Table 1
Disadvantages of the current 'Adding Cars' scenario

Interface weakness	Description
Large amount of input data on different screens of the mobile application	The user is forced to enter a lot of data about the car: make, model, year, colour. Information overload can be tedious. If the user has several cars, he has to repeat the current process for each one
Loss of context in the script	The current process of adding a car consists of multiple screens or transitions, which can cause the user to lose context
Lack of automation in the script	The current path is not optimised for the user. There is no integration with the ability to automatically fill in fields and search for a car without specifying more information
Low level of personalisation	The user has to assemble an image of his car – the image does not reflect reality. The user is not very interested in returning to this section when entering the application

Source: compiled by the author.

This confirmed the need to improve the user journey in the mobile application.

A UI study was then designed to answer the research question and confirm or refute the hypothesis.

Then the technical task was defined. Let's consider the technical task of the UI research using the example of a specific section 'Auto' of the banking application, described in Table 2.

Table 2
Terms of reference for conducting UX/UI research

Block	Description
Product name	The 'Auto' section of the bank's mobile application
Target audience	1. Customers using the Bank's car products: car loan CMTPL or CASCO. 2. Active customers of the 'Car' department 3. Users who own a car but do not use the 'Auto' section
Business value	Increase % retention of current MAU. Current MAU is 150 thousand customers, which is 1/3 of the active customer base of 6 million customers.
Deadline	2 months
Research objectives	1. Identify barriers and new motivations for using the 'Auto' section 2. Identify key patterns of using the 'Auto' section 3. Conduct concept testing of the 'Auto' section, determine user perception of current design concept 4. Determine attitudes towards AI technology, impact on personalisation of the user path within the framework of auto images
Key questions for interviews in the 'Auto' section	1. How does the user understand the overall meaning of the section? Is it valuable to them and why? 2. What functions of the section are obvious to the user? 3. Which features are less clear, but can be figured out with leading questions? 4. Which features are unclear? 5. Which features does the customer consider valuable? Why? 6. What do users feel is missing from the current interface? Why? 7. Which scenarios/functions/elements of the interface do users consider unnecessary? Why? 8. How does the user understand the importance of adding a car? Do they consider it valuable and why? 9. Does the user use the current section? If so, how often? For what purpose? If not, why? 10. What in the interface is critical to the user? If yes, what is it and why?
Questions about AI technology	1. We will now look at two prototypes of the scenario for adding a car: a) the first screen has a basic image of the car b) The second has an image of the car created using artificial intelligence (AI) 2. What do you think of the first prototype? What emotions did it arouse in you? Do you like the car? 3. What do you think of the second prototype? Are you put off by the fact that the car is generated by AI? Do you like your car now? 4. Which of the two prototypes do you like better and why? If neither, why? 5. What do you think about the use of AI technology in the banking sections of the mobile application?

Source: compiled by the author.

Next, in order to conduct in-depth interviews within the framework of the analysis of the current customer journey of the bank's mobile application using the example of the 'Auto' section, hypotheses were formulated for the current section of the banking application, which are presented in Table 3.

Hypothesis 1. Providing a more attractive and intuitive interface in the car section of the mobile application will attract new users to the car segment and increase the retention of existing users.

Hypothesis 2. The introduction of AI technology to generate car images will personalise the user experience of the 'Auto' section, and new car images as a gamification tool will increase the loyalty (NPS) of customers who have not used the section or have been inactive.

Benchmarking (analysis of best practices) was carried out to refine the questions and design prototypes for future demonstration in interviews. Let's consider a competitive analysis of the current product ('Auto' section) on the market (Table 3). The best practices on the market, according to the experts, were defined as Yandex.Zapravki and Auto.ru mobile applications.

Table 3
Competitive analysis of the 'Auto' section of the mobile application

Functionality	Yandex. Zapravki mobile application	Auto.ru mobile application	The 'Auto' section of the bank's mobile application
Ability to add a car	Yes	Yes	Yes
Onboarding when adding a car for the first time	No	No	No
Ability to choose the colour of the car when adding a car	Yes	Yes	Yes
Ability to track the status of a car	No	No	Yes
Ability to buy/sell a car	No	Yes	Yes
Ability to upload a picture of the car	Yes	Yes	Yes
Availability of gamification in the application	No	No	No
Ability to buy CMTPL	No	Yes	Yes
Ability to rate the car	No	Yes	Yes
Display the car	User's photo	Photorealistic cars	Standard car pictures
Ability to see fines for the car	No	No	No
Availability of support chat	Yes	Yes	Yes

Source: compiled by the author.

Based on the competitive analysis, a growth point was identified – displaying a car to the user. There are no solutions on the market that show a photo of a realistic car to the user as a tool to keep their attention in the application. It is the implementation of AI technology that will allow the personalisation of the user experience.

Next, two prototypes were created with the help of the design and development team. The first prototype contains a basic image of a car from the bank's directory, the second – an image of the user's car created using artificial intelligence (AI). The main difference in the second prototype is a photo-realistic image of the user's car.

After the prototypes were developed, a guide for conducting interviews was prepared. The guide with a list of questions for conducting an in-depth interview is shown in Table 4.

Table 4
In-depth interview guide

Interview stage	Description
Introduction (2 minutes)	Introducing the moderator Discussing the ground rules Video recording Confirming confidentiality of responses Communicating the general purpose of the interview
Getting to know (10 minutes)	How old are you and where do you live? Who do you live with? Where do you study/work? What is a typical weekday like? Do you drive – why, where, for how long? What do you do after work? How do you spend your weekends? What do you like to do? What don't you like to do, what do you want to get rid of? What do you watch/listen to/read? Which subjects?
Driving (5 minutes)	Please tell us your story, how did you get your licence? Why did you decide to get it?
About auto (20 minutes)	Please tell us how you acquired your current car? How did you choose it? How did you buy it? How often do you use your car? For what purpose? Where is it usually parked? What does its maintenance involve? Do you consult anyone about maintenance? In what situations do you contact the mechanics? How do you choose a garage/car wash/service? Are there any apps or websites that help with car maintenance (do you use automatic car washes or online petrol stations)?
Attitude to auto (5 minutes)	How would you continue the sentence 'My car is...'?
Discussion of prototypes (30 minutes)	List of questions from the technical task Showing prototypes
Conclusion (2 minutes)	Is there anything you would like to add? Additional questions from the team Giving thanks and closing the interview

Source: compiled by the author.

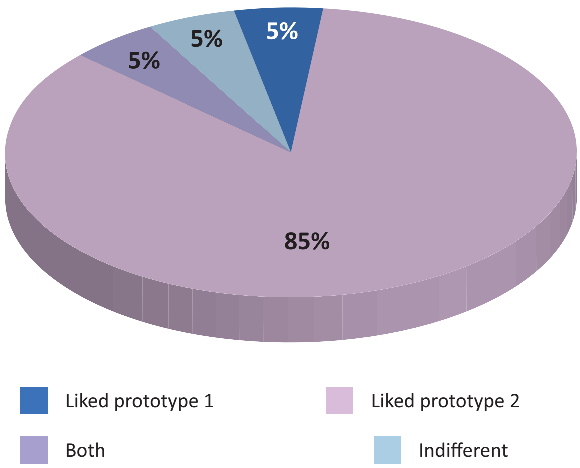
Subsequently, 20 in-depth interviews were conducted with respondents according to the developed scenario. Emotions and responses were recorded in the interview template. The transcript of the recordings to form a list of problems and ideas, as well as the quantitative and qualitative analysis are presented in the next section.

3.2. Justifying the impact of AI technology in improving the user experience of a banking application

The transition from purely financial activities to a single ecosystem encompassing all areas of users' lives has affected the UX/UI quality of new areas of mobile applications in the fintech industry.

The results of the 20 in-depth interviews showed that 85% of respondents preferred the app interface that used AI technology (Fig. 6). Of the respondents, 5% of each group said they liked both screens. Therefore, the AI-based interface increases interest and is more attractive to users.

Fig. 6. Respondents' attitudes towards UX/UI prototypes



Source: compiled by the author.

During the interview, the respondents' reaction to the interface screen where AI technology was used was also noted. Attitudes towards the AI technology are shown in Figure 7. When the interface was demonstrated, 65% of respondents had a positive reaction, noting that the new screen significantly increased their interest in visiting compared to the previous one. In addition, 20% of respondents noted that the user scenario has become visually more comfortable. It should be emphasised that users are not immersed in the technical features of AI technology, and ignorance of the technology itself can lead to a misunderstanding of how the operation of algorithms and information processing provides a personalised result for the user experience.

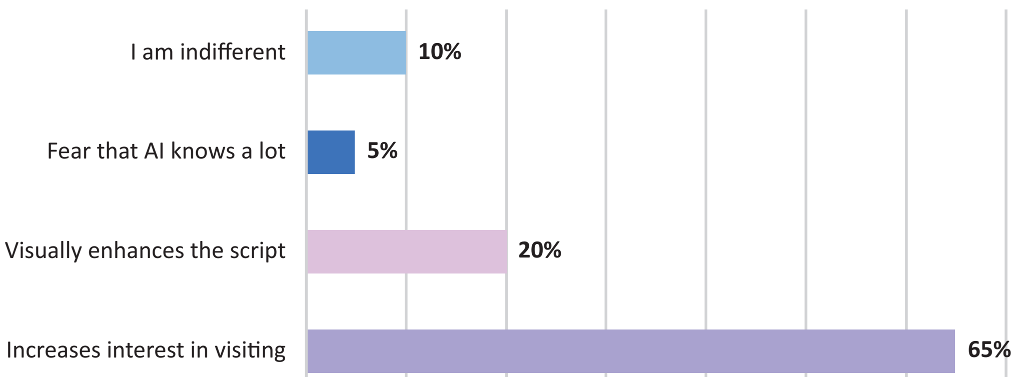
Let's summarise the results of the study using the example of the 'Auto' section in the bank's mobile application, based on the processing of the recordings of in-depth interviews with respondents (Table 5). The problems and drivers were considered in the context of the interface without the use of AI technology.

Table 5
Survey results of the current 'Auto' section of the mobile bank

Block	Description
Problems	Lack of knowledge about the availability and capabilities of the 'Auto' section
	Customers notice constant errors when adding a car in the mobile application
	The car when added does not correspond to the actual image of the customer's car
	The section is difficult to find or its nature is unclear
	Customers are not in the habit of visiting the section due to a lack of clear need
	Most customers know the name but do not remember what is in the section
Drivers	Everything online
	Customers have no contradictions when using car products (fines, insurance)
	Saving time (registering insurance, viewing repair offers, etc.)
	One place to track the condition of the car
	Separate reminder about the purchase/ discount/car service station

Source: compiled by the author.

Fig. 7. Fig. 7. Respondents' attitudes towards AI technology



Source: compiled by the author.

Based on the in-depth interviews conducted, the following conclusions can be drawn about the shortcomings of the 'Auto' section (without the use of AI technology) in the bank's mobile application:

– the current visual design of the section and its functionality do not inspire a desire to visit the service on a regular basis, but customers are positive about the idea of a service for the car segment;
– users do not understand the current capabilities of the 'Auto' section, but during interviews, users noted that a significant opportunity for them is to pay fines, check the cost of a car and view their expenses;
– customers react neutrally to the image of the car as it is not very close to their model, confirming low customer loyalty and lack of motivation to visit the 'Auto' service;
– most of the design elements are misunderstood. For example, the 'shield' icon means that there is insurance, but users do not intuitively grasp this meaning, and the element is not highlighted with an information note with a description.

Based on the results of the UI research, general recommendations were made for the further redesign of the 'Auto' section as one of the areas of a single ecosystem to improve the user experience in the bank's mobile application.

1. It is necessary to develop an entry point for the 'Auto' section on the main screen of the mobile application with high user recognition.

2. To develop a new design concept for the 'Auto' section with developed user scenarios based on the analysis and best practices in the market, as the current user path is very long and requires a lot of data entry.

3. To work out the maximum photorealistic image of the customer's car to increase the level of personalisation of the service. To generate a large number of car makes and models, it is necessary to use artificial intelligence. UX/UI research has shown that an image created using AI technology generates a high level of interest on the screen. In addition, AI generation will allow you to create: an online image for each user with a high level of automatic detail; automatic colours of a specific HEX value (code in the palette); when creating an image, manage the background, which will save time for editing artefacts by the design team in the future. For example, high-quality training of the model using detailed queries (object background, shadows, lighting, position, size) helps you generate an object with maximum detail.

4. To create a section with the ability to enter data about the car (mileage, consumables and when they need to be replaced). This will allow you to collect more data about the customer and send personalised notifications, e.g. about the need to replace parts/oil.

5. To develop the synchronisation of the mobile application using the REST API of government services with data (e.g. from the State Traffic Safety Inspectorate) in order to minimise their input by the client.

The existing IT infrastructure of the banking industry will allow, subject to the allocation of the necessary technical resources, the redesign of the mobile application through the introduction of AI technology to improve the user experience.

Thus, the results of the UI study confirmed the hypothesis that the introduction of a personalised user experience using AI technology (photorealistic images of cars) in the bank's mobile application will lead to increased customer satisfaction and engagement, which will ultimately increase the bank's profitability and competitiveness.

The proposed recommendations will optimise the user experience in the mobile application, improving the NPS and MAU metrics by a factor of two, according to the experts.

3.3. The efficiency of implementing AI technology in UI research processes

The analysis of the cost-effectiveness of introducing AI technology into the UI research processes during the redesign of the 'Auto' section of the mobile application is based on changes in key metrics:

– Increasing customer loyalty (users are more interested in using a product with an intuitive user interface);
– Increasing the number of unique users;
– Increasing sales of auto banking services and conversion to targeted actions through the 'Auto' section of the mobile application.

The economic viability of the car section will be achieved by improving the user experience through the redesign of the mobile application, which will ensure higher user satisfaction and increased sales of banking car products.

Based on actual data prior to the development of a new IT solution and a specialised analytical BI platform for product analysis provided by the bank, calculations were made for the indicators shown in Table 6.

Table 6
List of indicators to evaluate the effectiveness of an IT project

Indicator	Formula
NPS (consumer loyalty index)	NPS = % promoter – % critics (1)
MAU	Unique users per month
Conversion to target action (transition to 'Auto' section)	$Conversion = \frac{X_1}{X} * 100\%$, (2) where X_1 – the number of users who actually clicked through from the 'CMTPL' banner to detailed product cards, X – Total number of users who visited the 'Auto' section
Empty screens	Number of errors/zero-screens in user scenarios

Source: compiled by the author.

The Net Promoter Score (NPS) for the car section was calculated based on surveys and feedback from bank users. Before the redesign of the mobile app section, this figure was 35%. After the redesign of the car section, 400 customers responded to the bank's survey and the following ratio was obtained:

– promoters who rated it 9-10 – 276 people (69%);
– neutrals who rated it 7-8 – 82 people (20.5%);
– critics who rated it 0-6 – 42 people (10.5%).

Let's calculate the Net Promoter Score (NPS) using formula (1) from Table 6:

NPS = 69% promoters – 10.5% critics = 58.5%.

The value of the unique users indicator for the month before the redesign of the 'Auto' section of the mobile application MAU on the IOS and Android platforms was 150,000 users. After redesigning the mobile application by uploading data from the BI platform, the value of the MAU indicator increased 2 times and was 320,000 users.

The conversion rate of the transition to the 'Auto' section for the purpose of connecting car products was calculated using formula (2) from Table 6. Prior to the implementation of the project to improve the user experience of the 'Auto' section, the total number of users who visited this section was 1,250,000 and only 112,000 users went to the detailed view of the product cards. Accordingly, the conversion in the old design was no more than 8.96%. After the redesign, the BI platform was unloaded by the number of visits to sections and transitions to internal scenarios.

Let's calculate the conversion using formula (2) from Table 6:

$$Conversion = \frac{299\,010}{1\,350\,089} * 100\% = 22.15\%.$$

The effectiveness of the user experience is also affected by the presence of blank screens (empty pages or zero screens) in the mobile application within the 'Auto' section. Blank screens can create negative impressions for users, leading to misunderstandings and disappointment, which in turn can lead to lost users and reduced conversion. Before the redesign project, the total number of blank screens was 520, after – 147 (measured using the bank's product analysis and reports from the BI system), i.e. after improving the user experience, the number of blank screens was reduced by a factor of 3.

The results of the calculation of the changes in the banking metrics are presented in Table 7 before and after the redesign of the 'Auto' section of the mobile application.

After completing a mobile app redesign project for the bank's car division, the improved user experience and personalisation tools had a positive impact on the project's key metrics.

The increase in the NPS metric indicates an increase in user satisfaction and loyalty following the AI-powered redesign of the 'Auto' section of the mobile app. In addition, the increase in the MAU metric indicates a more active use of the app and the acquisition of new users. Such positive changes confirm that the AI-powered redesign was successful and contributed to the improvement of key project metrics.

The first major change was the growth of the monthly active audience (MAU) from 150,000 to 320,000 users, which means that the content has become useful and personalised for each user. The ability to track information about their own car in a mobile application attracts users.

The increase in the Net Promoter Score (NPS) from 35 to 58.5% is another indicator of the success of implementing AI in the design process. The increase in user satisfaction indicates that the new design and functionality of the 'Auto' section using AI has a positive impact on customer emotions. This positive response allows the bank to attract a new target group interested in the convenience and functionality of the application.

Conversion rates to the target action (transition to the 'CMTPL' product via the 'Auto' section) of 8.96 to 22.15% indicate the quality of the bank's personalised offers. An effectively designed user path encourages key actions, providing an opportunity to increase sales of the bank's car products.

It should be noted that the reduction in the number of blank screens from 520 to 147 plays an equally important role in improving the user experience. The absence of errors

Table 7
Changing metrics while improving the user experience

Metric name	Value before redesign (design without AI)	Value after redesign (AI-powered design)
MAU (number of users)	150 000	320 000
NPS (%)	35	58.5
Conversion to target action (transition to detailed banking product cards via the Notification Centre) (%)	8.96	22.15
Blank screens (number of errors/zero screens) (units)	520	147

Source: compiled by the author.

and a well-thought-out customer path with a minimisation of negative scenarios (blank screens) help to prevent negative impressions for users and ensure a comfortable interaction with the application.

So, the redesign of the bank's mobile application using AI within the 'Auto' functionality has really improved the user experience and improved the key performance metrics of the mobile application.

Conclusions

For example, the work shows an algorithm for developing and using AI technology to generate a personalised image of a car with a prediction of its colour to be displayed to the customer at the time of searching and adding their car to the section of the mobile application.

An evaluation of the effectiveness of the development of the redesign of the 'Auto' section for the bank was also carried out. The calculation of the economic efficiency of the project was based on changes in indicators such as NPS, MAU, conversion to target actions and display of zero screens. The data was obtained by surveying users after the development of the project and using an analytical BI platform. The results of the ROI assessment allow us to be sure of the feasibility of the decision to redesign the 'Auto' section.

As a result of the analysis carried out on the IT solution, improvements were identified in the key profitability indicators of the 'Auto' section of the mobile application.

When redesigning a mobile application and developing new functionality, banking organisations should consider the following recommendations:

To understand user needs and preferences. Companies should conduct UX/UI research, design user journeys, formulate potential challenges in scenarios and test them with in-depth interviews. Feedback can be used to assess the complexity and priority of features to be added to the mobile app.

To design layouts based on the results of UX/UI research within the minimum viable product. An intuitive interface helps increase customer loyalty and satisfaction.

To use AI technology to personalise the user experience. AI technology not only allows you to analyse user data and create personalised recommendations and products, but also to analyse user behaviour to improve the user experience.

To use AI to predict user behaviour, anticipate their needs and make appropriate recommendations. Developing effective predictive models and analytical algorithms will significantly improve user satisfaction.

To implement AI to recognise speech, images or other types of data. For example, generating icons or graphic images will reduce the cost of graphic designers. It is necessary to highlight the information that artificial intelligence has been used for functionality – this will significantly increase the interest and frequency of use of the mobile application.

The UI study confirmed that the implementation of AI technology in the bank's mobile application will personalise the user experience, increase customer satisfaction and engagement, and ultimately increase the bank's profitability and competitiveness in the market.

In addition, the results of the UI research will be used to suggest effective ways of using AI technology to improve the quality of the user journey.

The integration of AI technology into the bank's mobile application has great potential to increase customer satisfaction and enhance the bank's competitiveness. The scaling of AI technology will allow personalisation of the customer approach in all areas of the bank's mobile application. This is not only an important factor in improving functionality and attractiveness for users, but also serves as a competitive advantage in the banking industry.

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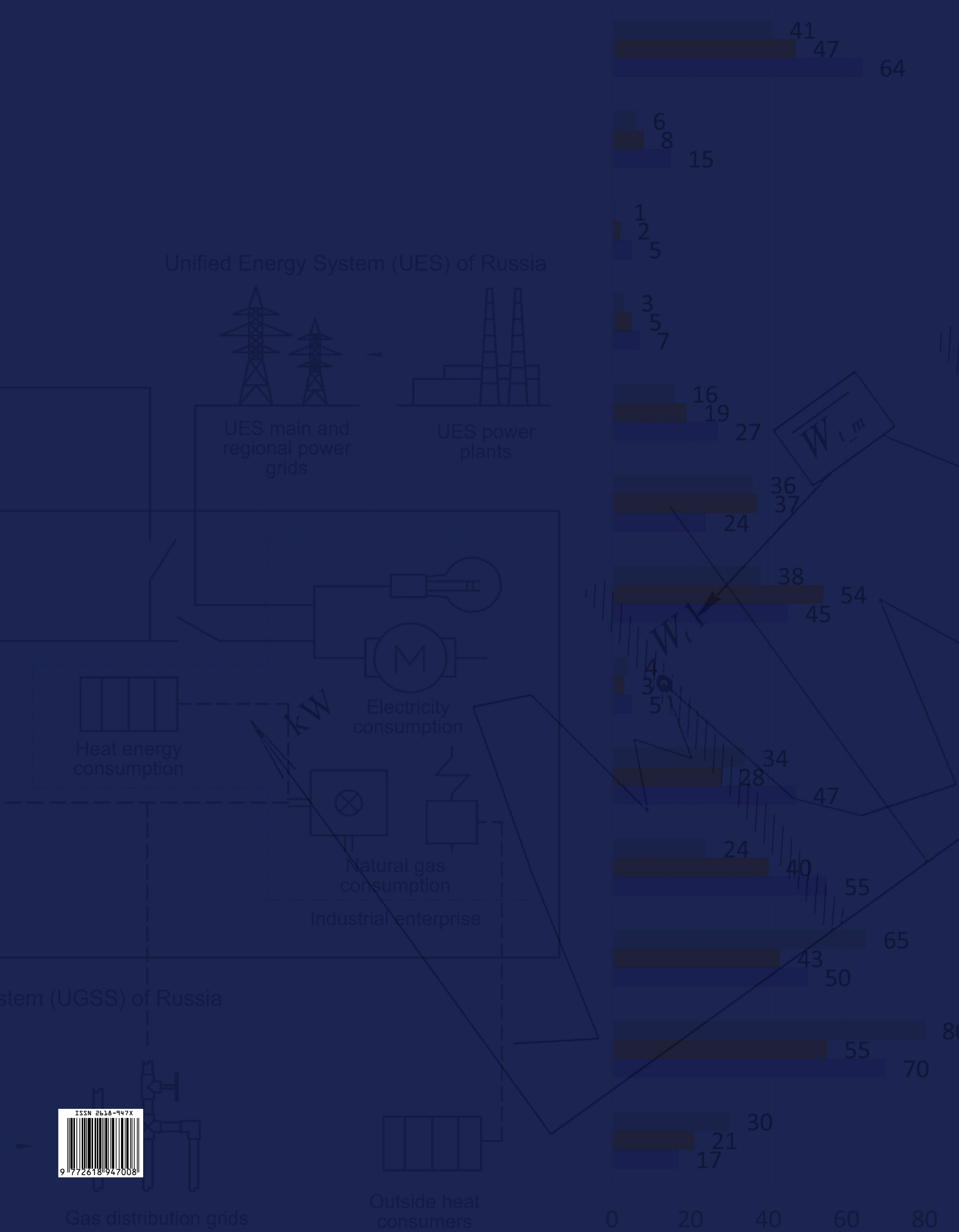
The article was submitted on 15.05.2024; revised on 16.06.2024 and accepted for publication on 21.06.2024. The author read and approved the final version of the manuscript.

文章于 15.05.2024 提交给编辑。文章于 16.06.2024 已审稿．之后于 21.06.2024 接受发表。作者已经阅读并批准了手稿的最终版本。



ISSN 2618-947X