ISSN 2782-6333

SUSTAINABLE DEVELOPMENT and ENGINEERING ECONOMICS

04 2022

Published by Peter the Great St. Petersburg Polytechnic University

Editor-in-chief: Irina Rudskaia (Peter the Great St. Petersburg Polytechnic University, Russia)

EDITORIAL BOARD

Alberto Tron (Boccony University, Milan, Italy)
Aleksei Bykov (Belarus State Economic University, Minsk, Republic of Belarus)
Andrew A. Alola (Istanbul Gelisim University, İstanbul, Turkey)
Angi E. Skhvediani (Peter the Great St.Petersburg Polytechnic University, Russia)
Arturas Kaklauskas (Vilnius Gediminas Technical University, Vilnius, Lithuania)
Cengiz Kahraman (Istanbul Technical University, Istanbul, Turkey)
Dmitrii G. Rodionov (Peter the Great St.Petersburg Polytechnic University, Russia)
Eduarda Pinto Ferreira (Instituto Superior de Engenharia do Porto, Poliécnico do Porto, Porto, Portugal)
Emma Juaneda-Ayensa (University of La Rioja, Logroño, La Rioja, Spain)
Gabriela Ignat (Ion Ionescu de la Brad "University of Agricultural Sciences and Veterinary Medicine", Iaşi, Romania)
Geoffrey Shen (The Hong Kong Polytechnic University, Hong Kong)
Gul Ipek Tunc (Middle East Technical University, Ankara, Turkey)
Gunnar Prause (Tallinn University of Technology, Tallinn, Estonia)
Hani Abu-Qdais (Jordan University of Science & Technology, Irbid, Jordan)
Igor I. Dukeov (LUT University, Lappeenranta, Finland)
Jessica Victoria Lichy (IDRAC Business School, Lyon, France)
Josef Windsperger (University of Vienna, Vienna, Austria)
Kiril Anguelov (Technical University of Sofia, Sofia, Bulgaria)
Lilia Șargu (University of European Studies of Moldova, Kishinev, Republic of Moldova)
Luis Borges Gouveia (University Fernando Pessoa, Porto, Portugal)
Lutfihak Alpkan (Istanbul Technical University, Istanbul, Turkey)
Mohammed Ali Berawi (Universitas Indonesia, Depok, Indonesia)
Nandy Putra (Universitas Indonesia, Depok, Indonesia)
Rangika Umesh Halwatura (University of Moratuwa, Moratuwa, Sri Lanka)
Sergey Sosnovskikh (De Montfort University, Leicester, United Kingdom)
Susanne Durst (Tallinn University of Technology, Tallinn, Estonia)
Tatiana J. Kudryavtseva (Peter the Great St.Petersburg Polytechnic University, Russia)
Tengiz Magradze (Georgian Technical University, Tbilisi, Georgia)
Vincenzo Bianco (University of Genoa, Genoa, Italia)
Wolfgang Dieter Gerstlberger (Tallinn University of Technology, Tallinn, Estonia)
Xinpeng Xu (The Hong Kong Polytechnic University, Hong Kong)
Zhikai Wang (Zhejiang University, Hangzhou, China)

EDITORS OFFICE

Executive editor
Angi Skhvediani
Executive Secretary
Viktoriia Brazovskaia
Development Manager
Anastasiya Kulachinskaya
Layout designer
Vladimir Nikiforov

Publisher
Peter the Great St. Petersburg
Polytechnic University
Corresponding address:
29 Polytechnicheskaya st., Saint-Petersburg,
195251, Russia

Contacts:
Email: sustainable@spbstu.ru
Web: https://sustainable.spbstu.ru/

Главный редактор: Ирина Андреевна Рудская (Санкт-Петербургский Политехнический университет Петра Великого, Россия)

РЕДАКЦИОННАЯ КОЛЛЕГИЯ

Альберто Трон (Университет Боккони, Милан, Италия)
Алексей Быков (Белорусский государственный экономический университет, Минск, Республика Беларусь)
Эндрю А. Алола (Стамбульский университет Гелисим, Стамбул, Турция)
Анги Е. Схведиани (Санкт-Петербургский политехнический университет Петра Великого, Россия)
Артурас Каклаускас (Вильнюсский технический университет имени Гедиминаса, Литва)
Ченгиз Кахраман (Стамбульский технический университет, Стамбул, Турция)
Дмитрий Г. Родионов (Санкт-Петербургский политехнический университет Петра Великого, Россия)
Эдуарда Пинту Феррейра (Политехнический университет Порту, Португалия)
Эмма Хуанеда-Айенса (Университет Ла-Риохи, Логроньо, Испания)
Габриэла Игнат (Ион Ионеску де ла Бред "Университет сельскохозяйственных наук и ветеринарной медицины", Яссы, Румыния)
Джеффри Шен (Гонконгский политехнический университет, Гонконг)
Гул Ипек Тунж (Ближневосточный технический университет, Анкара, Турция)
Гуннар Праузе (Таллиннский технологический университет, Таллин, Эстония)
Хани Абу-Кдаис (Иорданский университет науки и технологий, Ирбид, Иордания)
Игорь И. Дюков (Университет LUT, Лаппеенранта, Финляндия)
Джессика Виктория Личи (Бизнес-школа IDRAC, Лион, Франция)
Йозеф Виндспергер (Венский университет, Вена, Австрия)
Кирилл Ангелов (Софийский технический университет, София, Болгария)
Лилия Шаргу (Университет европейских исследований Молдовы, Кишинев, Республика Молдова)
Луис Борхес Говея (Университет Фернанду Песоа, Порту, Португалия)
Лутфихак Альпкан (Стамбульский технический университет, Стамбул, Турция)
Мохаммед Али Берави (Университет Индонезии, Депок, Индонезия)
Нанди Путра (Университет Индонезии, Депок, Индонезия)
Рангика Умеш Халватура (Университет Моратувы, Моратува, Шри-Ланка)
Сергей Сосновских (Университет Де Монфора, Лестер, Великобритания)
Сюзанна Дерст (Таллиннский технологический университет, Таллин, Эстония)
Кудрявцева Татьяна Юрьевна (Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия)
Тенгиз Маградзе (Грузинский технический университет, Тбилиси, Грузия)
Винченцо Бьянко (Университет Генуи, Генуя, Италия)
Вольфганг Дитер Герстльбергер (Таллиннский технологический университет, Таллин, Эстония)
Синьпэн Сюй (Гонконгский политехнический университет, Гонконг)
Чжикай Ван (Чжэцзянский университет, Ханчжоу, Китай)

РЕДАКЦИЯ
Ответственный редактор
Анги Схведиани.
Ответственный секретарь
Виктория Бразовская
Менеджер по развитию
Анастасия Кулачинская
Верстка
Владимир Никифоров

Учредитель
Санкт-Петербургский политехнический университет Петра Великого
Адрес:
195251, Россия, Санкт-Петербург, Политехническая 29

Контакты:
Почта: sustainable@spbstu.ru
Веб-сайт: https://sustainable.spbstu.ru/

Innovations and Territories: Sustainable Development in the Digital Economy Era

In conditions of elevated uncertainty, interest in ensuring enterprises' sustainable development and ability to quickly and efficiently diagnose and transform work and adequately respond to changes in their external and internal environments in the digital economy is sharply increasing. The implementation of digital technologies in all spheres is the most important condition for a country's sustainable development. Digitalising the economy is necessary to create convenient platforms that facilitate interactions between the state and enterprises, reduce the administrative burden on businesses and increase the efficiency and transparency of the economy and the entire system of public administration. At the present stage of development – digital – society is facing new management requirements, conditions and mechanisms. On the one hand, scientific and technological progress and breakthrough digital technologies are undoubted drivers of economic, technological and social development and open up new opportunities for improving various aspects of human life and the formation of regional innovation systems. On the other hand, the negative effect of the penetration of information and communication technologies into the sphere of relations developed in the pre-digital era can manifest as the disappearance of entire market segments or an increase in unemployment. The changes that are taking place do not concern a single sphere of human activity; they lead to systemic shifts that affect the stability of the entire economic system and each individual territory.

In the fourth issue of 2022 of the Sustainable Development and Engineering Economics journal, the authors examined various aspects of the sustainable development of enterprises and territories in the digital economy.

The first section, named 'Economics of engineering and innovation decisions as a part of sustainable development', consists of the article 'Connotation and development history of digital economy' by Rong and Gospodarik. In this study, the authors consider the history of the development of the digital economy, as well as its prerequisites and current state.

The 'Enterprises and the sustainable development of regions' section presents two articles. The first work, 'Model of global optimization and planning of research and development costs of an industrial region' by Rodionov, Koshelev, Gayomey and Ferraro, examines the patterns and prerequisites for the formation of regional innovation systems through the analysis and generalisation of a significant array of information on elements of interaction at the regional level based on economic and mathematical modelling. The second article, 'Organizational and economic model of innovation and resource potential management of a water supply enterprise in the context of sustainable development' by Furtatova, Viktorova and Wang, addresses the need to develop an organisational and economic model for managing the innovation and resource potential of water supply enterprises for their sustainable development.

To solve the problems of 'Sustainable development of regional infrastructure', Sayakbaeva, Akylbekova and Taalaibek consider the issues of migration processes in the Kyrgyz Republic in their article 'Diagnostics of migration processes for the sustainable development of the economy of the Kyrgyz Republic'. The authors note that migration processes have a significant impact on the republic's socio-economic situation and the balance of the labour market. Changes in economic and social status are often accompanied by changes in the educational and vocational training and the expansion of the needs of the people involved in the migration.

The final section, 'Management of knowledge and innovation for sustainable development', is based on the article 'Development of methodological provisions for rational material cutting in lean manufacturing at mechanical engineering enterprises', authored by Smirnov, Kobzev and Nuralieva, who note that in a market economy, ensuring the competitiveness and sustainable development of machine-building enterprises requires continuous improvement of business processes. In this article, the authors identify unsolved problems in the theory and practice of managing the business and non-business material resources obtained after cutting, which affect the waste disposal and the amount of time wasted during the cutting process.

Irina Rudskaia, *Editor-in-Chief, Doctor of Economics, professor*

TABLE OF CONTENTS

СОДЕРЖАНИЕ

SECTION 1

ECONOMICS OF ENGINEERING AND INNOVATION DECISIONS AS A PART OF SUSTANABLE DEVELOPMENT

РАЗДЕЛ 1

ЭКОНОМИКА ИНЖЕНЕРНЫХ И ИННОВАЦИОННЫХ РЕШЕНИЙ КАК ЧАСТЬ УСТОЙЧИВОГО РАЗВИТИЯ

Research article
DOI: https://doi.org/10.48554/SDEE.2022.4.1

Connotation and Development History of Digital Economy

Li Rong[1], Catherine Gospodarik[2*]

[1] Belarussian State University, Minsk. Republic of Belarus
[2*] Belarussian State University, Minsk, Republic of Belarus, gospodarik@bsu.by; Financial University under the Government of Russian Federation, Moscow, Russia, eggospodarik@fa.ru
Corresponding author: gospodarik@bsu.by

Abstract

With the spread of the COVID-19 pandemic, the digital economy has become a new engine of global economic growth, and new industries and economic models will continue to emerge. The digital economy has become a strategic high point of competition among countries and a new driving force of global economic growth in the new era, and all countries in the world are facing an important strategic opportunity period. This paper shows the value and potential of the digital economy by theoretically summarizing and analyzing its basic connotation, including its basic definition, development history, dissemination mechanism, and development law. The study released by the United Nations Conference on Trade and Development concluded that the epidemic crisis has intensified the digitalization process of the whole society, and the use of digital solutions, tools, and services has brought positive economic growth, which has also inspired many countries to find new breakthrough points for economic growth and accelerated the transformation of the global economy to digitalization. The digital economy in the post-crisis era will continue to accelerate this trend, and the underlying trends of the global digital economy will further strengthen, which will bring profound impacts and changes to digitally vulnerable countries. This presents an important research direction for studying the digital economy to enhance ESG development today.

Keywords: digital economy, development trend, information economy, network economy, smart economy

Citation: Rong, L., Gospodarik, C., 2022. Connotation and Development History of Digital Economy. Sustainable Development and Engineering Economics 4, 1. https://doi.org/10.48554/SDEE.2022.4.1

This work is licensed under a CC BY-NC 4.0

© Rong, L., Gospodarik, C., 2022. Published by Peter the Great St. Petersburg Polytechnic University

Научная статья
УДК 338
DOI: https://doi.org/10.48554/SDEE.2022.4.1

Значение и История Развития Цифровой Экономики

Ли Жун[1], Екатерина Господарик[2*]

[1] Белорусский государственный университет, Минск, Республика Беларусь
[2*]Белорусский государственный университет, Минск, Республика Беларусь, gospodarik@bsu.by; Финансовый университет при Правительстве Российской Федерации, Москва, Россия, eggospodarik@fa.ru
Автор, ответственный за переписку: gospodarik@bsu.by

Аннотация

С распространением пандемии COVID-19 цифровая экономика стала новым двигателем глобального экономического роста, в связи с чем будут постоянно появляться новые отрасли и экономические модели. Цифровая экономика стала стратегической точкой соперничества между странами и новой движущей силой глобального экономического роста в новую эпоху, и все страны мира сталкиваются с периодом важных стратегических возможностей. В этой статье показана ценность и потенциал цифровой экономики путем теоретического обобщения и анализа ее основного значения, включая ее базовое определение, историю развития, механизм распространения и закон о развитии. В исследовании, опубликованном Организацией Объединенных Наций по торговле и развитию, сделан вывод о том, что эпидемический кризис активизировал процесс цифровизации всего общества, а использование цифровых решений, инструментов и услуг привело к положительному экономическому росту, что также вдохновило многие страны на поиск новых точек прорыва для экономического роста и ускорило переход глобальной экономики к цифровизации. Цифровая экономика в посткризисную эпоху продолжит ускорять эту тенденцию, а развитие глобальной цифровой экономики будет усиливаться, что приведет к глубоким последствиям и изменениям в странах, уязвимых в цифровом отношении. Данная тема представляет собой важное направление исследований для изучения цифровой экономики с целью повышения эффективности развития других направлений, например, ESG.

Ключевые слова: цифровая экономика, тенденции развития, информационная экономика, сетевая экономика, умная экономика

Цитирование: Жун, Л., Господарик, Е., 2022. Значение и История Развития Цифровой Экономики. Sustainable Development and Engineering Economics 4, 1. https://doi.org/10.48554/SDEE.2022.4.1

Эта работа распространяется под лицензией CC BY-NC 4.0

© Жун, Л., Господарик, Е., 2022. Издатель: Санкт-Петербургский политехнический университет Петра Великого

1. Introduction

The concept of the digital economy is now widely used and studied. The definition of the "digital economy" is not a simple matter. According to a literature search, a considerable number of scholars attempted to define the digital economy from 1996 to 2018. With the development of Internet technology and the industrial economy, rapid changes in digital technology have led to changes in the economy of the world, the connotation of the economy has been enriched, and the boundaries have become increasingly blurred. Therefore, there is a need for an accurate redefinition of definitions. By collecting and collating literature on the understanding of the digital economy from the perspectives of governments and economic organizations in China, the US, Russia, Japan, the EU, and the OECD, we attempt to offer some generalizations about the changing understanding of the digital economy across countries. In addition to the origins and dissemination of the concept of the digital economy, research results, and issues, we also analyze the relationship between the digital economy and other related concepts, arguing that the essence of the digital economy is production by means of digital technology, which accurately reflects the essential characteristics of this economic form.

2. Literature review

Against the backdrop of slowing economic growth in countries around the world, the digital economy has shown vigorous development. According to Wenjun and Baowen (2019), the rapid development of the digital economy can provide a better matching mechanism and innovative power for the construction of China's modernized economic system. On the basis of sorting out the characteristics of China's development, the relationship between the digital economy and economic growth and its inner mechanism for promoting high-quality economic development are discussed at the micro and macro levels. Heping and Fuxiang (2021) constructed an evaluation system based on the dimensions of development environment, digital industrialization, industrial digitization, and digital governance, measured China's digital economy development index from 2016 to 2018 through the TOPSIS method, and put forward suggestions for a digital economy to promote high-quality economic development in China. Jiang (2022) discussed the value ontology of the digital economy in terms of both form and substance, distinguished the different meanings of "creating new value" in the industrial economy and in the digital economy, and separated the value ontology of the digital economy from the general exchange value. Yu (2021) analyzed the impact of four types of industrial policies—government subsidies, tax preferences, credit loans, and industry access systems—on industrial technology innovation in the digital economy using patent and financial data from digital economy listed companies in Shanghai and Shenzhen A-shares from 2008 to 2017. The results showed that government subsidies and industry access systems are still the more significant industrial policies affecting industrial technology innovation in the digital economy. There is industry heterogeneity in the influence of industrial policies on technological innovation in digital economy industries. Both government subsidies and credit loans can enhance the innovation ability of enterprises by increasing their R&D investment, while industry access systems and tax incentives can also enhance the innovation ability of enterprises by increasing their profits. Using Chinese household tracking survey data, He and Song (2016) empirically analyzed the impact of digital economy development on individuals' employment decisions. The results reveal that the digital economy dividend benefits the more educated group and helps alleviate the constraints of borrowing and insufficient resources for social connections for individual entrepreneurship, which can significantly facilitate their employment decisions. Gospodarik and Kovalev (2020) and Li and Gospodarik (2022) analyzed the main issues related to economic growth and the benefits associated with the implementation of digital economy innovation breakthrough scenarios in Eurasian Economic Union member countries through hybrid forecasting models and consensus forecasts. A study of the literature related to informatization, digital economy, and economic growth in China, Japan, Korea, Brunei, and Cambodia in the Asia-Pacific region revealed that the share of the digital economy is increasing in each country, and the development of the digital economy has a positive impact on economic growth (Rong, 2021).

Sustain. Dev. Eng. Econ. 2022, 4, 1. https://doi.org/10.48554/SDEE.2022.4.1

3. The Challenge in Defining the Digital Economy

3.1 The connotation of the digital economy

A. Origin and definition of the concept of the digital economy

It is not a simple task to define the "digital economy". According to a literature search of publications from 1996 to 2022, many scholars have attempted to define "digital economy". The difficulty in defining the concept is mainly due to the constant acceleration of the evolution of its structure, mechanisms, scale, and technological base, and the highly influential and driven changes in economic organization, economic systems, and even business models. In short, the digital economy is an extremely dynamic and increasingly complex concept. Moreover, traditional economic concepts are no longer adaptable to the digital economy. For example, the factors of production and cost concepts of the digital economy have drifted away from the traditional economy, and are even very different from it.

B. Early definition of the digital economy in various countries

The concept of the digital economy has been around for a long time. With the development of Internet technology and the industrial economy, it has been increasingly used and more widely, and the research on the connotation of the digital economy has also been enriched. However, the problem of unclear definitions of the connotation and confusion in the use of the concept remains. The definition of the digital economy varies from country to country, and the phrase "digital economy" first appeared in 1994. In 1996, the term first entered the industry literature, and in 1996, Don Tapscott, an American information technology (IT) consultant, published "The Digital Economy: Promise and Peril in the Age of Networked Intelligence", which not only highlighted "digital economy" in the title of the book, but also described various aspects of the digital economy in detail. Don Tapscott has been recognized as the "father of the digital economy". In 1999, Nicholas Negroponte, the founder of the MIT Media Lab, proposed a more influential definition, describing the digital economy as an economy of "from atoms to bits". This definition illustrates the network-based nature.

To promote the development of the digital economy, governments have begun to offer their own understanding of the concept of the digital economy. The first country to define the digital economy was Japan in the May 1997 report, in which the digital economy is one with four characteristics: it is possible without the physical movement of people, objects, and money; it electronically accomplishes contracting, value transfer, and asset accumulation; it allows the development of IT, which is the foundation of the economy, at a rapid pace; and it supports the broad expansion of electronic commerce. From this definition, it is clear that the Japanese government describes the digital economy as electronic commerce in a broad sense. In the 1990s, the US economy experienced high growth, low inflation, and low unemployment, which most people attributed mainly to the application of IT. In 1998, the US Department of Commerce released The Emerging Digital Economy, a report on the digital economy that captured e-commerce and the IT (information technology) industry that makes e-commerce possible as two aspects of the digital economy (see Table 1, Henry et al., 1999). Specifically, e-commerce is a means of conducting transactions, whereas the IT industry is the engine of change in the digital economy and the foundation that supports e-commerce. In October of the same year, the US Bureau of Statistics further proposed a specific scope of the digital economy based on this definition, which includes inter-networking, e-commerce, e-enterprise, and online transactions, and gave specific definitions accordingly. The US definition of the digital economy focuses on the digital economy as the sum of measurable e-commerce and IT industries (Mesenbourg, 2001). The US judged the arrival of the digital economy from the government's perspective and began to design measurement indicators, collect data, and include the digital economy in official statistics. Emerging Digital Economy II and Digital Economy 2000 were released one after another (Buckley, 1999, 2000). The concept of the "digital economy" has been widely used in society since then.

Table 1. US Department of Commerce Digital Industry Classification (1998)

Digital Industry	Industry Content	Digital Industry	Industry Content
Hardware manufacturing	Computers and computer equipment Computer wholesale and retail trade office computing equipment Optical and magnetic recording equipment＊★ Electronic tubes Printed circuit boards Semiconductor-related equipment Passive electronic components ★ Industrial measurement instruments Current measurement instruments and laboratory analysis instruments	Software and Computer services	Computer programming services Pre-installed software※ Software wholesale and retail trade Computer system design Computer data processing Information retrieval services* Computer service management※ Computer rental and repair Other computer-related services
Communication equipment manufacturing	Home audio-visual equipment★ Telephone equipment Radio and television communication equipment	Communication service industry	Telephone communication Broadcasting industry※ Television industry※ Cable TV and other pay TV services※

Source: Buckley et al., 2000

Note: ★ represents new industries or the change of industry name, ※ is the change of industry classification, ＊represents the deleted industries.

Sustain. Dev. Eng. Econ. 2022, 4, 1. https://doi.org/10.48554/SDEE.2022.4.1

Table 2. US Department of Commerce digital industry classification criteria (2002)

Digital industry	Industry content	Digital industry	Industry content
Hardware manufacturing	Computers and computer equipment Office computing equipment Computer wholesale and retail trade Electronic tubes Printed circuit boards Semiconductor-related equipment Various electronic components a★ Industrial measuring instruments Current measurement instruments, laboratory analysis instruments	Software and computing services	Pre-installed software※ Software wholesale and retail trade Computer system design Computer data processing Information retrieval services* Computer service management※ Computer rental and repair Other computer-related services
Communication equipment Manufacturing	Audio-visual equipment★ Telephone equipment Radio and television communication equipment Optical fiber★ Software replication★ Optical and magnetic recording equipment ✶	Communication Services	Telephone communications Broadcasting industry※ Television* Cable TV and other pay TV services※

Source: Margherio, Lynn, et al. The emerging digital economy.

Note: ★ represents new industries or the change of industry name, ※ is the change of industry classification, ✶ represents the deleted industries.

Rapid changes in digital technology have led to rapid changes in the scope of the digital economy. A comparison of Table 1 and Table 2 of the US Department of Commerce's 1998 and 2002 digital industry classification standards shows that more than 20 industries covered by the digital economy have undergone more than a dozen changes in just four years. Industries such as fiber optics, software publishing, software replication, programming services, equipment management, cable, and satellite communications were added to the digital economy, and industries such as radio, television, and information retrieval services were removed. The structure of the digital economy has made it quite difficult to define it by industry, and the human economic ecology has changed like never before. At almost the same time, the development of big data, cloud computing, artificial intelligence, and the creation of instant messaging software, such as Facebook, Telegram, and WeChat, have made the form of the Internet economy more diverse. Second, the iterative development of search engines (such as Google, Yandex, and Baidu) has significantly improved the comprehensiveness and accuracy of the query, the development of search engines to help the original e-commerce, and its own application boundaries are blurred.

Lastly, the rapid development of the mobile Internet has made the economic forms covered by the digital economy expand again, and the opening of geolocation-based services has injected new momentum into the economy. The new economic forms represented by the sharing economy have also joined the ranks of the digital economy.

C. Definition of digital economy by various countries and organizations nowadays

The term digital economy is currently used everywhere in government, industry, academia, and the media to describe the economic phenomena arising from the IT revolution. A search for "digital economy" in Google found 7.92 million results (June 25, 2022 search), and a search for the same term in Baidu found 1 million results (June 25, 2022 search). The OECD has been measuring the digital economy for many years and uses the digital economy in the titles of its reports, such as the OECD Digital Economy Outlook 2020[1]. The rising difficulty in defining the digital economy has led to a divergence of definitions across countries, but almost all stakeholders agree that the digital economy is an economic form brought about by IT and informatization, which is common to current research across countries. Research scholars in all countries agree that IT and informatization have brought about a digital economy. For example, Chohan U. argued that the digital economy, based on the economy of digital computing technology, is a business conducted through the marketplace based on the Internet and the World Wide Web (Chohan, 2020). According to Zhou X et al. (2022) the economy in which various social activities are based on the numbers of 0 and 1, which can be used to describe the flow of numbers dynamically, is called digital economy. According to Zhao Y. and Wang Zh. (2003), the digital economy is based on information and communication technology. Through the Internet, mobile communication networks, and the Internet of Things (IoT), the digitalization of transactions, communication, and cooperation has been realized to promote the development and progress of the economy and society (Jian and Xinmin, 2013). Deloitte reported in 2020 (Cassar et al., 2020) that it is based on the interconnection of people, organizations, and machines generated by the Internet, mobile technologies, and the IoT, which originates from billions of daily online connections between people, businesses, devices, data, and processes. The OECD (2014) considers the digital economy to be underpinned by the spread of ICT across all business sectors to enhance productivity.

China, Korea, and Russia all perceive the digital economy as an economic activity, although with different emphases. China proposed in the 2016 G20 Initiative on Digital Economy Development and Cooperation that "the digital economy refers to a series of economic activities in which the use of digital knowledge and information is a key factor of production, modern information networks are an important carrier, and the effective use of ICT is an important driving force for efficiency improvement and economic structure optimization", emphasizing that the digital economy is a collection of information and communication main industries and industrial integration. The National Bureau of Statistics[2] of China in G20 and the CPC Central Committee's proposals for formulating the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and the Long-Range Objectives Through the Year 2035 released the "Statistical Classification of Digital Economy and Its Core Industries (2021)". Russia, by contrast, specifies in its definition that the digital economy is an economic activity that safeguards national interests. The Russian Federation has published the "Digital Economy Plan of the Russian Federation"[3], in which it defines the digital economy as an economic activity that uses digital or ITs in production, management, administration, and other processes for the purpose of ensuring the national interests of the Russian Federation, including the improvement of the standard of living of the population and the competitiveness of the national economy. In Korea, the definition is more general and directly describes the digital economy as all economic activities based on the information and communication industry, including the Internet. This includes electronic transactions, Internet shopping, search services, etc.

The US, France, and the OECD, however, still place their focus on the measurement of the digital

[1] OECD Digital Economy Outlook 2020. Available at: https://www.oecd.org/sti/ieconomy/oecd-digital-economy-outlook-2020-bb167041-en.htm
[2] The National Bureau of Statistics, Statistical Classification of Digital Economy and Its Core Industries, 2021. Available at: http://www.stats.gov.cn/tjsj/tjbz/202106/t20210603_1818134.html
[3] On the approval of the program "Digital Economy of the Russian Federation". Available at: http://government.ru/docs/28653/

economy. On November 18, 2016, the US Bureau of Economic Analysis Advisory Committee stated in its showcase report Measuring the Digital Economy that measuring the digital economy should include, in addition to the e-commerce component, new digital services, such as the sharing economy, such as shared rides and advertising-supported free Internet services. France defines the digital economy from an industry perspective. The Digital Economy Monitoring Center under the French Ministry of Economy and Finance defines the digital economy as industries that depend on information and communication technologies, while the French Digital Economy Association considers the digital economy to include the telecommunications industry, the audiovisual industry, the software industry, the Internet industry, and those industries that need to use telecommunications, audiovisual, software, and Internet technologies to support their own activities. The OECD continues to define the digital economy as trade in goods and services enabled and conducted through electronic commerce (Strassner and Nicholson, 2020).

The UK focuses on understanding the digital economy in terms of output and considers the digital economy as the creation of socio-economic benefits through complex relationships between people, processes, and technologies. The "digital economy" refers to the total economic output generated by various types of digital inputs. Digital inputs include digital skills, digital devices (hardware, software, and communication devices), and digital intermediate goods and services used in the production chain. On December 19, 2018, Australia's Department of Industry, Innovation and Science released a strategy report entitled "Australia's Tech Future – Delivering a strong, safe, and inclusive digital economy", a strategic report designed to enable Australians to enjoy the improved quality of life enabled by technology, involve businesses to seize the opportunities of a rapidly growing modern economy, and compete globally. It sets out the measures needed to develop a strong digital economy in Australia in seven areas: skills, inclusion, digital government, digital infrastructure, data, cybersecurity, and regulation[4].

Most developed countries have recognized the importance of the digital economy earlier and have made a strategic layout of it. The US was the first country in the world to lay out the digital economy, and in the 1990s, the Clinton administration launched the "information superhighway" strategy, focusing on big data, artificial intelligence, smart manufacturing, and other areas to promote the development of the digital economy as the key to achieving continued prosperity and maintaining competitiveness. The UK was the first country to introduce a digital economy policy, releasing Building Britain's Future Plan in 2009, which was the first time digitalization appeared in the form of a national top-level reality. Subsequently, all countries have started to implement various strategies for the development of the digital economy according to their own definitions, although developing countries have lagged behind in the layout of the digital economy, and most of them have only started to lay out relevant strategies in recent years.

It is difficult to define the digital economy specifically, mainly because the evolution of the structure, mechanism, scale, and technological base of the digital economy is constantly accelerating and highly influencing and driving changes in economic organization, economic systems, and even business models. The concept of a traditional economy has been difficult to adapt to the digital economy. In the 1990s, it was easier to distinguish between the digital economy and the non-digital economy, but now it is increasingly difficult to make such a distinction. In the past half century, the digital economy has undergone a transformation from being insignificant in the traditional economy to occupying half of it. Now, the digital economy is entering a new stage in the history of transforming the traditional economy, and the general trend is that on the one hand, the scale of the digital economy is expanding, and on the other hand, the traditional economy is digitizing; it is somewhat analogous to a "solar eclipse", in which a new economy covers the traditional economy (Fig. 1).

[4] Digital Economy Act, 2010. UK Public General Acts. Available at: http://www.legislation.gov.uk/ukpga/2010/24/contents

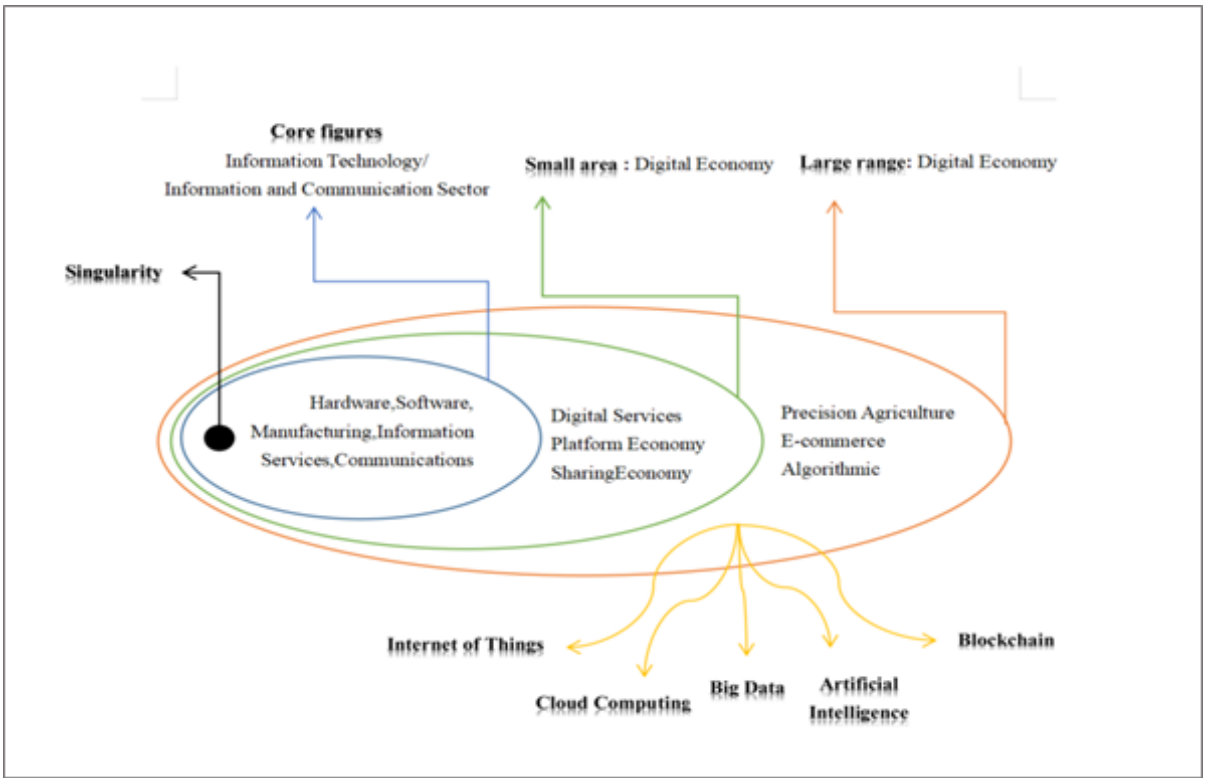

Figure 1. Conceptual evolution of the digital economy

Source: compiled by the authors

3.2 Digital economy development history

As a new economic model, the digital economy is the most important economic form, after the agricultural economy and industrial economy. It can be traced back to the information economy that emerged around the 1940s, which has experienced more than 70 years of development and has had a profound impact on the world's economic, political, and technological landscape. By combining the history of the development of the digital economy, we find that the development of the digital economy can be roughly divided into four stages.

A. The budding stage of the digital economy

In 1946, the US Department of Defense developed the world's first general-purpose computer, the ENICA, marking the official start of the digital economy. In the mid-1950s, the emergence of transistors led to the development of miniaturized computers, and in 1954, IBM built the first computer using transistors. In the mid-1960s, the invention of integrated circuits led to a revolution in circuit design, and in 1964, IBM developed the first general-purpose electronic computer using integrated circuits, the IBM 360. In 1971, Intel developed the world's first microprocessor, 4004, and the era of microcomputers based on microprocessors began. The software also appeared in standardized programming language, human-computer conversational BASIC language, and so on. From the technical development characteristics, with the progress of integrated circuit design and processing capabilities, the rapid development of computer core processing and storage technology, the size of the computer continues to shrink, the price also continues to decline, the reliability of enhanced, and faster computing speed. During this period, IBM and Hewlett-Packard occupied most of the market share of mainframe computers and minicomputers, respectively.

B. The first singularity of the digital economy explosion (1961–2008)

Compared with the traditional non-digital economy, the process of digital economy generation is peculiar. The starting point was neither material, labor, nor production, but ideas, and the idea that such

ideas could lead to a new economic form is called "singularity". At that time, there were already two types of information and communication in the world. In the United States, for example, AT&T was already a very large company, supporting a huge world communications network. However, there was a limit to the amount of information that could be transmitted by either telegraph or telephone. When the telephone is overloaded, occupied lines and busy signals occur. Obviously, new ideas are needed to solve the communication problem of information. For example, is there a way to decompose large-scale information, send it out through a form of network, and reassemble the deconstructed information afterwards. In 1969, the four nodes of UCLA, Stanford University, UC Santa Barbara, and the University of Utah were successfully networked through ARPANet. Human society has since entered the network era, laying the foundation for the infrastructure of the digital economy. In the 1970s, cables to support the Internet began to be laid globally, connecting the world and forming a physics infrastructure to support the digital economy. The emergence of the Internet can be traced back as far as the ARPAnet established by the US Department of Defense in 1969, and over the course of its subsequent development, backbone networks, such as the NSFnet (1986) and the World Wide Web (1989), were gradually formed. During the development of the Internet, a number of historical milestones occurred, such as the birth of the e-mail "@", the development of the Transmission Control Protocol (TCP), and the first registered domain name, Symbolics.com" wave, as well as the impact of Microsoft Windows and the formation of the Hyper Text Transfer Protocol (HTTP) rules in 1989.

From the 1970s to the 1980s, the development of the Internet surged forward. 1977 saw the founding of Oracle Corporation and the development of a commercial SQL database. Japanese companies also began to enter the IT field, with NEC, Sharp, and Toshiba using memory as an entry point to achieve rapid growth in the field of semiconductor chips. Toshiba also designed the world's first laptop computer, and NEC and Fujitsu exported supercomputers to the world. In the field of mobile communication, mobile communication technology began to develop rapidly after the 1970s, and Qualcomm was established in 1985 to rapidly transform the original military communication technology, CDMA, into civilian use.

From the mid-1990s to the beginning of the new century, the network economy developed rapidly, along with the development of personal computers and network technology. In 1993, the US Clinton administration launched the "Information Superhighway" strategy, vigorously promoting the construction of information infrastructure, marking the entry of computer networks into the information superhighway development stage. In 1990, Archie was the first Internet search engine. In 1994, Netscape was established and developed the Navigator browser, and the market value of the stock reached billions of dollars on the first day of listing, which triggered the explosive growth of the IT industry, with the Internet as the core of IT. As the core of the Internet, IT began to penetrate all aspects of society and economics. In the search service, Yahoo and Google were established in 1995 and 1998, respectively. In the field of e-commerce, Amazon and eBay were founded in 1995 to challenge traditional commerce, and Netflix was established in 1997 to expand online movie rentals. Further, CISCO, 3COM, and BNC, the three major suppliers in the network hardware field, became the main beneficiaries, with revenues reaching US$1 billion. In China, Internet companies such as Tencent (1998), Alibaba (1999), and Baidu (2000) also started to take off. Since then, the digital economy has ceased to evolve non-consciously, and these emerging economic entities' platforms have become leaders and started to dominate the process of the digital economy explosion.

The boom in the development of the network economy reached its peak in 2000, as the speed of computing, storage size, and network speed of personal computers increasingly became the shackles of emerging economic development, making many business models that can be widely used today without effective technical support, and the development of the network economy far outpaced the development needs of the real economy, eventually leading to the bursting of the network economy bubble in 2000. In the 7th year after the burst of the Internet bubble in 2000, the subprime mortgage crisis (2007) broke out in the US, and the following year in 2008, a global financial crisis broke out that not only affected traditional economic sectors, but also involved the emerging digital economy. The impact of this crisis has been profound and long-lasting.

C. The second singularity of the digital economy explosion (2008–2014)

Under Moore's Law, with the geometric growth of computing speed, storage scale, and network speed of personal computers, the continuous progress of mobile communication technology, and the emergence of smartphones, the once-broken network economy ushered in another wave of prosperity driven by the new technology represented by mobile Internet and entered the mobile Internet era from PC Internet. In the field of mobile communication, mobile communication technologies, such as 3G and 4G, have gradually been put into use. In the mobile aspect, Apple launched the iPhone smartphone in 2007 and released the IOS operating system the following year. Samsung and other companies quickly followed, overturning the position of traditional cell phone manufacturers represented by Nokia and Motorola. In terms of Internet enterprises, new digital economic entities represented by social networking platforms have taken the stage of history, and Internet 1.0 companies represented by Yahoo are gradually replaced by Internet 2.0 companies, such as Alipay (2003), Facebook (2004), YouTube (2004), Twitter (2006), and WeChat (2013). Airbnb (2008), Uber (2009), and other sharing economy models began to lead the way. Among these, the Uber model has obvious innovative features (Fig. 2). In terms of the new generation of IT, cloud computing was officially introduced in 2006, and it has become a trend in the IT field. Satoshi Nakamoto's paper[5] soon spawned the first blockchain and the first bitcoin. His paper on Bitcoin triggered another type of sustained explosion in the digital economy that changed the perceived inertia of wealth. In this sense, the two Big Bang "singularities" are strikingly similar: both came from a single idea, both took the form of published papers, and both had negligible weight in material form.

When Bitcoin was first traded, 400 bitcoins were exchanged for $1 (equivalent to $0.0025, or RMB 0.17, for one bitcoin). The price of bitcoin has had its ups and downs, but today it is in the tens of thousands of dollars. On November 8, 2021, the highest price of bitcoin was $67,556: as of January 1, 2022, the price was $47,137 (down 30.22%), and the market cap was $887.92 billion (down 29.52%). Bitcoin originated with an idea, an article, and a development process that was much shorter in time and exploded with a much larger equivalent than the dramatic changes in the digital economy triggered by Leonard Kleinrock's paper in 1961 and the changes triggered by Satoshi Nakamoto's Bitcoin article. In 2013–2014, the second big change in the digital economy sparked by Satoshi Nakamoto's article was by a 20-something Vitalik Buterin, who brought about the birth of Ether (Ethereum) (Buterin, 2014). Ethereum became an open source and public blockchain platform with smart contracts, or the next generation of cryptocurrencies and decentralized applications. In 2014, Ether 1CO was successfully crowdfunded, and Ether became the second largest cryptocurrency. The highest price of Ether occurred on November 8, 2021, with a price of $4,812, and a market cap of $569.09 billion. As of January 1, 2022, the price of Ether was $3,700.34, with a market cap of $440.5 billion.

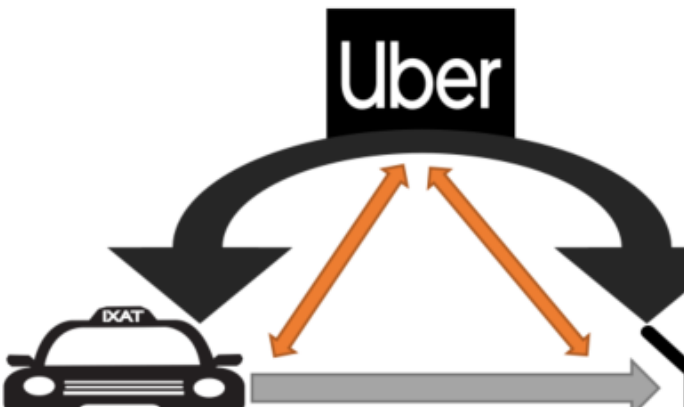

Figure 2. Uber Operating Mode

Source: compiled by the authors

[5] Nakamoto, S. Bitcoin. Available at: https://bitcoin.org/bitcoin.pdf

Buterin's creation of Ether is a big event in the history of crypto-digital currencies since 2008, which constituted the scale and stimulated the expansion of the blockchain application atmosphere. Due to Bitcoin and Ether, the number of crypto-digital currencies worldwide has exploded, and the digital economy driven by blockchains has become more vibrant. Digital currencies have continued to heat up in recent years, with Bitcoin currently having the highest market capitalization at over $700 billion, and the combined market capitalization of the top 15 cryptocurrencies ranked as of January 1, 2022 is over 1.2 trillion dollars. If we use the world's GDP as a reference, the total market capitalization of cryptocurrencies will be more than $2,244.1 billion as of January 2022, according to CoinMarketcap. This figure is close to the GDP of Switzerland in 2020 and exceeds that of Turkey and Saudi Arabia. There are no more than 20 countries in the world, with a GDP of more than $800 billion. Compared to the total market cap of $191.542 billion at the beginning of 2019, the entire digital currency market is up by $2052.56 billion, an increase of about 11 times year over year. The birth and development of digital currencies are inextricably linked to blockchain ideas and technologies, and the development of digital currencies has strong and constantly improving technical support, the core technology of which is the blockchain. The book "Blockchain Economics: Implications of Distributed Ledgers-Markets, Communications Networks, and Algorithmic Reality" by Melanie Swan (2016) and five other American scholars explains the new economic models that have emerged in the field of blockchain economics with the implementation of blockchain technology through distributed ledger technology (Long and Ascent, 2020).

The current acceptance of cryptographic digital currencies varies from country to country, but many countries are enthusiastic about the underlying blockchain technology that reduces social costs, improves social efficiency, and enhances the transparency of transactions. Cryptographic digital currencies are still one of the most popular blockchain applications, and the cryptocurrency industry chain is mainly focused on hardware manufacturers and trading platforms. There is still a long way to go in terms of popularization among the general public, but the rapid development of cryptographic digital currencies has driven the rapid development of the digital economy industry.

D. Digital economy in transition (2014–Present)

Since the first digital economy "singularity" in the 1960s, and the second digital economy "singularity" triggered by the birth of Bitcoin in 2008, there has been and is a "superposition effect", leading to a new digital economy explosion. We are now at the junction of the two "singularities". In terms of the history of the digital economy, "Singularity 1" is the digital economy trend that emerged from the 1960s–2010s based on the ICT industrial revolution, with the curve declining around the year 2000. "Singularity 2" is the new journey of the digital economy that originated from the Bitcoin blockchain. When the two curves intersect, why they intersect, and what the characteristics of the intersection are inconclusive for now, but the digital economy has reached a point in its history where it has developed new financial and monetary instruments to transform the capital model on its own (Fig. 3). In recent years, the digital economy has begun to form to reach a complete industrial chain and value, and the transformation to a new economic form, the intersection point, may arrive in the near future. The digital economy is now in the middle of a superposition process of two types of digital economy explosion, and continues to generate enormous energy, and it is certain that the superposition effect contributes significantly to the GDP, so that all countries benefit from it.

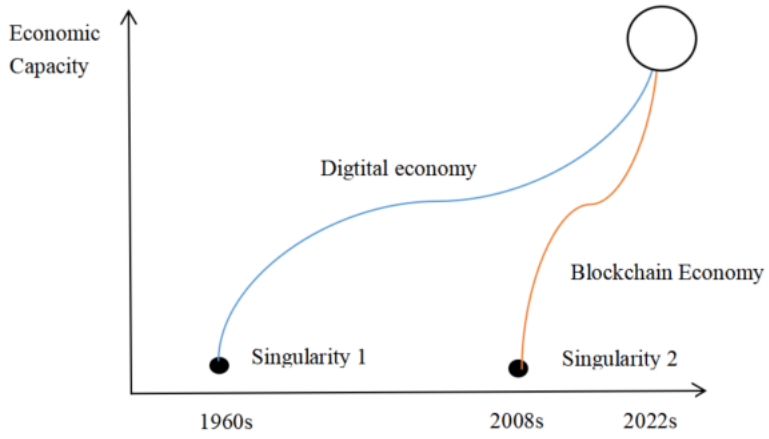

Figure 3. Digital Economy Explosion

Source: compiled by the authors

In 2016, the technological foundation of the digital economy came to a critical point in time, and a new digital economy change was quite brewing (Aitken, 2016). The key foundation of IT—microelectronics technology with integrated circuits as the core—will enter the 7 nm level from the current stage of 14 nm, and the manufacturing process is constantly approaching the physical limit. The traditional Moore's Law that will also come to an end, the digital economy will develop toward the IoT, cloud computing, big data, the IoT, AI intelligence, and so on. From the International Telecommunication Union (ITU) established in 2005 to formally putting forward the concept of the IoT after 15 years of cultivation and exploration, the global IoT is moving from the initial stage of fragmentation, isolated application-oriented into a new stage of focus, cross-border integration, and integrated innovation.

After the accumulation of technology in the early stages, cloud computing has entered a comprehensive explosion stage since 2016. According to Cisco's statistics, global cloud data center traffic will reach 19.5 ZB per year in 2021, cloud data center traffic will account for 95% of total data center traffic, compared with 88% in 2016, and the number of IoT connections will reach 13.7 billion, up from 5.8 billion in 2016 (Swan, 2017). Cloud service applications have penetrated all industries and become an important force for digital transformation in many industries. Big data is now widely used by governments and enterprises in decision-making, transportation, logistics, finance, advertising, telecommunications, healthcare, entertainment, and agriculture. According to the Cisco 2020 Internet Report, 5G will support more than 10% of the world's mobile connections by 2023, more than 70% of the world's population (5.7 billion people) will have a mobile connection (2G, 3G, 4G, or 5G), and 66% of the world's population (5.3 billion people) will be Internet users. With continued growth in mobile applications driven by social networking, video streaming and downloading, enterprise productivity, e-commerce, and gaming, the number of downloads will approach 300 billion by 20236.

According to IDC estimates this year, global Big Data market spending will reach approximately $298.3 billion by 2024, achieving a compound growth rate (CAGR) of approximately 10.4% from 2020-2024 (over 5 years). Meanwhile, China's big data spending as a whole is growing steadily, and the total market is expected to exceed $20 billion in 2024, an increase of 145% compared to 2019. The CAGR of China's big data market over the next five years is about 19.7%, leading the world in growth7. Nowadays, the digital economy has constituted a new ecosystem, from ICT to the knowledge industry, finance, and insurance, retail, all the way to the traditional processing industry, and the healthcare industry can see the length and future trend of the impact of digitalization on it. Now, any enterprise urgently needs to realize the transformation of digitalization or "algorithm", otherwise, it will not be able to coordinate

[6] New Cisco Annual Internet Report Forecasts 5G to Support More Than 10% of Global Mobile Connections by 2023. Available at: https://newsroom.cisco.com/press-release-content?type=webcontent&articleId=2055169

big data processing, the intervention of AI intelligence, and the embedding of blockchain, which will eventually ensure that enterprises can survive in the space and time dimension of the growing digital economy.

4. Results

4.1 Structural characteristics and development rules of the digital economy

A. Influence of Moore's law and Metcalfe's law

Two laws are often mentioned in the structural development of the digital economy: Moore's law and Metcalfe's law. Moore's law was proposed by Gordon Moore, one of the founders of Intel, in 1965 and originally described that the number of components that an integrated circuit can hold doubles approximately every 18-24 months with a doubling of performance at a constant price7. Moore's law reveals the speed of IT's progress (Keyes, 2006).

Metcalfe's law was introduced by George Gilder in 1993 but named after the last name of Robert Metcalfe, a computer networking pioneer and founder of 3Com, to honor and recognize his contributions to Ethernet. Its core is that the value of a network is equal to the square of the number of network nodes, and the value of a network is proportional to the square of the number of connected users. Metcalfe's law reveals the rule that the value of the Internet grows arithmetically or quadratically as the number of users grows. According to Metcalfe's law, the more users a network has, the greater the value of the entire network and each computer within that network—that is, the value of the network $V = K \times N2$ (K is the value factor and N is the number of users). The Internet has been growing exponentially since 1990, and its explosive penetration and expansion into all spheres of the economy and society have confirmed this law.

B. The wide application of ICT technology

Under the effect of Moore's law, the relative price of ICT products continues to fall, and investment in ICT continues to increase, making ICT a new driving force for economic development by largely replacing other factors of production, such as labor and capital. In the traditional manufacturing industry, industrial robots, AI, big data, and other information technologies are being used on a large scale. While reducing the demand for general labor and greatly improving production efficiency, ICT can simultaneously optimize the ability to transmit, process, and store information, thus enhancing the level of informatization of social life and industrial production. Since economic growth efficiency is generally expressed through total factor productivity (TFP), the study of ICT and economic growth efficiency is transformed into a study of the relationship between ICT and TFP. Based on the results of the analysis of 10 countries in Southeast Asia, we found that ICT contributes to the improvement of TFP, which means that ICT can improve economic growth efficiency.

There are two main paths for ICT to enhance economic growth efficiency: first, ICT is used to build an informatization network; the more network users there are, the greater the value of the informatization network, the greater the role of ICT for informatization spillover and diffusion, and the greater the role of ICT capital in contributing to TFP through network effects, thus enhancing economic growth efficiency; second, ICT can play a great role in enhancing the synergy among various elements in the production process of enterprises, solving the problem of information asymmetry, improving the efficiency of the IT production sector, which also has a positive effect on the IT using sector, and the TFP of each sector is improved, and the efficiency of economic growth is also improved.

C. Innovation by emerging technologies and talent-intensive output

The digital economy is a technology- and talent-intensive sector with the strongest innovation dynamics and the most pronounced boost to TFP, and it is often the main driver of economic recovery

[7] China Internet Network Information Center. Available at: https://www.cnnic.com.cn/

in economic downcycles. Innovative companies in the digital economy influence the economic environment under a crisis shock from two aspects: on the one hand, they can provide support and cushion the overall downward economy; on the other hand, in the economic recovery phase, innovative companies will rise rapidly and grow to lead the industry and even the whole economy as an engine with the advantages of technology and experience, while continuously exporting positive externalities to the economy. In the late 1970s, the world economy fell into a trough, affecting many developed countries. In this context, some economies took a different approach to revive the economy, no longer relying on traditional industries. Instead, they took the lead in supporting the country through the crisis by developing the digital economy, making it the leader in leading the economy out of the gloom. The regions of Emilia and Tuscany in central and northeastern Italy ("Third Italy"), Baden-Württemberg in Germany, Auyenax in France, Jutland in Denmark, Smyrna in Sweden, Barcelona in Spain, and Silicon Valley in the southern part of San Francisco in the US are all typical cases of new economy-led economic recovery. The 2019 PCT (patent cooperation treaty) application data released by the World Intellectual Property Organization show that computer technology and digital communications ranked in the top two of all technology areas, with digital economy-related companies occupying six of the top ten seats.

D. The digital economy has changed the industrial structure

Through the development of the digital economy, it can be found that the development of the digital economy has the following five major rules: it has risen from a mere industrial issue to a development question in terms of status. The digital economy is a new form of economic and social development following agricultural and industrial economies. It has upgraded and reshaped human society from multiple dimensions. In terms of production factors, with the advancement of new generation information and communication technologies, such as big data and artificial intelligence, data has become an important production factor in the new round of industrial competition, surpassing land and labor in agricultural civilization. Among the machines and equipment in the first industrial revolution and the capital in the second industrial revolution, whoever has information and data can take the lead in the digital era. In the construction of infrastructure, information and communication technologies are less costly and more efficient than traditional transportation infrastructures, such as railroads and highways, and will play a more important role in modern society, where the digital economy is increasingly critical. This is because of the borderless nature of the Internet. Therefore, in the era of the digital economy, the Internet closely connects all countries, and no country can be excluded from the wave of informatization. In the field of social life, the new generation of communication technologies has changed people's office and social habits, and the work and life patterns of the digital age are gradually being built up.

Technology and the market become the twin core drive of digital economy development, in which technology is the basic driving force to provide technical source assurance for the development of the digital economy, while the market application feedback makes the digital economy bigger and stronger. Take virtual reality (VR) as an example. As early as 1965 in the US, Ivan Sutherland's presentation during the IFIP conference entitled "The Ultimate Display" was an ultimate display of this concept. However, due to the lack of hardware capacity, algorithm defects, and other technical reasons of the 1980s, the development of VR technology was slow until the late 1980s, when the rapid development of information processing technology contributed to the progress of VR technology. After IT was invented and created, it was only with the impetus of the market that it could acquire a faster pace of development. For example, the Internet was first developed by the US military and began to be used in the military field in 1969, not open to the market. In 1980, the US began to popularize the Internet in academic institutions, and in 1989, commercial Internet service providers were established. In 1995, the Internet was fully commercialized in the US, bringing huge economic benefits to US enterprises.

Talent and data are the core elements of digital economy development, among which talent with high digital literacy is the most important resource in future digital economy development, while data is the main business kernel of today's society and future digital economy development. In the digital economy, especially in asset-light Internet enterprises with high technology content and data, highly skilled

talents are the core competitiveness of enterprise development. Further, data resources have the endowment of being analyzable, shareable, infinite growth and supply, breaking the constraints of a limited supply of traditional natural resources on growth and becoming a key production factor and an important resource for the development of the digital economy. With the progress and gradual popularization of IoT and Internet technologies, data interfaces are growing geometrically, and data storage technologies and data security precautions are constantly upgraded, making data an important strategic resource for individuals and enterprises and a core element of the digital economy. Data from the Internet Data Center (IDC) shows that the world created about 64 ZB of data in 2020, and by 2025, the global total data will reach 163 ZB, of which enterprises will account for 60%.

Close cooperation between industry and research is an important foundation for the development of the digital economy. Looking at the development history of the digital economy, we find that digital technologies often start with military needs and spread to the civilian sector after mature applications in the military field. From historical experience, once the high-quality innovative resources and technologies that have long been accumulated in strategic national security science and technology fields are accelerated and shared with the civilian sector and combined with market demand, they will stimulate endless innovative vitality and give rise to a large number of new technologies, products, and industries. For example, the US—from the "Manhattan Project" and the "Apollo Project" to the "Star Wars Project"—has attached great importance to the cooperation between government and enterprises on the pulling effect of science and technology innovation on industrial upgrading. The role of basic research is organically linked to overall national goals. This makes it the key to the development of the digital economy, with computers, the Internet, wireless communications, data security and recovery, and wireless video transmission as typical representatives.

Emerging small- and medium-sized high-tech enterprises are more innovative and dynamic. Small and medium-sized enterprises with flat organizational structures and management are more likely to develop into leading enterprises in an emerging field and lead the development of the industry to which they belong in the future for a period of time. In Europe and the US, for example, in each window of the digital technology revolution, a number of emerging IT companies emerged and formed a corresponding leadership position.

4.2 Measuring the digital economy

In the post-epidemic era, the digital economy is taking the development of human society into a whole new world. New approaches to leapfrogging are being developed, and new industries and economic models are emerging. The post-epidemic digital economy is rapidly evolving across sectors and industries, breaking down geographic constraints and becoming highly cross-cutting. This makes it impossible for governments and international organizations around the world today to fully measure the scale of digital economy development, and the construction of a digital economy development index is critical for understanding the current status and trends of the global digital economy. The digital economy is changing global economic activities through various forms of penetration, and also bringing new elements and ideas to various fields.

Measurement of major digital economy countries

As the digital economy continues to evolve, the European Union, the US Department of Commerce, the International Telecommunication Union, the World Economic Forum, the OECD, and the China Academy of Information and Communications Technology have all proposed building their own measurement standards and systems. For example, the OECD released "Measuring the Digital Economy a New Perspective". The Digital Economy and Society Index (DESI) was published by the European Commission, the Networked Readiness Index (NRI) was published by the WEF, the ICT Development Index (IDI) was published by the International Telecommunication Union (ITU), and the Digital Economy Index (DEI) was constructed by the China Academy of Information and Communication Research.

Table 3. Major Digital Economy National Measurement Standards

Country or region	Institution	Name of measurement system	Method of use	Date of publication
OECD Member	OECD	ICT Digital Economy Statistical Indicator System	Index Development Methodology	2014-2021
EU countries	European Commission	DESI		2014—2021
130 Economies	WEF	NRI		2002—2021
ITU Member States	ITU	ICT Development Index		1995—2017
CHINA		Digital industrialization, digitalization of industry Infrastructure	Infrastructure and fee-based digital services	2017—2021
US	Bureau of Economic Analysis	Infrastructure and fee-based digital services		2016—2021

Source: compiled by the author.

There is wide variation among countries and institutions in terms of measurement methods, regional scope, indicator content, and measurement results. The literature analysis shows that the digital economy measurement methods mainly focus on the indexing method and the value-added measurement method. At present, the digital economy is a concept of economic form, named after the outstanding features of that period. Although the conceptual content of the digital economy will continue to change with the expansion of the scope of the digital economy, measurement, and accounting indices have not yet formed a unified standard. As a result, the statistical results vary greatly. However, governments and international organizations are increasingly paying attention to the identification of the elements of the digital economy, and the concept of the connotation is becoming increasingly clear.

5. Discussion

The digital economy is growing and changing rapidly due to pandemic factors, and according to the United Nations Human Development Index and China (CAICT), the digital economy in developed countries is $24.4 trillion, or 74.4 percent of the global total. This is three times larger than the digital economy of developing countries. The digital economy in developed countries accounts for 54.3% of the GDP, far exceeding the 27.6% level of developing countries. Most people enjoy the "digital benefits" of digital technology, which improve efficiency and reduce the cost of time. However, due to different levels of economic development and geographical differences, the development of the digital economy has even increased digital inequality. There is consensus on how to narrow the digital divide, reduce digital inequality, and improve the digital literacy (digital skills) of the digitally "disadvantaged". To improve digital literacy, governments need to continue to increase the pace of digital transformation, strengthen digital governance, and end the digital "disadvantage" by reducing income inequality caused by the digital divide through proactive or reactive education and skills training. This will help people enjoy the dividends of the digital economy in economic development and achieve common prosperity.

6. Conclusion

With the rapid development of the global digital economy, it has become a key factor in reshaping the economic model and structure. This new form of economic form of digital economy requires more

cooperation among countries to make a good definition of the concept of digital economy and strengthen the depth of research on major issues, such as the impact of digital platforms, digital quality of life, digital divide, and other aspects of the economy and society. A clear grasp of the connotations of the digital economy and statistical accounting are issues that need to be focused on. One suggestion for promoting the high-quality development of the digital economy is to first promote the establishment of a standard, scientific, top-level measurement system. This can be done by strengthening theoretical research on the digital economy, exploring the measurement of the digital economy on the basis of a clear definition and extension, and taking the initiative to study and learn from the measurement methods. Second, there is a need to strengthen the operation and accounting testing of the digital economy. Third, we innovate data acquisition and processing methods. The upgrading of big data technology must be accelerated while establishing a training mechanism for data analysts and improving the efficiency of data acquisition and processing. Finally, we must accelerate the training of young people's digital literacy and digital capabilities. With the popularity and popularity of smartphones and social networks, the role of digital tools and media is becoming increasingly important, and people are demanding higher participation and sharing in work, learning, and life in a digital society. The empowerment of the digital economy allows disadvantaged groups in the model to be very lightly empowered by technology and to become a force for sustainable development in global regions. There is evidence in the UK that CTTI 4.0 has a positive impact on financial performance, and companies with good ESG tend to be more engaged in the digital economy. The digital economy is closely related to ESG, carbon neutrality, big data, and the green economy and has also become an important manifestation of sustainable social development (Alkaraan et al., 2022). The digital divide caused by the uneven spatial distribution of digital technologies has become a major factor in the creation of the digital disadvantaged, but the characteristic of the digital economy is that its various developmental stages can be crossed, and the maturity of ICT technology makes it possible for digitally backward countries to leapfrog the digital stage and reach the networked stage directly by connecting to the global network. This feature greatly reduces the cost of digital leapfrogging for digitally disadvantaged countries, and national governments have to formulate digital economy development strategies according to their own national digital economy development status, so as to realize the mission of the digital economy to change the future.

References

Aitken, R., 2016. Digital gold 'done right' with digixdao crypto-trading on openledger. Forbes.

Alkaraan, F., Albitar, K., Hussainey, K., Venkatesh, V. G., 2022. Corporate transformation toward Industry 4.0 and financial performance: The influence of environmental, social, and governance (ESG). Technological Forecasting and Social Change 175, 121423.

Bowman, J., 1996. The Digital Economy: Promise and Peril in the Age of Networked Intelligence. Academy of Management Perspectives 10(2), 69–71.

Buckley, P., Montes, S., Henry, D., Dalton, D., Gill, G., Dumagan, J., Shapiro, R., 2000. Digital economy 2000. Economics and Statistics Administration Office of Policy Development, Washington, DC: US Department of Commerce. Available at: http://www.esa.doc.gov/sites/default/files/de2kapp_0.pdf

Buterin, V., 2014. A next-generation smart contract and decentralized application platform. White Paper, 3 (37), 2–1.

Cassar, C., Heath, D., Micallef, L., 2020. What is digital economy? Unicorns, transformation and the internet of things. Deloitte Article.

Chohan, U., 2020. Some precepts of the digital economy. Productivity, Innovation & Technology eJournal. Social Science Research Network (SSRN), January.

Dresang, E. T., 1999. Radical Change: Books for Youth in a Digital Age. New York: HW Wilson Company. ISBN 0-679-76290-6.

Gospodarik, C.G., Kovalev, M.M., 2020. Belarus' v EAES: problemy i perspektivy ekonomicheskogo rosta [Belarus in the EAEU: Problems and perspectives of economic growth]. Journal of the Belarusian State University. Economy 1, 86–95

Henry, D.K., Buckley, P., Gill, G., Cooke, S., Dumagan, J., Pastore, D., 1999. The Emerging Digital Economy II. Washington, DC: US Department of Commerce. Available at: https://www.commerce.gov/sites/default/files/migrated/reports/ede2report_0.pdf

Heping, G., Fuxiang, W., 2021. Digital economy enables high-quality economic development: theoretical mechanism and empirical evidence. Nanjing Social Sciences (01), 24–33.

Jiang, Q., 2022. On value ontology of digital economy. Journal of Dongbei University of Finance and Economics. ISSN 1008-4096, CN 21-1414/F.

Jing, W.J., Sun, B.W., 2019. Digital economy promotes high-quality economic development: A theoretical analysis framework. Economist, 2, 66–73.

Keyes, R.W., 2006. The impact of Moore's Law. IEEE Solid-State Circuits Society Newsletter 11 (3), 25-27. https://www.doi.org/10.1109/N-SSC.2006.4785857

Li, K., Kim, D.J., Lang, K.R., Kauffman, R.J., Naldi, M., 2020. How should we understand the digital economy in Asia? Critical assessment and research agenda. Electronic Commerce Research and Applications 44, 101004.

Li, R., Gospodarik, C.G., 2022. The Impact of Digital Economy on Economic Growth Based on Pearson Correlation Test Analysis. In International Conference on Cognitive based Information Processing and Applications (CIPA 2021) (pp. 19-27). Singapore: Springer.

Long, A., Ascent, D., 2020. World Economic Outlook. International Monetary Fund.
Mansell, R., Steinmueller, W.E., 2013. Copyright infringement online: The case of the Digital Economy Act judicial review in the United Kingdom. New Media & Society 15 (8), 1312–1328.
Mesenbourg, T.L., 2001. Measuring electronic business: definitions，underlying concepts，and measurement plans. US Bureau of the Census.
Negroponte, N., 1999. Being Digital. New York: Knopf. ISBN 0-679-76290-6
OECD, 2014. The Digital Economy, New Business Models and Key Features. Addressing the Tax Challenges of the Digital Economy. OECD/G20 Base Erosion and Profit Shifting Project. Paris: OECD Publishing.
Pang, J., Zhu, X., 2013. The development trend of foreign digital economy and the national development strategy of digital economy. Scientific and Technological Progress and Countermeasures 30 (8), 124–128.
Rong, L., 2021. The future determines the present: A new era in the global future economy–digital economy. Available at: https://elib.bsu.by/handle/123456789/268050
Strassner, E. H., Nicholson, J.R., 2020. Measuring the digital economy in the United States. Statistical Journal of the IAOS 36 (3), 647–655.
Swan, M., 2017. Anticipating the economic benefits of blockchain. Technology Innovation Management Review 7 (10), 6–13.
Tapscott, D. 1996) The Digital Economy: Promise and Peril in the Age of Networked Intelligence. New York: McGraw Hill.
Woodward, R., 2009. The Organization for Economic Co-operation and Development (OECD). Routledge. Available at: http://www.oecd.org/daf/competition/The-Digital-Economy-2012.pdf
Xuguang, S., Zongyue H., 2016. Quantitative characteristics of China's long-range economic development. Journal of Beijing Normal University (Social Sciences) 2016.05.
Yu, C., 2021. Industrial policy and technological innovation of China's digital economy industry. Statistical Research 38 (1), 51–64.
Zhang, W., Zhao, S., Wan, X., Yao, Y., 2021. Study on the effect of digital economy on high-quality economic development in China. PloS One 16 (9), e0257365.
Zhao, Y., Wang, Z., 2003. Discussion on digital economy and digital economy era. Journal of Guangxi University for Nationalities: Philosophy and Social Science Edition (S1), 113–114.
Zhou, X., Zhou, D., Zhao, Z., Wang, Q., 2022. A framework to analyze carbon impacts of digital economy: The case of China. Sustainable Production and Consumption 31, 357–369.

Список источников

Aitken, R., 2016. Digital gold 'done right' with digixdao crypto-trading on openledger. Forbes.
Alkaraan, F., Albitar, K., Hussainey, K., Venkatesh, V. G., 2022. Corporate transformation toward Industry 4.0 and financial performance: The influence of environmental, social, and governance (ESG). Technological Forecasting and Social Change 175, 121423.
Bowman, J., 1996. The Digital Economy: Promise and Peril in the Age of Networked Intelligence. Academy of Management Perspectives 10(2), 69–71.
Buckley, P., Montes, S., Henry, D., Dalton, D., Gill, G., Dumagan, J., Shapiro, R., 2000. Digital economy 2000. Economics and Statistics Administration Office of Policy Development, Washington, DC: US Department of Commerce. Available at: http://www.esa.doc.gov/sites/default/files/de2kapp_0.pdf
Buterin, V., 2014. A next-generation smart contract and decentralized application platform. White Paper, 3 (37), 2–1.
Cassar, C., Heath, D., Micallef, L., 2020. What is digital economy? Unicorns, transformation and the internet of things. Deloitte Article.
Chohan, U., 2020. Some precepts of the digital economy. Productivity, Innovation & Technology eJournal. Social Science Research Network (SSRN), January.
Dresang, E. T., 1999. Radical Change: Books for Youth in a Digital Age. New York: HW Wilson Company. ISBN 0-679-76290-6.
Henry, D.K., Buckley, P., Gill, G., Cooke, S., Dumagan, J., Pastore, D., 1999. The Emerging Digital Economy II. Washington, DC: US Department of Commerce. Available at: https://www.commerce.gov/sites/default/files/migrated/reports/ede2report_0.pdf
Heping, G., Fuxiang, W., 2021. Digital economy enables high-quality economic development: theoretical mechanism and empirical evidence. Nanjing Social Sciences (01), 24–33.
Jiang, Q., 2022. On value ontology of digital economy. Journal of Dongbei University of Finance and Economics. ISSN 1008-4096, CN 21-1414/F.
Jing, W.J., Sun, B.W., 2019. Digital economy promotes high-quality economic development: A theoretical analysis framework. Economist, 2, 66–73.
Keyes, R.W., 2006. The impact of Moore's Law. IEEE Solid-State Circuits Society Newsletter 11 (3), 25-27. https://www.doi.org/10.1109/N-SSC.2006.4785857
Li, K., Kim, D.J., Lang, K.R., Kauffman, R.J., Naldi, M., 2020. How should we understand the digital economy in Asia? Critical assessment and research agenda. Electronic Commerce Research and Applications 44, 101004.
Li, R., Gospodarik, C.G., 2022. The Impact of Digital Economy on Economic Growth Based on Pearson Correlation Test Analysis. In International Conference on Cognitive based Information Processing and Applications (CIPA 2021) (pp. 19-27). Singapore: Springer.
Long, A., Ascent, D., 2020. World Economic Outlook. International Monetary Fund.
Mansell, R., Steinmueller, W.E., 2013. Copyright infringement online: The case of the Digital Economy Act judicial review in the United Kingdom. New Media & Society 15 (8), 1312–1328.
Mesenbourg, T.L., 2001. Measuring electronic business: definitions，underlying concepts，and measurement plans. US Bureau of the Census.
Negroponte, N., 1999. Being Digital. New York: Knopf. ISBN 0-679-76290-6
OECD, 2014. The Digital Economy, New Business Models and Key Features. Addressing the Tax Challenges of the Digital Economy. OECD/G20 Base Erosion and Profit Shifting Project. Paris: OECD Publishing.
Pang, J., Zhu, X., 2013. The development trend of foreign digital economy and the national development strategy of digital economy. Scientific and Technological Progress and Countermeasures 30 (8), 124–128.
Rong, L., 2021. The future determines the present: A new era in the global future economy–digital economy. Available at: https://elib.bsu.by/handle/123456789/268050

Strassner, E. H., Nicholson, J.R., 2020. Measuring the digital economy in the United States. Statistical Journal of the IAOS 36 (3), 647–655.
Swan, M., 2017. Anticipating the economic benefits of blockchain. Technology Innovation Management Review 7 (10), 6–13.
Tapscott, D. 1996) The Digital Economy: Promise and Peril in the Age of Networked Intelligence. New York: McGraw Hill.
Woodward, R., 2009. The Organization for Economic Co-operation and Development (OECD). Routledge. Available at: http://www.oecd.org/daf/competition/The-Digital-Economy-2012.pdf
Xuguang, S., Zongyue H., 2016. Quantitative characteristics of China's long-range economic development. Journal of Beijing Normal University (Social Sciences) 2016.05.
Yu, C., 2021. Industrial policy and technological innovation of China's digital economy industry. Statistical Research 38 (1), 51–64.
Zhang, W., Zhao, S., Wan, X., Yao, Y., 2021. Study on the effect of digital economy on high-quality economic development in China. PloS One 16 (9), e0257365.
Zhao, Y., Wang, Z., 2003. Discussion on digital economy and digital economy era. Journal of Guangxi University for Nationalities: Philosophy and Social Science Edition (S1), 113–114.
Zhou, X., Zhou, D., Zhao, Z., Wang, Q., 2022. A framework to analyze carbon impacts of digital economy: The case of China. Sustainable Production and Consumption 31, 357–369.
Господарик, Е.Г., Ковалев, М.М., 2020. Беларусь в ЕАЭС: проблемы и перспективы экономического роста. Журнал Белорусского государственного университета. Экономика 1, 86–95.

The article was submitted 03.10.2022, approved after reviewing 12.12.2022, accepted for publication 16.12.2022.

Статья поступила в редакцию 03.10.2022, одобрена после рецензирования 12.12.2022, принята к публикации 16.12.2022.

About the authors:

1. Li Rong, PhD student at the Department of Analytical Economics and Econometrics, Belarussian State University, Republic of Belarus, Minsk

2. Catherine Gospodarik, Head of the Department of Analytical Economics and Econometrics, PhD, Associate Professor Belarussian State University, Republic of Belarus, Minsk, gospodarik@bsu.by, Professor at the Department of Business-analytics, Financial University under the Government of Russian Federation, eggospodarik@fa.ru

Информация об авторах:

1. Ли Жун, аспирант кафедры аналитической экономики и эконометрики Белорусского государственного университета, Республика Беларусь, Минск

2. Екатерина Господарик, заведующая кафедрой аналитической экономики и эконометрики, кандидат экономических наук, доцент Белорусского государственного университета, Минск, Республика Беларусь, gospodarik@bsu.by, профессор кафедры бизнес-аналитики Финансового университета при Правительстве Российской Федерации, eggospodarik@fa.ru

SECTION 2

ENTERPRISES AND THE SUSTAINABLE DEVELOPMENT OF REGIONS

РАЗДЕЛ 2

ПРЕДПРИЯТИЯ И УСТОЙЧИВОЕ РАЗВИТИЕ РЕГИОНОВ

Research article
DOI: https://doi.org/10.48554/SDEE.2022.4.2

Model of Global Optimisation and Planning of Research and Development Costs of an Industrial Region

Dmitrii Rodionov[1], Egor Koshelev[2*], John Gayomey[3], Olga Ferraro[4]

[1] Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, Russia, drodionov@spbstu.ru
[2] Lobachevsky State University of Nizhny Novgorod, Nizhny Novgorod, Russia, ekoshelev@yandex.ru
[3] Tamale Technical University, Tamale, Ghana, gayomey@hotmail.com
[4] University of Calabria, Italy, olga.ferraro@unical.it
[*] Corresponding author: ekoshelev@yandex.ru

Abstract

The subject of the work is a study of the patterns and prerequisites for the formation of regional innovation systems along with the analysis and synthesis of a significant array of information on elements of interaction at the regional level on the basis of economic and mathematical modelling. The purpose of this work is to develop a science-based flexible management model that, on the one hand, takes into consideration the specificity of the development cycle for the innovative system of an industrial region, as well as the level of its socio-economic development, and on the other hand, contributes to overcoming the economic determinism of territories and stimulating the economic growth of an industrial region. A regional model for planning innovative development programmes has been created, which consists of the global optimisation of current domestic research and development (R&D) costs of the industrial region, depending on its investment planning according to the fixed capital investment data, production planning according to the gross regional product (GRP) data, and financial planning for the accounts payable data of organisations. In the Nizhny Novgorod region, to minimise all R&D costs, investments in fixed assets and GRP should be increased, and the quantity of accounts payable by organisations should be reduced. However, for basic research, there is a limit on the debt of organisations, the excess of which is impractical because it leads to an outflow of the necessary funds for basic research. The increase in this debt also leads to an increase in the costs of applied research. For developments, there is a lower limit on the amount of GRP, below which it is not advisable to drop, as it leads to an outflow of the funds necessary for development.

Keywords: innovative development of the region, investment planning, production planning, financial planning, research and development costs

Citation: Rodionov, D., Koshelev, E., Gayomey, G., Ferraro, O., 2022. Model of Global Optimisation and Planning of Research and Development Costs of an Industrial Region. Sustainable Development and Engineering Economics 4, 2. https://doi.org/10.48554/SDEE.2022.4.2

This work is licensed under a CC BY-NC 4.0

© Rodionov, D., Koshelev, E., Gayomey, G., Ferraro, O., 2022. Published by Peter the Great St. Petersburg Polytechnic University

Научная статья

УДК 332.142.2

DOI: https://doi.org/10.48554/SDEE.2022.4.2

Модель Глобальной Оптимизации и Планирования Затрат на Научно-Исследовательские Работы Промышленного Региона

Дмитрий Родионов[1], Егор Кошелев[2*], Джон Гайомей[3], Ольга Ферраро[4]

[1] Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия, drodionov@spbstu.ru

[2] Нижегородский государственный университет им. Н.И. Лобачевского, Нижний Новгород, Россия, ekoshelev@yandex.ru

[3] Технический университет Тамале, Тамале, Гана, gayomey@hotmail.com

[4] Университет Калабрии, Италия, olga.ferraro@unical.it

[*] Автор, ответственный за переписку: ekoshelev@yandex.ru

Аннотация

Предметом работы является исследование закономерностей и предпосылок формирования региональных инновационных систем с учетом анализа и обобщения значительного массива информации по элементам взаимодействия на региональном уровне на основе экономико-математического моделирования. Цель работы заключается в разработке научно-обоснованной гибкой управленческой модели, с одной стороны, учитывающей специфику цикличности развития инновационной системы промышленного региона, а также уровень его социально-экономического развития, с другой стороны, способствующей преодолению экономического детерминизма территорий и стимулирующей экономический рост промышленного региона. Создана региональная модель планирования программ инновационного развития, которая заключается в глобальной оптимизации внутренних текущих затрат на научно-исследовательские работы (НИР) промышленного региона в зависимости от его инвестиционного планирования по данным об инвестициях в основной капитал, производственного планирования согласно данным о валовом региональном продукте (ВРП) и финансового планирования по данным о кредиторской задолженности организаций. В Нижегородской области с целью минимизации всех затрат на НИР следует увеличивать инвестиции в основной капитал и объем ВРП, а также снижать размер кредиторской задолженности организаций. При этом для фундаментальных исследований существует предел задолженности организаций, превышение которого нецелесообразно, т. к. это приводит к оттоку необходимых средств на фундаментальные исследования. Увеличение данной задолженности приводит также к повышению затрат на прикладные исследования. Для разработок существует нижний предел объема ВРП, ниже которого опускаться нецелесообразно, т. к. это приводит к оттоку необходимых средств на разработки.

Ключевые слова: инновационное развитие региона, инвестиционное планирование, производственное планирование, финансовое планирование, затраты на научно-исследовательские работы

Цитирование: Родионов, Д., Кошелев, Е., Гайомей, Д., Ферраро, О., 2022. Модель Глобальной Оптимизации и Планирования Затрат на Научно-Исследовательские Работы Промышленного Региона. Sustainable Development and Engineering Economics 4, 2. https://doi.org/10.48554/SDEE.2022.4.2

Эта работа распространяется под лицензией CC BY-NC 4.0

© Родионов, Д., Кошелев, Е., Гайомей, Д., Ферраро, О., 2022. Издатель: Санкт-Петербургский политехнический университет Петра Великого

1. Introduction

Currently, the conditions of the external environment in the Russian Federation suggest considering the issues of nationally effective and balanced socio-economic and innovative development of the nation's industrial regions by modelling their innovative development processes. In this regard, works on the problems of functioning of regional innovation systems, developed by Russian and foreign scientists, summarise that most systems have a stable set of structural elements, which are well studied and described, and the institutional relationships of innovation chains have been identified. However, the role of regional innovation systems is still underestimated, most of the works are devoted to national innovation systems, and most studies are socially oriented without proper economic and mathematical description. The present study is distinguished by the analysis and generalisation of a significant array of information on the elements of interaction at the regional level based on economic and mathematical modelling. In the framework of this study, we propose analysing regularities and considering prerequisites for the formation of regional innovation systems. The goal of this study is to develop a science-based flexible management model that, on the one hand, considers the specifics of cyclic development of the innovation system in an industrial region and its socio-economic development level, and on the other hand, contributes to overcoming the economic determinism of territories and stimulating the economic growth of the industrial region. To achieve this goal, it is necessary to create a regional model of simultaneous investment, production, and financial planning of innovative development programmes.

The problems of planning for investment, production, and financial programmes and their interrelation were studied by scientists such as Brigham and Gapenski (1993), Kruschwitz and Lorenz (2019), and Limitovskiy (2019). Brigham and Gapenski (1993) investigated the planning processes of investment programmes for commercial companies' projects. Kruschwitz and Lorenz (2019) studied the processes of simultaneous investment and financial planning, as well as simultaneous investment and production planning. Limitovskiy (2019) supplemented their results by considering the systemic financial effects of investment programmes. However, the processes of simultaneous investment, production, and financial planning have not been sufficiently investigated. In addition, these technologies have yet to be adapted into state structures to plan the innovative development programmes of regions.

2. Literature review

Overall, various scientists have studied the processes of simultaneous and financial planning. The available extant findings allow for individual perspectives on this issue by supplementing the already established technologies with production planning. Thus, Naumenkova and Glazun (2002) used simulation and analytical methods of quantitative analysis and forecasting to study the management processes of the investment and financial activity of an enterprise. By including the time parameter, the authors mutually linked the key variables and functional areas of the model created in time. Hahn and Kuhn (2012) found that since the aggregate planning of capital (one-time) investments is done in the long term, the detailed timing of their adjustment remains at the medium-term level. In combination with capacity control measures to optimise the use of assets, the time of capacity adjustment can also be used. The study presents a relevant technology for cost- and risk-based performance optimisation in supply chains, simultaneously covering investment, operations, and financial planning.

Nedosekin and Abdulaeva (2013), in their monograph, reviewed the models and methods of various planning options—strategic, investment, operational, and financial in a narrow sense—providing simplified types of plans while considering the issue of normalising plan parameters. Rytikov et al. (2014) presented a model of simultaneous planning and a corresponding tool that takes into consideration the conditions of financial feasibility, liquidity, and the impact of the tax burden. The model enables optimisation of the project financing scheme (its full financial plan) according to one of two criteria (maximum final property value or maximum net discounted income). The study showed that the proposed model makes it possible to find balanced financing schemes for investment projects, to determine the optimal sequence of commissioning their capacities, and to effectively use free funds generated by the project. In their monograph, Dinges and Pozdeyeva (2018) proposed methods for optimising the investment

and financial programmes of road organisations, providing: (1) dynamic formulation of the problem for enterprise development in the short and medium term; (2) interrelated consideration of possible options for investment and financial activities of enterprises; and (3) an indicator that maximises the value of enterprise capital at the end of its implementation as a criterion for the optimality of programme formation.

The useful findings of these studies of simultaneous and financial planning, they should be used to create innovative development programmes for manufacturing companies and industrial regions. In this regard, the works of the following researchers are of separate interest. Fabiana et al. (2016) investigated how the technological innovation process occurs in small- and medium-sized technology companies located in the metropolitan region of Paraiba Valley and the Northern Coast of Brazil. The theoretical methodology they used consisted of the authors' six models of innovation: the technology push, the market pull, the coupling innovation process, the functional integration innovation process, the systems integration and networking innovation process, and open innovation. By observing models of innovative development adopted by companies, it appeared to the researchers that the models were closer to what was proposed as the chain interaction model. They concluded that the development of innovation depends on the type of economic activity that the company develops, and the interactions that it has with the internal and external environment.

Vasconcellos et al. (2016) argued that the resources invested in research do not guarantee immediate practical application. Companies and governments are increasingly looking for mechanisms to prioritise R&D projects when resources are scarce. Thus, the researchers aimed to develop and present a methodology that could be used to evaluate a research portfolio and to help select the best investment in research. The findings show that risk and return criteria should be used to manage an R&D portfolio when selecting projects. Thus, the problem of planning the costs of scientific research work (SRW) becomes relevant, and Feoktistova (2014) identified the following key principles in this process:

1) Understanding that scientific research work is a unique process, different in its characteristics from any other work, and requires a special methodological and legislative approach;

2) Using the project approach in planning R&D and its financing as the most effective and proven strategy in Russian and international practice;

3) Applying competitive principles of funding research projects and independent expert scientific evaluation, which allows for selecting truly best performers and ensuring high-quality results;

4) Selecting the expected results of a research project as one of the key criteria in planning the costs of the project;

5) Selecting the results already achieved by a potential contractor is the key criterion in determining the funding of a research project.

Gaponenko (2018) considered situations in which it is potentially possible to reduce the actual costs of conducting SRW, highlighting the following:

1) Carrying out SRW similar to the works carried out earlier by the same contractor, that is, a scientific organisation or a researcher.

2) Carrying out SRW close to what was previously done by other contractors—that is, scientific organisations.

3) Carrying out (possibly simultaneously) similar SRW for different customers.

4) Using previously obtained research results, previously collected findings in a new study in case the subjects of old and new research are not related.

5) Including in the terms of reference tasks that do not correspond to the goal of the SRW, the results of which can be used, for example, in another SRW or a publication, a patent.

Thus, there is a need to solve the problem of reducing the cost of SRW in such a way that it would increase the efficiency of the industrial regions' economies. For example, by predicting the evolution of the innovation system of a federal district using a multipurpose genetic algorithm, Yashin et al. (2020) showed that to increase its synergy effect, the federal district should redirect investment resources and SRW costs to regions where economic and financial resources are insufficient. This will eventually increase the average per-capita income in the regions of the federal district, which will, in turn, lead to population growth. In this regard, the issue of managing SRW costs in innovation-industrial clusters, which contribute to the socioeconomic development of the regions where these clusters are located, is relevant. For this purpose, it is necessary to solve the relevant problems of cluster management. Thus, Polyanin et al. (2020) developed scientific and methodological guidelines that can contribute to the timely identification of real and potential economic threats in a cluster. The authors created a methodology for assessing the economic security of a cluster that is characterised by a comprehensive approach that allows for all possible risks and threats in the functioning of individual components of the cluster structure.

Tashenova et al. (2020) developed a method for assessing the digital potential of backbone innovative active industrial clusters. The method was developed based on existing methods and approaches to assessing the innovation potential of industrial clusters and the digital potential of industrial enterprises, and enables calculation of the final integral assessment. The proposed method has been successfully tested on the example of the cluster "Development of information technology, radio electronics, instrumentation, communication, and information and telecommunication devices of St. Petersburg".

However, in a broader sense, the issue of managing SRW costs in an industrial region, rather than in its individual cluster, is important. To this end, regional SRW costs should be optimised. Thus, Xu (2018) found that innovation factor theory considers that regional investment in research and development (R&D) directly affects the new product development (NPD) indicators of the enterprise, and innovation efficiency theory considers that regional investment in R&D affects the NPD indicators of the enterprise, which, in turn, affect the internal efficiency of the enterprise's R&D. The researcher compared data from a Chinese provincial region with enterprise data from China's industrial enterprise database. The empirical results showed that the innovation factor theory and the innovation efficiency theory exist simultaneously. Regional investment in R&D can affect the NPD indicators of enterprises. However, investment in the R&D of other enterprises in the same region has a beneficial effect on the internal R&D efficiency of enterprises. Regional R&D investment in human resources positively affects the internal R&D performance of enterprises. According to the findings, the researcher formulated three policy recommendations: increasing regional investment in R&D, expanding and consolidating the enterprise as the basis for R&D status, and increasing regional investment in R&D in the area of human resources.

Chen et al. (2019), using a stochastic fixed-effects frontier model based on transregistration of the production function, estimated the elasticity of production and substitution of R&D in universities at the provincial level of China during 2009–2016. The authors found that the technical R&D efficiency of Chinese universities tended to become relatively stable after rapid growth. Increasing the degree of internationalisation and externalisation of R&D capabilities contributes to the technical efficiency of R&D, whereas spending on government subsidies hinders the technical efficiency of R&D; the effects of deepening R&D and internet connectivity are not evident. The production elasticity of R&D capital is much higher than that of R&D personnel, suggesting that R&D capital is the main driver of the research results. The elasticity of substitution between R&D capital and personnel has changed from replacement to addition since 2014. To ensure sustainable growth in research results, it is necessary to increase the contribution of R&D with positive output elasticity or to decrease the contribution of R&D with negative output elasticity by making the necessary compromises according to the ratio of substitution between the two R&D inputs.

Dobrzanski and Bobowski (2020) determined whether funds spent on R&D are used in the countries of the Association of Southeast Asian Nations (ASEAN). Fifteen countries were examined over the period of 2000–2016. R&D expenditure efficiency was measured using a non-parametric methodology

of data envelopment analysis (DEA), which measures input–output efficiency. The study included the following cost and output variables: annual public and private spending on innovations, high-tech exports as a percentage of manufacturing exports, patent applications to the World Intellectual Property Organisation (WIPO) according to priority years for millions of residents, applications for trademarks (TK) for millions of residents, and information and communication technology (ICT) exports as a percentage of manufacturing exports. Hong Kong and the Philippines are found to be the top-performing countries in R&D when analysed using the constant return to scale (CRS) approach. However, according to the variable return to scale (VRS) approach, Hong Kong, Indonesia, Singapore, and the Philippines are the most efficient ASEAN countries. The study also confirmed that an increase in spending on innovation leads to disproportionate effects.

The solution to the above problems inspires the central question of the present research: How can SRW costs be optimised in an industrial region? Despite the unconditional importance of identifying the necessary parameters of the optimised target function, it is also necessary to determine the methods of global optimisation, that is, to choose those that will allow for obtaining the most reliable final solution to the problem. To solve this problem, we apply the following approaches, which are subsequently described in detail:

1) Genetic algorithm (GA)

2) Simulated annealing (SA)

3) Pattern search (PS)

Let us describe their advantages in more detail.

1. Evolutionary algorithms (genetic algorithms) are relatively new but very powerful methods used to find solutions to many real search and optimisation problems. Most of these problems have multiple objectives, which leads to the need to obtain a set of optimal solutions known as efficient solutions. The use of GAs has been found to be a highly effective way of finding multiple efficient solutions in a single simulation run (Kalyanmoy, 2001).

2. The annealing method makes it possible to avoid a “trap” in the local extrema of the function being optimised and to continue the search for a global extremum. Moreover, even in conditions of insufficient computing power for finding a global extremum, the annealing method usually provides a good solution—that is, one of the local extrema (Lopatin, 2005). A comparison of adaptive simulated annealing (ASA) and GAs revealed that the SA method does not lose to GAs in most problems, and even wins in a number of them (Ingber, and Rosen, 1992).

3. Direct search (pattern search) is a method for solving optimisation problems; it does not require any information about the gradient of the target function. Unlike more traditional optimisation methods that use information about the gradient or higher derivatives to find the optimal point, the PS algorithm looks for a set of points around the current point to identify the point where the value of the target function is lower than the value at the current point. A direct search can be used to solve problems for which the target function is not differentiable or even continuous (Conn et al., 1991; Conn et al., 1997; Kolda et al., 2006).

Thus, using three different algorithms to optimise SRW costs, we can test the resulting solution.

3. Materials and methods

The optimisation of the SRW costs for the industrial region is carried out considering the following factors:

1. Investment planning. For this, we used information on the dynamics of investment in fixed capital in the region.

2. Production planning. Here, we relied on data on the dynamics of the gross regional product (GRP).

3. Financial planning. Given that in this task, we considered the possibility of external financing, which provides an additional opportunity for industrial companies in the region to develop their innovations, we use information about the dynamics of organisations' accounts payable.

Thus, the optimisation of the SRW costs is dependent on the simultaneous processes of investment, production, and financial planning, which allows for obtaining the most effective combination of the values of these three factors. It is also necessary to define what is meant by the optimisation of the SRW costs: their maximisation or minimisation. Obviously, in the ideal case, it is necessary to investigate the problem of finding opportunities to increase SRW costs, because in this case, the industrial region will develop more intensively due to receiving and implementing new technologies, which, in turn, will have a positive effect on the innovative development of the whole country. However, we look for possibilities to decrease the costs of SRW to that optimal value, which will be achievable by simultaneous investment and industrial and financial planning of the region, allowing us to determine the most expedient proportions of the three listed planning factors in monetary terms.

Lastly, the regional model of simultaneous investment, production, and financial planning of innovative development programmes should be sufficiently detailed; thus, several target functions of the internal current costs of SRW for an industrial region are investigated: the total costs of SRW and their three components—basic research, applied research, and developments. This eventually allows us to draw more reasonable conclusions about how an industrial region should develop its internal current costs of SRW, depending on the planning of investment in fixed capital, GRP, and accounts payable of organisations.

Taking these assumptions into consideration, we present the stages of implementing the model under consideration in Fig. 1, followed by a detailed description of the stages.

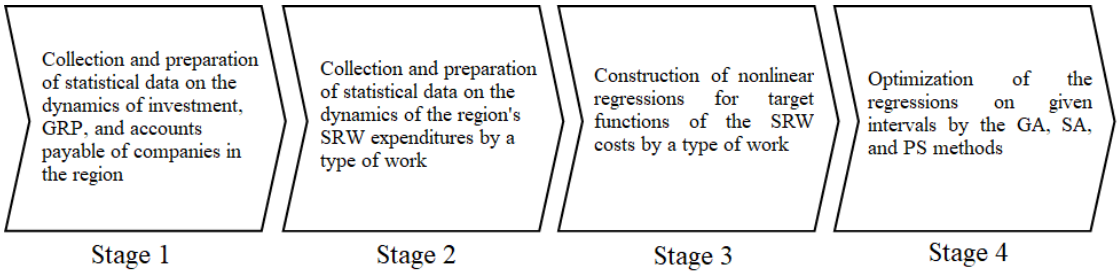

Figure 1. Stages of implementing the regional model of simultaneous investment, production, and financial planning of innovative development programmes

Stage 1 – Collection and preparation of statistical data on the dynamics of investment, GRP, and accounts payable of companies in the region. To construct high-quality future nonlinear regressions of the target functions of SRW expenditure, we needed data on the dynamics of investment in fixed capital (x1), GRP (x2), and accounts payable of organisations (x3) over a long period covering 10 years. Since the website of the Federal State Statistics Service1 contains data on the internal current costs of SRW, investment in fixed capital, and accounts payable of organisations for the period up to and including 2020, but there are no such data on GRP for 2019 and 2020, we forecast them ourselves using WolframAlpha2. Further, to make the collected data comparable, they were adjusted by all the annual inflation rates for the period under consideration.

[1] the Federal State Statistics Service. Available at: https://www.gks.ru
[2] WolframAlpha. Available at: www.wolframalpha.com

Stage 2 – Collection and preparation of statistical data on the dynamics of the region's SRW expenditures by type of work. At this stage, statistical information was collected about the internal current costs of SRW in total (y), as well as by type of work: basic research ($y1$), applied research ($y2$), and developments ($y3$). These data were also for the same period covering 10 years as the period of the previous stage, and were also adjusted by all the annual inflation rates for the period in question.

Stage 3 – Construction of nonlinear regressions for target functions of SRW costs by type of work. Nonlinear regressions reflect economic processes more realistically than linear ones. Moreover, in our case, regressions of the form $y = f(x_1, x_2, x_3)$ were multiple. To obtain them, we used the *Statistica* package. We judged the quality of the target function regressions by the determination coefficient ($R2$) and the adjusted $R2$, that is, by the closeness of their values to 1.

Stage 4 – Optimisation of the regressions on given intervals by the GA, SA, and PS methods. This global optimisation was performed with *Matlab* using GA, SA, and PS. To refine the results of the GA and SA methods, we supplemented the optimisation results of the target functions with the hybrid functions of PS and the inner point method (Babynin and Zhadan, 2008). That is, the GA or SA algorithms were run first, and then their results were used as a starting point for the subsequent optimisation of the target function using the hybrid function. This provided a better solution in each case of optimisation of all costs of SRW, basic research, applied research, and developments.

In addition, if we do not set the lower and upper values of each parameter of the target function of the corresponding SRW costs, its minimum value can turn out to be minus infinity. Therefore, for each parameter $x1$, $x2$, $x3$ of the corresponding target function, we set their actual lower and upper values for the period under study. This approach also allowed us to compare the optimal (minimum) value of the corresponding SRW costs with their actual minimum value for the period under study.

4. Results and discussion

In what follows, we illustrate the implementation of the presented model using the example of the Nizhny Novgorod region, which is a large industrial region.

Stage 1 – Collection and preparation of statistical data on the dynamics of investment, GRP, and accounts payable of companies in the region. At this stage, the necessary raw data were collected from the website of the Federal State Statistics Service1. These are presented in columns x1, x2, and x3 in Table 1. Since the above website contains data on internal current expenditures on SRW only for the period from 2015 to 2020, as well as for 2010, we selected the data on investment in fixed capital and accounts payable of organisations for the same years. To make the collected data comparable, we corrected them for all the annual inflation rates for the period in question, according to the data in Table 2. Thus, all the data in Table 3 are presented in the 2020 prices.

Table 1. Initial data on the Nizhny Novgorod region (million rubles)

Years	Investments in fixed capital, x_1	Gross regional product, x_2	Accounts payable of organisations, x_3	Internal current expenses on SRW by type of work			
				Total, y	Basic research, y_1	Applied research, y_2	Developments, y_3
2010	192072.4	652805.9	313700	26992.8	1224.7	4211.6	21556.4
2015	235066.7	1104643.2	623100	56870.6	1912.0	5222.2	49736.4
2016	232010.4	1160782.3	836700	66317.1	1901.6	6592.4	57823.2
2017	245268	1261939.4	869200	64278.4	2026.0	6620.8	55631.5
2018	259392.9	1367544	999200	66202.2	2219.5	9123.8	54858.9
2019	295252.2		1249100	76896.2	4738.0	9506.0	62652.2
2020	383102.1		1425600	68750.3	5220.1	8560.3	54969.9

Table 2. Annual rates of inflation (%)

2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
8.78	6.1	6.58	6.45	11.36	12.91	5.38	2.52	4.27	3.05	4.91

Table 3. Initial data on the Nizhny Novgorod region in 2020 prices (million rubles)

Years	Investments in fixed capital	Gross regional product	Accounts payable of organisations	Internal current expenses on SRW by type of work			
				Total	Basic research	Applied research	Developments
	x_1	x_2	x_3	y	y_1	y_2	y_3
2010	354041.7	1203298.9	578234.4	49755.1	2257.5	7763.1	39734.3
2015	286274.2	1345281.2	758837.5	69259.4	2328.5	6359.8	60571.1
2016	268126.9	1341478.2	966946.9	76640.5	2197.6	7618.6	66824.4
2017	276480.9	1422534.3	979814.8	72458.5	2283.8	7463.4	62711.2
2018	280429	1478448.5	1080232.7	71571	2399.5	9863.7	59307.8
2019	309749.1	1462385.4	1310430.8	80671.8	4970.6	9972.7	65728.4
2020	383102.1	1474349.6	1425600	68750.3	5220.1	8560.3	54969.9

We also solved the problem of the lack of data on GRP for 2019 and 2020 on the website of the Federal State Statistics Service. We forecast them independently in the 2020 prices using, for this purpose, the period from 2009 to 2018 and *WolframAlpha*[2] (Fig. 2):

Cubic polynomial (formula 1):

$$2733.04x^3 - 50181.7x^2 + 293422x + 831795 \quad (1)$$

$$R^2 = 0.962 \text{, adjusted } \boldsymbol{R}^2 = 0.943$$

Quartic polynomial (formula 2):

$$239.151x^4 - 2528.28x^3 - 11678.4x^2 + 188195x + 913872 \quad (2)$$

$$R^2 = 0.97 \text{, adjusted } \boldsymbol{R}^2 = 0.946$$

Logarithm (formula 3):

$$137502 \ln x + 1.13267 \cdot 10^6 \quad (3)$$

$$R^2 = 0.811 \text{, adjusted } \boldsymbol{R}^2 = 0.787$$

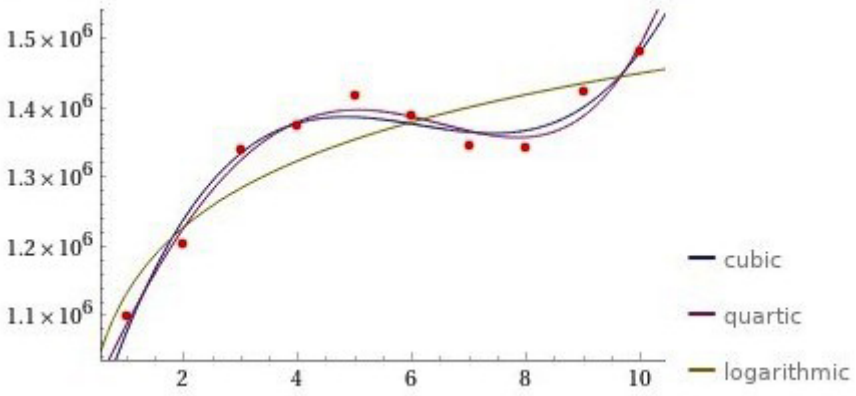

Figure 2. Graphs of the three best forecast functions of the GRP of the Nizhny Novgorod region in 2020 prices (million rubles)

Despite the lowest *R*2 and adjusted *R*2 values, the forecast, according to the natural logarithm, seems the most plausible from an economic point of view, since in 2020, we expect the GRP values to decrease due to the pandemic.

Stage 2 – Collection and preparation of statistical data on the dynamics of the region's SRW expenditures by type of work. At this stage, statistical information was collected on the internal current costs of SRW in total and the type of work: basic research, applied research, and developments. They are presented in columns *y*, *y*1, *y*2, and *y*3, respectively, in Table 1. The data are for the same period of time as in the previous stage. They were also adjusted by all the annual inflation rates for the period under consideration (Table 2). The results are presented in Table 3.

Stage 3 – Construction of nonlinear regressions for target functions of the SRW costs by type of work. Based on the values in Table 3, the following most accurate nonlinear regressions were obtained in the *Statistica* package:

Regression for all SRW costs (formula 4):

$$y = 1741889 - 0.8089667x_1 - 0.4449632x_2 - \frac{75140630000}{x_1} - \frac{715718200000}{x_2} - \frac{36550920000}{x_3} \quad (4)$$

$$\boldsymbol{R}^2 = 0.999, \text{ adjusted } \boldsymbol{R}^2 = 0.995$$

Regression for basic research (formula 5):

$$y_1 = 25140.5 - 0.04x_3 \quad (5)$$

$$\boldsymbol{R}^2 = 0.992, \text{ adjusted } \boldsymbol{R}^2 = 0.985$$

Regression for applied research (formula 6):

$$y_2 = 5310.287 + 0.003x_3 \quad (6)$$

$$\boldsymbol{R}^2 = 0.41, \text{ adjusted } \boldsymbol{R}^2 = 0.292$$

Regression for developments (formula 7):

$$y_3 = -814037 + x_2 \quad (7)$$

$$\boldsymbol{R}^2 = 0.9999, \text{ adjusted } \boldsymbol{R}^2 = 0.9996$$

Stage 4 – Optimisation of the regressions on given intervals by the GA, SA, and PS methods. This global optimisation was performed in the *Matlab* package. GA, SA, and PS were used for this purpose. To refine the results of the GA and SA methods, the optimisation results of the target functions were supplemented with hybrid functions of the PS and interior point methods (fmincon). To this end, all target functions were investigated on the segments of actual values of parameters *x*1, *x*2, and *x*3 for the period under study, according to Table 3, that is, $x_1 \in [268126.9;383102.1]$, $x_2 \in [1203298.9;1478448.5]$, and $x_3 \in [578234.4;1425600]$. The results of optimisation for all costs of SRW, basic research, applied research, and developments are presented in Tables 4-7.

Table 4. Global optimisation results for regression for all SRW costs (million rubles)

Algorithm	Investments in fixed capital	Gross regional product	Accounts payable of organisations	Total SRW costs
	x_1	x_2	x_3	y
GA	383 039.2	1 473 402.4	582 875.9	31 776.3
GA + fmincon	383 102.1	1 478 448.5	578 234.4	30 666.8
GA + PS	383 102.1	1 478 448.5	578 234.4	30 666.8
SA	363 744.5	1 203 308.3	578 253.4	47 626.6

SA + fmincon	383 102.1	1 203 298.9	578 234.4	42 402.3
SA + PS	383 101.9	1 478 448.1	578 235.1	30 667
PS	383 102.1	1 478 448.5	578 234.4	30 666.8

Table 5. Optimisation results for regression for basic research (million rubles)

Algorithm	Investments in fixed capital	Gross regional product	Accounts payable of organisations	Basic research
	x_1	x_2	x_3	y_1
Analytically	-	-	25,140.5	0

Table 6. Optimisation results for regression for applied research (million rubles)

Algorithm	Investments in fixed capital	Gross regional product	Accounts payable of organisations	Applied research
	x_1	x_2	x_3	y_2
Analytically	-	-	0	5,310.3

Table 7. Optimisation results for regression for developments (million rubles)

Algorithm	Investments in fixed capital	Gross regional product	Accounts payable of organisations	Developments
	x_1	x_2	x_3	y_3
Analytically	-	814 037	-	0

As shown in Table 4, the PS algorithm is the most ideal method for solving the problem in question. In addition, adding this algorithm as a hybrid function for the GA or SA allows for achieving a rather high-quality solution to the optimisation problem. On the contrary, adding the interior point method (fmincon) as a hybrid function did not always significantly improve the quality of global optimisation.

Comparing the optimal (minimum) value of the relevant costs of SRW with their actual minimum value for the period under study, we draw the following conclusions:

For all internal current costs of SWR, based on the results in Table 4:

1. The global optimisation algorithms allow planning the minimum of all SRW costs (30,666.8 million rubles), which is less than the minimum value observed in the period under study (49,755.1 million rubles).

2. It is possible to achieve the minimum of all SRW costs at the maximum observed investments in fixed capital (383,102.1 million rubles), the maximum GRP (1,478,448.5 million rubles), and the minimum accounts payable of organisations (578,234.4 million rubles). This means that investment and GRP volume should be increased, and the debt of organisations should be reduced.

For basic research, based on the type of regression and the results of Table 5:

1. The amount of spending on basic research depends only on the accounts payable of organisations.

2. Reducing this debt below 25,140.5 million rubles requires spending on basic research.

3. An increase in debt above 25,140.5 million rubles is inexpedient, because it leads to an outflow of necessary funds for basic research.

For applied research, based on the type of regression and the results of Table 6:

1. The amount of spending on applied research depends only on the accounts payable of organisations.

2. The minimum value of these costs (5,310.3 million rubles) is achieved in the absence of the debt under consideration.

3. The increase in this debt requires an increase in the cost of applied research.

For developments, based on the type of regression and the results of Table 7:

1. The amount of spending on developments depends only on the GRP.

2. The increase in the amount of GRP above 814 037 million rubles requires development costs.

3. Reducing the amount of GRP below 814 037 million rubles is inexpedient because it leads to an outflow of necessary funds for developments.

Comparing the obtained results with the findings of other researchers, we observed that for planning R&D and financing, Feoktistova (2014) highlighted the use of the project approach, indicating the choice of the expected results of the research project as one of the key criteria, and the choice of the results already achieved by the research project by its potential contractor as the key criterion.

Gaponenko (2018) also considered situations in which it is potentially possible to reduce the actual cost of performing SRW: (1) performing SRW similar to work previously performed by the same contractor—that is, a scientific organisation or researcher; (2) performing SRW similar to work previously performed by other contractors—that is, scientific organisations; performing (possibly simultaneously) similar SRW for different customers; (3) using previously obtained research results, previously collected findings in a new study in case the unrelated old and new research topics; and (4) including in the terms of reference tasks that do not correspond to the purpose of research, the results of which can be used, for example, in another study, publication, or patent.

We propose reasonable quantitative guidelines for planning the costs of SRW in an industrial region, obtained as a result of conventional and global optimisation of the indicated costs. The presented model will allow state agencies and their experts to make better decisions regarding the planning of innovative development of industrial regions in the country.

5. Conclusion

The following are the most important conclusions from the results of the study:

1. The regional model for planning of innovative development programmes implies optimisation of internal current costs of SRW for an industrial region, depending on its investment planning according to the data on the dynamics of investment in fixed capital in the region, production planning according to the data on the dynamics of GRP, and financial planning according to the data on the dynamics of accounts payable of organisations.

2. Under optimisation of the SRW costs, we understand the possibilities to reduce them to that optimal value, which will be achievable with simultaneous investment, production, and financial planning of the region, allowing determining the most appropriate proportions of the above three planning factors in monetary terms.

3. The presented regional model should be sufficiently detailed, for which purpose several target functions of the internal current costs of SRW for an industrial region are investigated: the total costs of SRW and their three components—basic research, applied research, and developments. This will eventually allow for drawing more reasonable conclusions on how an industrial region should develop its internal current costs of SRW, depending on the planning of investments in fixed capital, GRP, and

accounts payable of organisations.

4. The most ideal for solving the problem under consideration is the PS algorithm. In addition, adding this algorithm as a hybrid function for the GA or SA allows for achieving a sufficiently high-quality solution to the optimisation problem. On the contrary, adding the inner point method as a hybrid function does not always significantly improve the quality of global optimisation.

5. In the Nizhny Novgorod region, to minimise all the internal current SRW costs, it is necessary to increase investment in fixed capital and GRP volume, as well as to reduce the amount of accounts payable by organisations.

6. However, for basic research, there is a limit of indebtedness of organisations, the exceeding of which is inexpedient, because it leads to an outflow of necessary funds for basic research.

7. The increase in this debt also leads to an increase in the cost of applied research.

8. For developments, there is a lower limit of the GRP amount, below which it is inadvisable to go, as it leads to the outflow of the necessary funds for developments. Since developments constitute the main part of all SRW costs and the management of GRP, production constitutes the main part of the successful financing of all SRW costs in the industrial region under consideration.

Acknowledgements

The research was supported by the Russian Foundation for Basic Research within the framework of the scientific project No. 19-010-00932 “Creating a model for the evolution of the innovation system of industrial regions in modern conditions of socio-economic development”.

References

Babynin, M.S., Zhadan, V.G., 2008. Pryamoy metod vnutrenney tochki dlya lineynoy zadachi poluopredelionnogo programmirovaniya [Direct internal point method for a linear semi-definite programming problem]. Journal of Computational Mathematics and Mathematical Physics 48(10), 1780–1801.

Brigham, E.F., Gapenski, L.C., 1993. Intermediate Financial Management, fourth ed. The Dryden Press, Orlando, FL.

Chen, Zh., Yang, Zh., Yang, L., 2019. How to optimize the allocation of research resources? An empirical study based on output and substitution elasticities of universities in Chinese provincial level. Socio-Economic Planning Sciences 69. https://doi.org/10.1016/j.seps.2019.04.004

Conn, A.R., Gould, N.I.M., Toint, Ph.L., 1991. A globally convergent augmented Lagrangian algorithm for optimization with general constraints and simple bounds. SIAM Journal on Numerical Analysis 28(2), 545–572.

Conn, A.R., Gould, N.I.M., Toint, Ph.L., 1997. A globally convergent augmented Lagrangian barrier algorithm for optimization with general inequality constraints and simple bounds. Mathematics of Computation 66(217), 261–288.

Dinges, E.V., Pozdeyeva, S.N., 2018. Metody Planirovaniya Investitsionno-Finansovoy Deyatel’nosty Predpriyatiy Dorozhnogo Khozyaystva: Monographiya [Methods of Planning Investment and Financial Activities of Road Enterprises: Monograph], MADI, Moscow, 116 p.

Dobrzanski, P., Bobowski, S., 2020. The efficiency of R&D expenditures in ASEAN countries. Sustainability 12, 1–26. https://doi.org/10.3390/su12072686

Fabiana, M.S., Edson, A.A., Querido, O., Marcela, B.M., 2016. Innovation development process in small and medium technology-based companies. RAI Revista de Administração e Inovação 13, 176–189. http://dx.doi.org/10.1016/j.rai.2016.04.005

Feoktistova, O.A., 2014. Planirovaniye zatrat na nauchniye issledovaniya: proektniy podkhod [Research cost planning: project approach]. Financial Journal 1, 69–80.

Gaponenko, V.F., 2018. Voprosy planirovaniya zatrat na vypolneniye nauchno-issledovatel’skikh rabot v sisteme MVD Rossii [The questions of costs’ planning on implementation of the scientific research works in the system of the Interior Ministry of Russia]. Proceedings of Management Academy of the Ministry of the Interior of Russia 1(45), 58–62.

Hahn, G., Kuhn, H., 2012. Simultaneous investment, operations, and financial planning in supply chains: a value-based optimization approach. International Journal of Production Economics 140, 559–569. https://doi.org/10.1016/j.ijpe.2012.02.018

Ingber, L., Rosen, B., 1992. Genetic algorithms and very fast simulated reannealing: a comparison. Mathematical and Computer Modelling 16(11), 87–100.

Kalyanmoy, D., 2001. Multiobjective Optimization Using Evolutionary Algorithms, John Wiley & Sons, Inc., New York.

Kolda, T.G., Lewis, R.M., V. Torczon, V., 2006. A generating set direct search augmented Lagrangian algorithm for optimization with a combination of general and linear constraints, Technical Report SAND2006-5315, Sandia National Laboratories, Oak Ridge.

Kruschwitz, L., Lorenz, D., 2019. Investitionsrechnung, De Gruyter Oldenbourg (Verlag), Munchen, Wien.

Limitovskiy, M.A., 2019. Investitsionnye Proekty i Realnye Optsiony na Razvivayuschikhsya Rynkakh [Investment Projects and Real Options in Developing Markets], Yurayt, Moscow.

Lopatin, A.S., 2005. Metod otzhiga [Annealing method]. Stochastic Optimization in Computer Science 1, 133–139.

Naumenkova, S.V., Glazun, O.I., 2002. Ispol’zovaniye metodov kolichestvennogo prognozirovaniya v protsesse finansovogo planirovani-

ya deyatel'nosti predpriyatiya [Use quantitative forecasting methods in the financial planning of an enterprise]. Visnyk of the Ukrainian Academy of Banking Affairs 1, 32–36.

Nedosekin, A.O., Abdulaeva, Z.I., 2013. Modeli i metody finansovogo planirovaniya: monographiya [Models and methods of financial planning: monograph], Peter the Great St. Petersburg Polytechnic University, St. Petersburg.

Polyanin, A., Pronyaeva, L., Pavlova, A., Fedotenkova, O., Rodionov, D., 2020. Integrated approach for assessing the economic security of a cluster. International Journal of Technology 11(6), 1148–1160. https://doi.org/10.14716/ijtech.v11i6.4420

Rytikov, S.A., Bogdanov, A.V., Kulakov, A.D., 2014. Primeneniye modeley odnovremennogo investitsionno-finansovogo planirovaniya pri expertize investitsionnykh proyektov rezidentov osoboy ekonomicheskoy zony [Applying the models of simultaneous investment and financial planning for preliminary appraisal of investment projects in a special economic zone]. Economic Analysis: Theory and Practice 40(390), 57–68.

Tashenova, L., Babkin, A., Mamrayeva, D., Babkin, I., 2020. Method for evaluating the digital potential of a backbone innovative active industrial cluster. International Journal of Technology 11(8), 1499–1508. https://doi.org/10.14716/ijtech.v11i8.4537

Vasconcellos, E.P.G., Muritiba, S.N., Prado, S.M.A., Vancetto, M.D.C., Muritiba, P.M., 2016. Analyzing R&D projects on health products. RAI Revista de Administração e Inovação 13, 199–210. http://dx.doi.org/10.1016/j.rai.2016.06.001

Xu, H., 2018. Regional R&D investment and new product development performance of enterprises under the background of knowledge activities. Open Journal of Social Sciences 6, 183–199. https://doi.org/10.4236/jss.2018.63013

Yashin, S., Yashina, N., Koshelev, E., Kashina, O., Pronchatova-Rubtsova, N., 2020. Foresight of Volga Federal District innovation system development using a multi-objective genetic algorithm. International Journal of Technology 11 (6), 1171–1180. https://doi.org/10.14716/ijtech.v11i6.4432

Список источников

Brigham, E.F., Gapenski, L.C., 1993. Intermediate Financial Management, fourth ed. The Dryden Press, Orlando, FL.

Chen, Zh., Yang, Zh., Yang, L., 2019. How to optimize the allocation of research resources? An empirical study based on output and substitution elasticities of universities in Chinese provincial level. Socio-Economic Planning Sciences 69. https://doi.org/10.1016/j.seps.2019.04.004

Conn, A.R., Gould, N.I.M., Toint, Ph.L., 1991. A globally convergent augmented Lagrangian algorithm for optimization with general constraints and simple bounds. SIAM Journal on Numerical Analysis 28(2), 545–572.

Conn, A.R., Gould, N.I.M., Toint, Ph.L., 1997. A globally convergent augmented Lagrangian barrier algorithm for optimization with general inequality constraints and simple bounds. Mathematics of Computation 66 (217), 261–288.

Dobrzanski, P., Bobowski, S., 2020. The efficiency of R&D expenditures in ASEAN countries. Sustainability 12, 1–26. https://doi.org/10.3390/su12072686

Fabiana, M.S., Edson, A.A., Querido, O., Marcela, B.M., 2016. Innovation development process in small and medium technology-based companies. RAI Revista de Administração e Inovação 13, 176–189. http://dx.doi.org/10.1016/j.rai.2016.04.005

Hahn, G., Kuhn, H., 2012. Simultaneous investment, operations, and financial planning in supply chains: a value-based optimization approach. International Journal of Production Economics 140, 559–569. https://doi.org/10.1016/j.ijpe.2012.02.018

Ingber, L., Rosen, B., 1992. Genetic algorithms and very fast simulated reannealing: a comparison. Mathematical and Computer Modelling 16(11), 87–100.

Kalyanmoy, D., 2001. Multiobjective Optimization Using Evolutionary Algorithms, John Wiley & Sons, Inc., New York.

Kolda, T.G., Lewis, R.M., V. Torczon, V., 2006. A generating set direct search augmented Lagrangian algorithm for optimization with a combination of general and linear constraints, Technical Report SAND2006-5315, Sandia National Laboratories, Oak Ridge.

Kruschwitz, L., Lorenz, D., 2019. Investitionsrechnung, De Gruyter Oldenbourg (Verlag), Munchen, Wien.

Polyanin, A., Pronyaeva, L., Pavlova, A., Fedotenkova, O., Rodionov, D., 2020. Integrated approach for assessing the economic security of a cluster. International Journal of Technology 11(6), 1148–1160. https://doi.org/10.14716/ijtech.v11i6.4420

Tashenova, L., Babkin, A., Mamrayeva, D., Babkin, I., 2020. Method for evaluating the digital potential of a backbone innovative active industrial cluster. International Journal of Technology 11(8), 1499–1508. https://doi.org/10.14716/ijtech.v11i8.4537

Vasconcellos, E.P.G., Muritiba, S.N., Prado, S.M.A., Vancetto, M.D.C., Muritiba, P.M., 2016. Analyzing R&D projects on health products. RAI Revista de Administração e Inovação 13, 199–210. http://dx.doi.org/10.1016/j.rai.2016.06.001

Xu, H., 2018. Regional R&D investment and new product development performance of enterprises under the background of knowledge activities. Open Journal of Social Sciences 6, 183–199. https://doi.org/10.4236/jss.2018.63013

Yashin, S., Yashina, N., Koshelev, E., Kashina, O., Pronchatova-Rubtsova, N., 2020. Foresight of Volga Federal District innovation system development using a multi-objective genetic algorithm. International Journal of Technology 11(6), 1171–1180. https://doi.org/10.14716/ijtech.v11i6.4432

Бабынин, М.С., Жадан, В.Г., 2008. Прямой метод внутренней точки для линейной задачи полуопределенного программирования. Журнал вычислительной математики и математической физики 48(10), 1780–1801.

Гапоненко, В.Ф., 2018. Вопросы планирования затрат на выполнение научно-исследовательских работ. Труды Академии управления МВД России 1(45), 58–62.

Дингес, Э.В., Поздеева, С.Н., 2018. Методы планирования инвестиционно-финансовой деятельности предприятий дорожного хозяйства: Монография, МАДИ, Москва, 116 с.

Лимитовский, М.А., 2018. Инвестиционные проекты и реальные опционы на развивающихся рынках, Юрайт, Москва.

Лопатин, А.С., 2005. Метод отжига. Стохастическая оптимизация в информатике 1, 133–149.

Науменкова, С.В., Глазун, О.И., 2002. Использование методов количественного прогнозирования в процессе финансового планирования деятельности предприятия. Вестник Украинской академии банковского дела 1, 32–36.

Недосекин, А.О., Абдулаева, З.И., 2013. Модели и методы финансового планирования: Монография. Издательство Политехнического университета, Санкт-Петербург, 176 с.

Рытиков, С.А., Богданов, А.В., Кулаков, А.Д., 2014. Применение моделей одновременного инвестиционно-финансового планирования при экспертизе инвестиционных проектов резидентов особой экономической зоны. Экономический анализ: теория и практика 40(390), 57–68.

Феоктистова, О.А., 2014. Планирование затрат на научные исследования: проектный подход. Финансовый журнал 1(19), 69–80.

The article was submitted 01.09.2022, approved after reviewing 13.11.2022, and accepted for publication 17.11.2022.

Статья поступила в редакцию 01.09.2022, одобрена после рецензирования 13.11.2022, принята к публикации 17.11.2022.

About the authors:

1. Dmitrii Rodionov, Doctor of Economics, professor, Head of Graduate School of Industrial Economics, Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, Russia.
drodionov@spbstu.ru, https://orcid.org/0000-0002-1254-0464

2. Egor Koshelev, candidate of economic science, Associate Professor of the Department of Management and Public Administration, Lobachevsky State University of Nizhny Novgorod, Nizhny Novgorod, Russian Federation. ekoshelev@yandex.ru, https://orcid.org/0000-0001-5290-7913

3. John Gayomey, Lecturer, Department of Accountancy, Tamale Technical University, Tamale, Ghana. gayomey@hotmail.com

4. Olga Ferraro, Ph.D. in Business Administration, Resercher of the Department in Business Administration and Law, University of Calabria, Italy. olga.ferraro@unical.it, https://orcid.org/0000-0001-7070-2815

Информация об авторах:

1. Дмитрий Григорьевич Родионов, доктор экономических наук, профессор, директор Высшей инженерно-экономической школы, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Российская Федерация. drodionov@spbstu.ru, https://orcid.org/0000-0002-1254-0464

2. Егор Викторович Кошелев, кандидат экономических наук, доцент кафедры менеджмента и государственного управления, Нижегородский государственный университет им. Н.И. Лобачевского, Нижний Новгород, Российская Федерация. ekoshelev@yandex.ru, https://orcid.org/0000-0001-5290-7913

3. Джон Гайомей, преподаватель кафедры бухгалтерского учета Технического университета Тамале, Тамале, Гана. gayomey@hotmail.com

4. Ольга Феррaро, PhD в области делового администрирования, преподаватель кафедры делового администрирования и права, Университет Калабрии, Италия. olga.ferraro@unical.it, https://orcid.org/0000-0001-7070-2815

Research article
DOI: https://doi.org/10.48554/SDEE.2022.4.3

Organisational and Economic Model of Innovation and Resource Potential Management of a Water Supply Enterprise in the Context of Sustainable Development

Alina Furtatova[1*], Natalia Viktorova[1], Diankai Wang[2]

[1] Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, Russian Federation, alina_furtado@mail.ru, viktorova_ng@spbstu.ru
[2] Zhejiang International Studies University, Hangzhou, PRC, wangdiankai@zisu.edu.cn
[*] Corresponding author: alina_furtado@mail.ru

Abstract

This paper is devoted to the problems of managing the innovation and resource potential of water supply enterprises for the purpose of their sustainable development. The study develops an organisational and economic model of innovation and resource potential management of water supply enterprises, tests the model within the activities of a particular enterprise, and, consequently, forms recommendations to improve the management of the innovation and resource potential of the water supply enterprise. The creation of the model is based on the results of earlier studies in which we proved the necessity of using the term "innovation and resource potential of an enterprise" in scientific and practical vocabulary. We previously substantiated the significance of considering innovation and resource potential, studying its essence and structure in relation to water supply enterprises as economic entities that implement the most important goal of sustainable development associated with providing the population with high-quality drinking water. Our previous methodology assessed the innovation and resource potential of a water supply enterprise. The present study applies various methods of analysis, synthesis, structuring, and generalisation, as well as regression analysis. In the proposed model, the external and internal environments and input and output parameters specific to water supply enterprises are reflected in their interrelations. The model is tested on the example of the State Unitary Enterprise "Vodokanal of St. Petersburg". In particular, the influence of the introduction of an intelligent automated system of management in Saint Petersburg's water supply system on the value of the innovation and resource potential (in terms of its sub-potentials) and on the resultant indices of the enterprise performance is evaluated. We propose guidelines for managing each structural element of innovation and resource potential.

Keywords: sustainable development; innovation and resource potential; water supply enterprise; drinking water production; management; model

Citation: Furtatova, A., Viktorova, N., Wang, D., 2022. Organisational and economic model of innovation and resource potential management of a water supply enterprise in the context of sustainable development. Sustainable Development and Engineering Economics 4, 3. https://doi.org/10.48554/SDEE.2022.4.3

This work is licensed under a CC BY-NC 4.0

© Furtatova, A., Viktorova, N., Wang, D., 2022. Published by Peter the Great St. Petersburg Polytechnic University

Научная статья

УДК 338.242

DOI: https://doi.org/10.48554/SDEE.2022.4.3

Организационно-Экономическая Модель Управления Инновационно-Ресурсным Потенциалом Предприятия Водоснабжения

Алина Фуртатова[1*], Наталья Викторова[1], Дянькай Ван[2]

[1] Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Российская Федерация., alina_furtado@mail.ru, viktorova_ng@spbstu.ru

[2] Чжэцзянский университет международных исследований, Ханчжоу, КНР. wangdiankai@zisu.edu.cn

[*] Автор, ответственный за переписку: alina_furtado@mail.ru

Аннотация

Статья посвящена проблемам управления инновационно-ресурсным потенциалом предприятий водоснабжения в целях их устойчивого развития. Основной посыл исследования связан с необходимостью разработки организационно-экономической модели управления инновационно-ресурсным потенциалом предприятий водоснабжения, ее апробацией в деятельности конкретного предприятия и на основе этого формирования рекомендаций по совершенствованию управления инновационно-ресурсным потенциалом предприятия водоснабжения. Построение модели базируется на следующих результатах ранее проведенных авторских исследований. Во-первых, доказавших необходимость использования в научно-практическом обороте термина «инновационно-ресурсный потенциал предприятия». Во-вторых, обосновавших значимость рассмотрения инновационно-ресурсного потенциала, изучения его сущности и структуры применительно к предприятиям водоснабжения, как экономическим субъектам, реализующим важнейшую цель устойчивого развития, связанную с обеспечением населения качественной питьевой водой. В-третьих, реализовавших методику оценки инновационно-ресурсного потенциала предприятия водоснабжения. В исследовании применены методы анализа и синтеза, структурирования и обобщения, регрессионного анализа. В предлагаемой модели во взаимосвязи отражены специфические для предприятий отрасли водоснабжения внешняя и внутренняя среда, входные и выходные параметры. Модель апробирована на примере ГУП «Водоканал Санкт-Петербурга». В частности, оценено влияние от внедрения автоматизированной системы интеллектуального управления водоснабжением Санкт-Петербурга на величину инновационно-ресурсного потенциала (в разрезе его субпотенциалов) и на результирующие показатели деятельности предприятия. Предложены рекомендации по управлению каждым структурным элементом инновационно-ресурсного потенциала.

Ключевые слова: управление, модель, инновационно-ресурсный потенциал, предприятие водоснабжения, устойчивое развитие, прогнозирование

Цитирование: Фуртатова, А., Викторова, Н., Ван, Д., 2022. Организационно-экономическая модель управления инновационно-ресурсным потенциалом предприятия водоснабжения. Sustainable Development and Engineering Economics 4, 3. https://doi.org/10.48554/SDEE.2022.4.3

Эта работа распространяется под лицензией CC BY-NC 4.0

© Фуртатова, А., Викторова, Н., Ван, Д., 2022. Издатель: Санкт-Петербургский политехнический университет Петра Великого

1. Introduction

Given the technological transformations affecting all social relations today, the need to consider economic objects and phenomena in the state of their movement and constant variability has become crucial (Barykin et al., 2020). These innovations accompany the naturally inevitable progressive nature of the progressive development of economic systems. Therefore, as an economic object and part of the economic system, an enterprise should seek innovative technological solutions to improve the efficiency of its activities, taking into consideration the rational use of available resources. Thus, there is a need to study the innovation potential of enterprises together with their resource potential, which requires theoretical and science-to-practice approaches to the representation of the total innovation and resource potential, identifying their essence and structure, and proposing methods for managing such a potential. Solving such problems is important for enterprises in any industry. This is especially relevant for enterprises in resource-intensive industries, which, in particular, include water supply enterprises. With regard to the activities of such enterprises, accounting, rational use of water resources (due to their qualitative and quantitative instability), and applied and innovative technologies are required.

Identifying, evaluating, and managing the potential of enterprises in the water supply industry is also of high priority in the framework of Sustainable Development Goal 6—"Ensure availability and sustainable management of water and sanitation for all"—of the 2030 Agenda for Sustainable Development. According to the UN annual reports, the global challenge for states by 2030 is "to achieve universal and equitable access to safe and affordable drinking water for all". The solution to this task is the main objective of the functioning of resource-supplying organisations in the water supply industry. Water supply enterprises are obliged to provide consumers with drinking water of guaranteed quality to maintain decent standards of living for the population and ensure the sustainable development of their activities through the application of innovative technologies in the industry. This requires improving the management of enterprise activities, including the management of innovation and resource potential, which is also confirmed by the literature.

2. Literature review

Numerous studies conducted by scientists around the world have been devoted to the study of such a phenomenon as potential, its characteristics and properties, determination methods, and management models. In the socio-economic aspect, the purpose of potential management is to ensure the sustainable development of a country, industry, or enterprise (Rudskaia and Rodionov, 2018, Rodionov et al., 2018, Tereshko et al., 2021). Depending on the territorial, economic, political, cultural, and other features of economic objects, researchers analyse potential, categorising it into components or considering its integrated essence (Tashenova et al., 2020), using a variety of tools for managing potential (Niewöhner et al., 2021). To manage this potential, it is necessary to correctly assess it, as tackled by a number of studies for various purposes.

According to Yashin et al. (2021), innovation potential is considered a combination of production, financial, labour, and other resources, assessment, and management that contributes to successful development of the region. Rakhmeeva (2020) emphasised that the key role in improving the economic efficiency of enterprises under the conditions of transformation of economic relations and institutional changes is innovation potential. The study of company performance management through innovation potential examines the issue of innovation management in a highly competitive environment, rapid technological change, and market uncertainty. Today, it is extremely important for enterprises to introduce advanced innovative technologies into their production processes and manage their innovation potential to survive (Ahmed et al., 2020). Thus, Cansi (2021) presented an assessment of the country's innovation potential (using the example of the United States) over the past few decades. The author proves that there is a connection between the innovation potential of enterprises and the general state of the state economy.

The branch specificity of the assessment and management of innovation potential has been emphasised in a few studies. For example, in the agricultural sector, a special role is played by issues related to

the management of the innovation potential in the industry. Somkuwar et al. (2022) associated this type of potential with the application of various kinds of innovation in agro-industrial enterprises. The existing problems of large-scale physical and chemical pollution in soils threaten food security as the population increases. Thus, agro-industrial enterprises require the introduction of environmentally sustainable innovative technologies to avoid huge losses in agricultural production. Fallah-Alipour et al. (2018) demonstrated the potential of agricultural enterprises. Their methodology for assessing the potential of agricultural areas was based on a system of environmental, social, economic, and other indicators. The obtained results allowed for the formulation of recommendations for the effective use of land to ensure the sustainable development of the country.

Dzikuć et al.'s (2021) study on the prospects of low-carbon development in Poland and switching to renewable energy sources raises one of the most important problems of the need to assess and manage innovation potential through the effective implementation of energy production technologies based on low-carbon fuels. Martins et al. (2018) studied the issues of research into the fuel and energy complex enterprise, proposing a model for assessing the innovation potential of power generation companies in Portugal. The essence of the model was to develop areas of effective management mechanisms for such enterprises to achieve environmental sustainability in the form of reducing greenhouse gas emissions through the introduction of innovative "green" technologies. The potential of electric power companies was also considered in the example of Pakistan, where the created model of enterprise management justified the feasibility of power generation using wind power plants (Hulio et al., 2017).

Summarising the above efforts, problems affecting the innovation potential of an enterprise are relevant and up-to-date. The present study focuses on the question of the importance of such problems in the sphere of water supply, which has been underscored by recent studies. Kydyrbekova et al. (2022) used the example of Kazakhstan and a number of other countries to systematise potential problems associated with water resources, which require improvement of the innovation activities of water supply enterprises. Based on a survey of related companies, the authors substantiated the potential impact of the COVID-19 pandemic on the formation of innovations in the water supply and sanitation sectors. Such crises have been shown to have a negative impact on large water supply enterprises. Other researchers have come to a similar conclusion. For example, Maryati and Azizah (2022) considered six informal settlements in Indonesia. The main innovations during the COVID-19 pandemic were described as arrangements for the use of common facilities and the provision of hand-washing devices, which can hardly be called breakthrough innovations for the water supply sector. The authors' recommendations are related to the need for the transformation of the institutional environment.

The connection between innovations in water supply and the sustainable development of territories can be traced in the literature. The technological innovation "biofarm", which enables the rational use of rain and storm water for domestic needs and the creation of a surface water reservoir, was proposed by Rybicki et al. (2022). Such a design is aimed at improving the quality of life of the population and the ecological conditions of the environment. Puppim de Oliveira et al. (2022) proposed innovations in urban green and blue infrastructure, including progressive technological solutions in the use of water resources, to implement the goals of sustainable development. According to the authors, such an approach is relevant to the concepts of a closed-loop economy, urban transformation, and smart cities. This conclusion was reinforced by Wuijts et al. (2022), who analysed the impact of water sources on urban development in terms of climate change and socio-economic transformations (tourism, urbanisation, and increasing social inequality). In their study of five European cities (Amsterdam, Barcelona, Plymouth, Tallinn, and Thessaloniki), the authors showed the importance of considering the characteristics and state of local water sources when making managerial decisions regarding sustainable urban development.

These previous studies clearly substantiated the importance of innovations in the sphere of water supply and sanitation for the sustainable development of territories. However, the problem of improving the management of water supply enterprises in the context of innovation potential is equally significant. This problem has not drawn sufficient attention in scientific research. Therefore, the purpose of the pres-

ent study is to construct an organisational-economic model of the management of the innovation and resource potential of water supply enterprises, testing its performance in the activities of a case enterprise to determine the areas of sustainable development.

3. Materials and methods

The proposed study systematises the authors' earlier developments of the theoretical and methodological nature of the issues of the innovation and resource potential of water supply enterprises (Furtatova and Viktorova, 2020) to obtain new scientific and practical results, which are implemented in the following logical sequence:

1. Development of an organisational and economic model of managing the innovation and resource potential of a water supply enterprise with an allowance for the specifics of its activities for sustainable development. The object of management, its structural parts, external and internal environments, input and output parameters, methodological tools, and the relationship between all elements of the model are identified.

2. Testing of the organisational and economic model of managing the innovation and resource potential on the example of State Unitary Enterprise (SUE) "Vodokanal of St. Petersburg" during the adoption of an innovative technological solution—an intelligent automation system of water supply management in St. Petersburg

3. Proposal of recommendations for each sub-potential to improve the management of the innovation and resource potential of the water supply enterprise.

To develop the elements of the organisational and economic model, we used general scientific methods of analysis and synthesis, structuring, and generalisation. We determined the specific external and internal environments of the water supply enterprise, formulated the notion and content of the category "innovation and resource potential of a water supply enterprise", and identified the aggregated elements of such a potential (sub-potential). We also applied economic and mathematical methods of regression analysis (Song and Li, 2021) in developing this potential resource for assessing innovation. To assess the impact of introducing an innovative technology on innovation and resource potential and the resultant performance indicators of the enterprise, we used mathematical calculations to predict changes in the value of the innovation and resource potential up to 2025. The innovation and resource potential were considered in terms of the following sub-potentials: educational and personnel, scientific, and research, production and technological, information technology, socio-environmental, financial and economic, and organisational and managerial (Furtatova and Viktorova, 2020). The resultant indicators were represented by the following set: water loss during transportation, total water loss, revenue, profit, costs, and volume of the water consumed.

As the initial information, we used the data from annual reports of St. Petersburg water supply enterprise – State Unitary Enterprise "Vodokanal of St. Petersburg" for 2011–2020 (hereafter, the water supply enterprise).

4. Results

A summary of our previous work on the organisational and economic model for managing the innovation and resource potential of the water supply enterprise is presented in Figure 1. We describe this model, emphasising the results obtained earlier (elements of the model) in their interrelation and interdependence.

The proposed model identifies the external environment factors that are significant for water supply enterprises: economic, environmental, infrastructural, political, and technological. The input parameter is water from a water source. It passes through the stages of water treatment, transportation, and water consumption. The output is drinking water and water supply services. Business processes are implemented with the use of innovation and resource potential, which is the object of management for en-

terprise administration. The described elements are compactly reflected in organisational and economic models. The core of the organisational and management model is the innovation and resource potential of the water supply enterprise. We define such potential as "a set of structural elements (sub-potentials), with the help of which a water supply enterprise is able to use available resources in the best way, taking into consideration the application of progressive achievements of science and technology, to implement its statutory activities—providing consumers with high-quality water supply services—and to develop the innovative activities of these enterprises" (Furtatova and Viktorova, 2020).

The innovation and resource potential in the model is considered in terms of its seven sub-potentials. The selection of these sub-potentials is conditioned by the following circumstance. The components of the innovation and resource potential adopted for enterprises in other spheres of activity (financial, labour, production, and innovation sub-potentials), as well as specific ones, are characteristic of water supply enterprises. Taking this into consideration, the present study examined the following sub-potentials: financial and economic, educational, and personnel, organisational, and managerial, information technology, production and technological, scientific and research, socio-environmental. The choice of such varieties of sub-potentials is substantiated in detail in the authors' publication (Furtatova and Viktorova, 2020). Innovation and resource potential, as reflected in the model, directly affect the results of innovation activity (output parameters). We propose assessing this potential and analysing its impact on the resultant performance indicators of the enterprise in accordance with the algorithm in Figure 2, which is described in detail in our previous study (Furtatova et al., 2021).

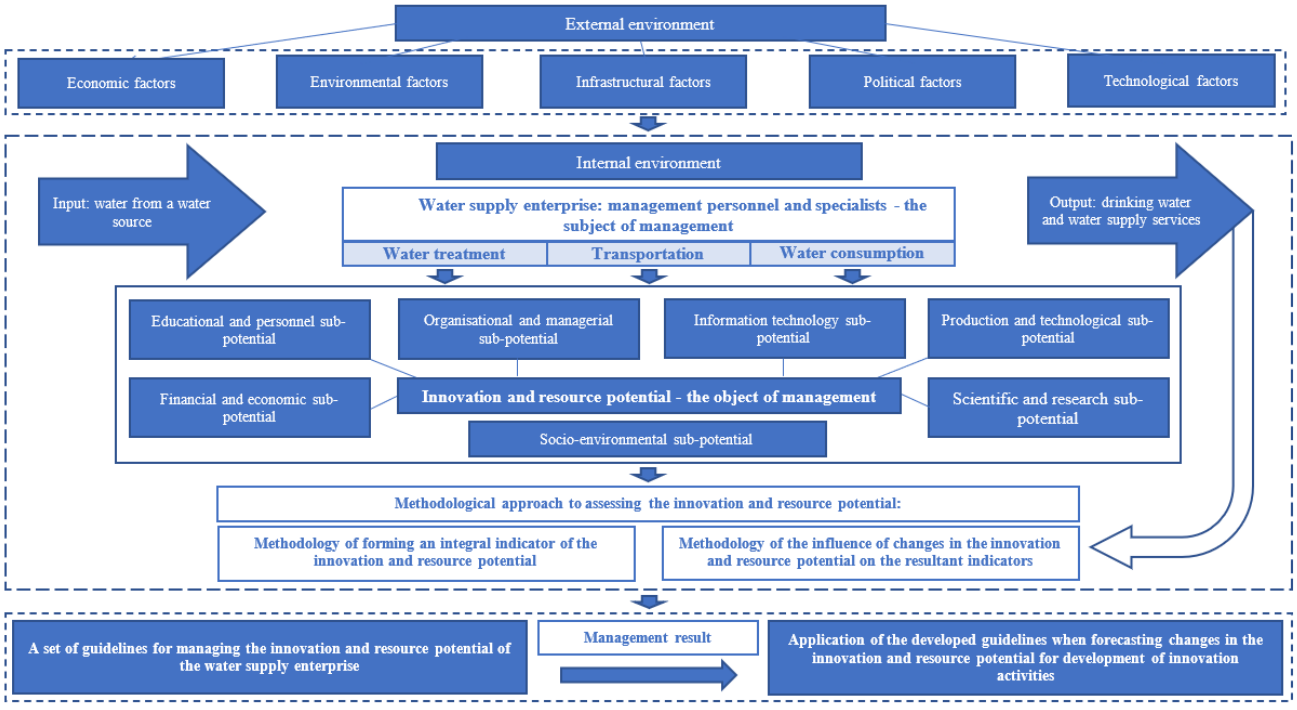

Figure 1. Organisational and economic model of management of the innovation and resource potential of water supply enterprises

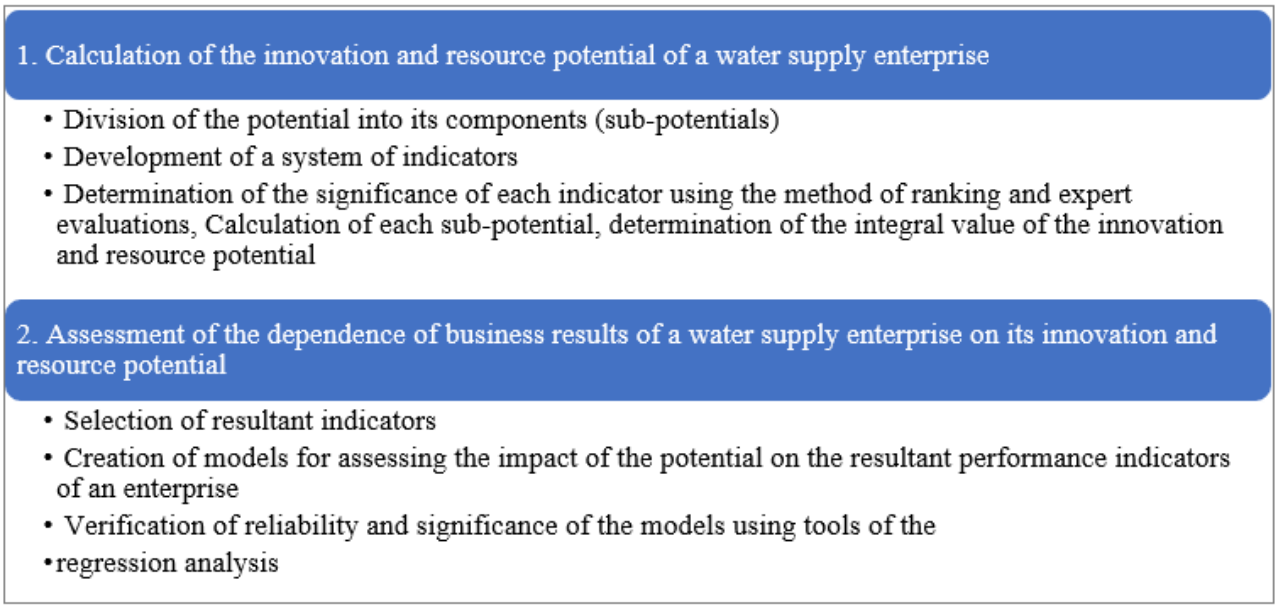

Figure 2. Algorithm for assessing the innovation and resource potential of a water supply enterprise

For modelling, we chose the indicators that characterise the sustainability of development of a water supply enterprise: 1) group of environmental indicators (water loss during transportation and total water loss); 2) group of economic indicators (profit, costs, and revenue); 3) social indicator – drinking water supply to consumers (volume of the water consumed). As shown in the organisational and economic model of innovation and resource potential management (Figure 1), problem areas are highlighted, and recommendations for improving each of the sub-potentials are formed for predicting the development of activities of a water supply enterprise, taking into consideration the use of various kinds of innovations. The model (its methodological part) was tested on the example of the data on SUE "Vodokanal of St. Petersburg".

We determined the values of the integral indicator of the innovation and resource potential (Table 1) by calculating the integral values for each sub-potential according to the following formula (1):

$$I_p = \sum_{i=1}^{m} w_i \times k_i \quad (1)$$

where:

I_p is the value of the integral indicator by a sub-potential;

k_i is the value of the indicator describing the sub-potential;

w_i is the weighting factor obtained by applying the ranking method and expert evaluations (Furtatova et al., 2021).

We calculated the integral value of the innovation and resource potential of the water supply enterprise using Formula (2), where $I_{\text{IRP...EPS}}$ represents the integral values of the corresponding sub-potential (potential).

$$I_{\text{IRP}} = I_{\text{EPS}} + I_{\text{SRS}} + I_{\text{ITS}} + I_{\text{PTS}} + I_{\text{SES}} + I_{\text{FES}} + I_{\text{OMS}} \quad (2)$$

Table 1. Value of the innovation and resource potential of SUE "Vodokanal of St. Petersburg" in 2010-2020

Sub-potential / Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Educational and personnel	0.268	0.294	0.293	0.298	0.303	0.309	0.302	0.300	0.296	0.289	0.291
Scientific and research	0.312	0.316	0.323	0.320	0.319	0.316	0.311	0.314	0.315	0.319	0.321
Information technology	0.472	0.485	0.517	0.529	0.539	0.532	0.543	0.556	0.563	0.569	0.575
Production and technological	0.365	0.367	0.389	0.383	0.379	0.386	0.385	0.386	0.379	0.378	0.380
Socio-environmental	0.611	0.612	0.617	0.613	0.630	0.629	0.623	0.640	0.644	0.642	0.651
Financial and economic	0.284	0.284	0.288	0.285	0.275	0.276	0.259	0.279	0.299	0.311	0.328
Organisational and managerial	0.299	0.292	0.306	0.328	0.329	0.322	0.336	0.339	0.337	0.337	0.331
TOTAL, integral indicator	2.610	2.651	2.733	2.756	2.775	2.769	2.761	2.814	2.834	2.844	2.876

We assessed the impact of the innovation and resource potential on resultant indicators of an enterprise (Georgiev et al., 2018). The results are summarised in Table 2.

Table 2. Summary of the results of regression models

Model	Assessing the impact of the innovation and resource potential on:	Regression equation and coefficient of determination	Elasticity coefficient
1	Water loss during transportation	$y = -218976x + 681908$ $R^2 = 0.896$	-7.9%
2	Total water loss	$y = -417828x + 1E+06$ $R^2 = 0.8975$	-5.5%
3	Service revenue	$y = 3E+07x - 6E+07$ $R^2 = 0.6901$	6.1%
4	Profit	$y = 2E+08x^2 - 8E+08x + 1E+09$ $R^2 = 0.8605$	6.5%
5	Costs	$y = 1E+07x - 3E+07$ $R^2 = 0.6389$	4.7%
6	Volume of the water consumed	$y = -512903x + 2E+06$ $R^2 = 0.835$	-2.6%

Based on the calculated the elasticity coefficients, the following conclusions are drawn:

1. Environmental indicators (water loss during transportation, total water loss): To a great extent, the rise of the innovation and resource potential by 1% will cause a decrease in the indicator of "water loss during transportation" by almost 8%. This will have a positive impact on the decrease in water loss during transportation, that is, the difference between the volume of the water consumed and the water supplied after water treatment. Thus, the higher the innovation and resource potential that the water supply enterprise has through changes in indicators by sub-potentials, the less water the enterprise will lose

during transportation. A 1% increase in the innovation and resource potential will result in reducing the indicator of "total water loss" by 5.5%, which is lower than the value of the previous indicator by 2.4%. This is explained by the fact that this indicator includes water loss during production, and the reduction of this indicator requires large-scale measures to modernise capacities and water treatment facilities.

2. Social indicator (the volume of the water consumed). With a 1% increase in the innovation and resource potential, the lowest change is the decrease in water consumption by 2.6%. This situation is regular, as the strategic goal of a water supply enterprise is the rational use of resources, which ensures sustainable growth for the good of future generations. The water supply enterprise adopts resource-saving technologies that reduce the amount of initial water from the water source. The hydraulic operation of the water piping system and its regular checks can contribute to cutting water loss.es Additionally, mutual cooperation with customers aimed at raising awareness of environmentally friendly water consumption can ensure a decrease in the indicator of "the volume of the water consumed".

3. Economic indicators (service revenue, profit, costs): The rise of the innovation and resource potential by 1% will lead to the increase of all financial and economic resultant indicators considered in the given model. The rise of costs is determined by the necessity to fund activities for maintaining innovation and resource potential through the system of sub-potentials, which are mandatory for the sustainable development of a water supply enterprise. However, the increase in the profit and service revenue of the water supply enterprise is much higher than the increase in costs, which ensures the efficiency of the water supply enterprise's performance.

Based on these conclusions, we affirm that, primarily, the change in the innovation and resource potential of the water supply enterprise by 1% will cause a decrease in the percentage of the environmental indicators, namely, *water loss (total and during transportation).*

Next, we identified several efficiency potentials for the use of water resources based on the water supply stages (business processes).

At the water treatment stage, a considerable amount of water (about 20%) is spent on washing filter facilities to ensure a smooth technological process. The process of washing filter facilities at the water supply enterprise requires pure water, which undergoes technological purification with the use of the following: chemicals, electricity, materials, and other economic resources. This approach shows the wasteful and irrational use of the complex of resources (water and economics). After washing the filter facilities, the polluted wash water is sent untreated to nearby water bodies, causing a negative environmental impact on them. For a complex solution to the problems (economic and environmental), it is essential to introduce a closed-cycle technology aimed at purifying and recycling the wash water.

At the transportation stage, to cut water loss, it is necessary to ensure timely maintenance and renovation of water pipelines and utilities (to reduce the risk of emergencies), as well as additional scheduled checks and surveys of water pipelines (to detect defected and broken sections of water supply systems). To reduce water consumption (during emergency and scheduled work), innovative technologies should be adopted to optimise maintenance work for water pipelines in the process of eliminating leaks with an allowance for minimum water consumption for washing. At the production stage, the emphasis is on the competence of maintenance teams who do emergency and scheduled work for water pipelines. Consequently, water supply enterprises should organise regular trainings, tests, and exams for workers in order to increase productivity while maintaining water pipeline systems.

At the water consumption stage, we identified high water losses due to unauthorised consumers who intervene illegally in the centralised drinking water supply system. To reduce these water losses, it is necessary to increase the number of regular checks and control tests of water metre readings, automatic entry of information into the centralised database of water consumption. This will become part of the organisational and managerial information systems of the water supply enterprise. Further, consumers (residents, industrial enterprises, institutions, social objects, etc.) should be educated to raise awareness of water consumption, and rational use of water resources should be emphasised through seminars, ex-

hibitions, conferences, and other events. Based on the example of a group of environmental indicators of water loss, we demonstrated the necessity to undertake measures aimed at increasing the efficiency of using the innovation and resource potential of water supply enterprises at each stage of the production process and by each sub-potential.

Further, we assessed the impact of implementing a promising innovative project for automation of the water supply management system on the innovation and resource potential and resultant performance indicators of an enterprise. The choice of this particular project is due to the current programme of innovative development of SUE "Vodokanal of St. Petersburg for the period of up to 2025".

The implementation of the project, which is aimed at introducing the intelligent automation system for water supply management in St. Petersburg, will help obtain the following results.

1. Increase the ratio of drinking water samples in the water distribution network in compliance with the current legislation of the Russian Federation (on average, by 1.5%).

2. Increase customer satisfaction with water supply services by improving the quality of drinking water and eliminating accidents in water supply networks promptly (on average by 30%).

3. Cut production costs at the expense of ensuring control over the performance of the water supply system and regular maintenance and repair of the equipment (on average by 15%).

4. Cut energy costs at the expense of introducing energy-saving equipment and frequency regulations (on average by 30%).

5. Reduce water loss during production and water loss during transportation (on average, 20%).

To test the proposed model of managing the innovation and resource potential of SUE "Vodokanal of St. Petersburg", we forecast the change in the value of the innovation and resource potential of the enterprise, with allowance for the implementation of the project of introducing the intelligent automation system of water supply management of St. Petersburg, for the period of up to 2025" (Figure 3).

Thus, the forecast shows the growth of the considered potential by 5.5%, compared to the value of 2020. The forecast was made on the basis of the analysis of the effects of the results of the project, aimed at introducing the intelligent automation system of water supply management in St. Petersburg, upon the indicators of the innovation and resource potential, taking into account specifics of sub-potentials. Generally, all the sub-potentials expect growth within 1–8% up to 2025, depending on the impact of the project results on a particular sub-potential:

The educational and personnel sub-potential will rise via recruiting experts with top professional knowledge and competencies to support the management system's functioning.

The scientific research sub-potential will increase due to using intellectual property in enterprise performance, organising cooperation with research and commercial institutions to exchange experience;

The information technology sub-potential of the enterprise will grow as a result of automation and digitalisation of the enterprise's business processes at the expense of introducing innovative software into the management system (Furtatova and Viktorova, 2020).

The production and technological sub-potential will increase due to intensifying the work on renovation, modernisation, and construction of new water supply facilities.

The socio-environmental sub-potential will grow as a result of an increase in customer satisfaction with water supply services and employee satisfaction with working conditions; the implementation of the project will also help protect the environment.

The financial and economic sub-potential, primarily related to the enterprise's property and its funding sources, will rise due to the necessity of long-term funding of the project via various sources.

The organisational and managerial sub-potential will grow as a result of optimising the management structure of the enterprise and encouraging senior managers to gain additional educational qualifications in the area of digital technologies.

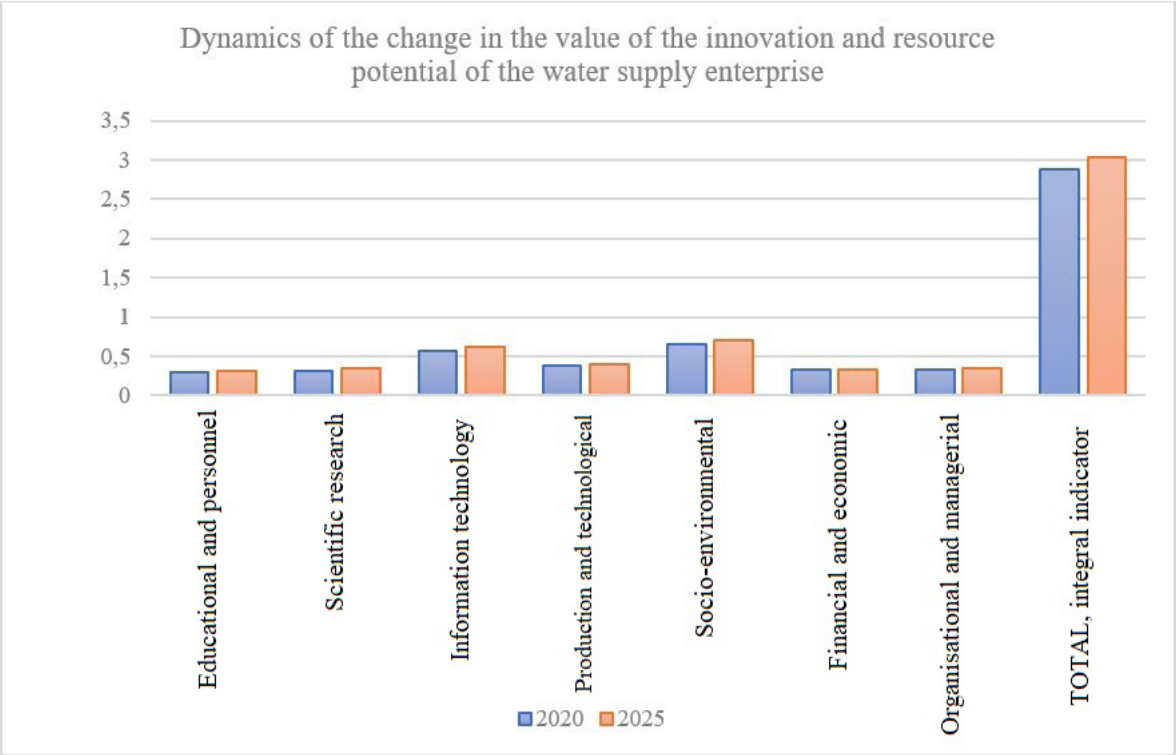

Figure 3. Forecast of changes in the integral value of the innovation and resource potential of the water supply enterprise

The next step in testing the organisational and economic model is to apply the proposed methodology in calculating the forecast values of the resultant indicators for 2025 (the scheduled completion of the project). The calculation results are shown in Figures 4–6.

The introduction of the intelligent automation system of water supply management in St. Petersburg will increase the innovation and resource potential of the water supply enterprise by 5.5%, which will lead to a decrease in these indicators: water loss during transportation (by 70%), total water loss (by 38%), volume of the water consumed (by 20%), profit growth (by 18%), revenue (by 15%), and costs (by 13%) by 2025.

In summary, the organisational and economic model of the innovation and resource potential management for water supply enterprises, which takes into account internal and external environments and input and output parameters, allows the managerial staff to make reasonable recommendations for innovative development of water supply companies. In the general view, and in the view of sub-potentials, such recommendations can be applied to the performance of SUE "Vodokanal of St. Petersburg". These are shown in Figure 7.

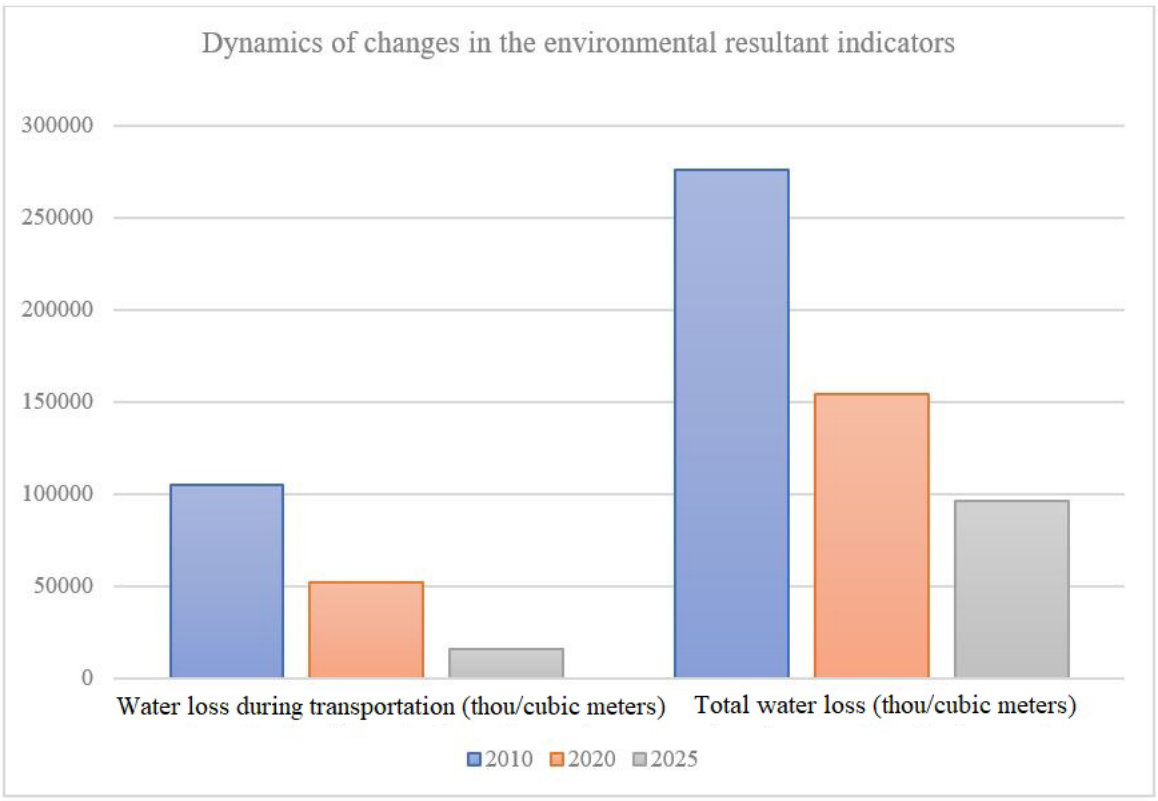

Figure 4. Dynamics of changes in the resultant environmental indicators

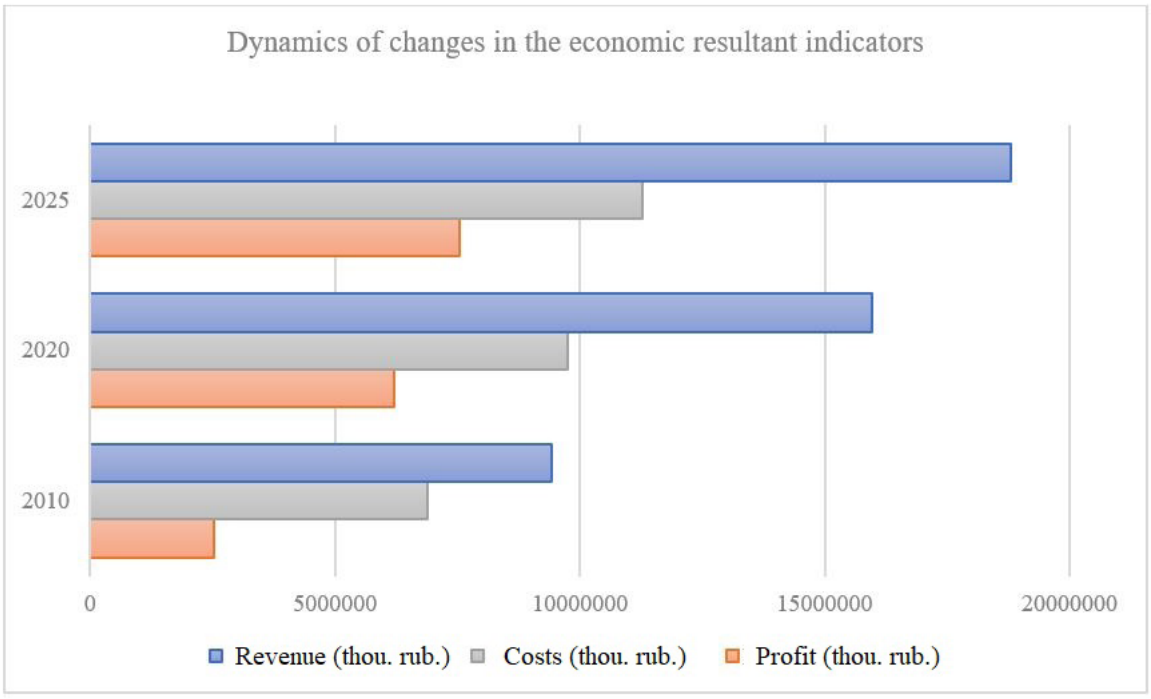

Figure 5. Dynamics of changes in the resultant economic indicators

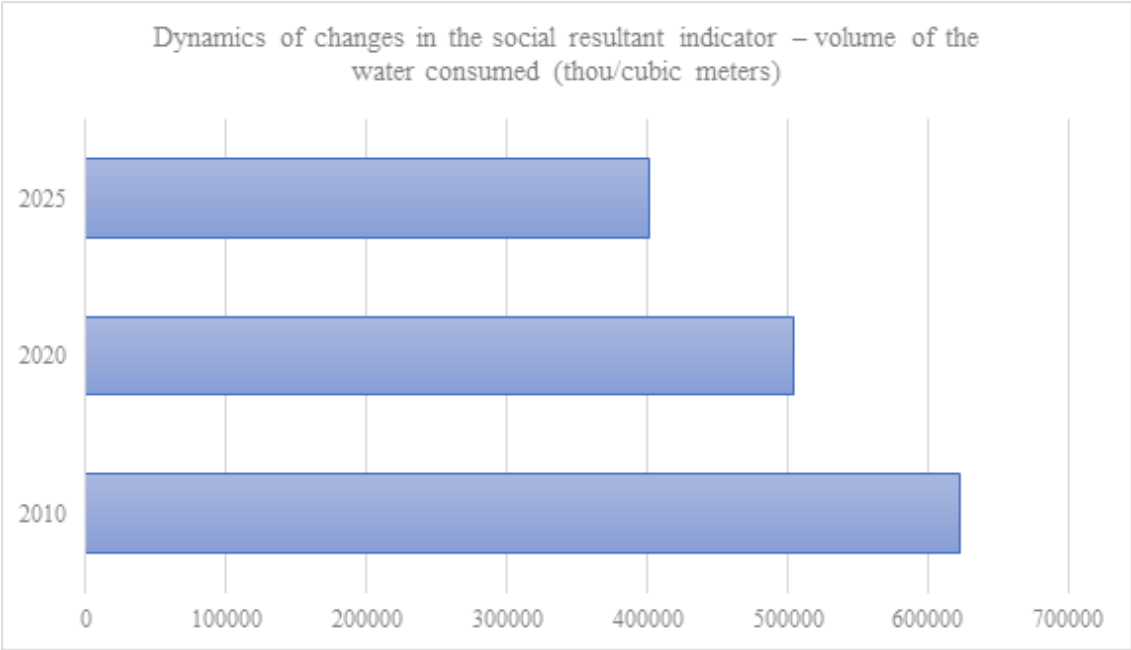

Figure 6. Dynamics of changes in the resultant social indicator

In summary, the organisational and economic model of the innovation and resource potential management for water supply enterprises, which takes into account internal and external environments and input and output parameters, allows the managerial staff to make reasonable recommendations for innovative development of water supply companies. In the general view, and in the view of sub-potentials, such recommendations can be applied to the performance of SUE "Vodokanal of St. Petersburg". These are shown in Figure 7.

5. Discussion

The findings of this study are relevant and coherent. For instance, they can logically explain the significance and specificity of the socio-environmental sub-potential as part of the innovation and resource potential of the water supply enterprise. The indicators of this sub-potential inform recommendations for increasing it, with the focus on two directions: providing the staff of the water supply enterprise with decent working conditions, and monitoring the state of water bodies and the environmental quality.

Regarding the first direction, we recommend that stakeholders:

1. Create a social environment that is favourable for enterprise development enhances the efficiency of managing social programmes and projects.

2. Ensure safe and comfortable working conditions via continuous improvement of labour protection and industrial safety.

3. Change employees' wages depending on the rate of inflation and financial capacity of the water supply enterprise, launching a system of additional tangible and intangible incentives for employees.

4. Develop a system of awards and remuneration for employees who are diligent in performing their duties, excellent work, improvement of the quality of water supply services provided by the water supply enterprise, and other professional achievements.

5. Maintain an effective system of general remuneration and a set of additional benefits to attract, retain, and motivate the staff.

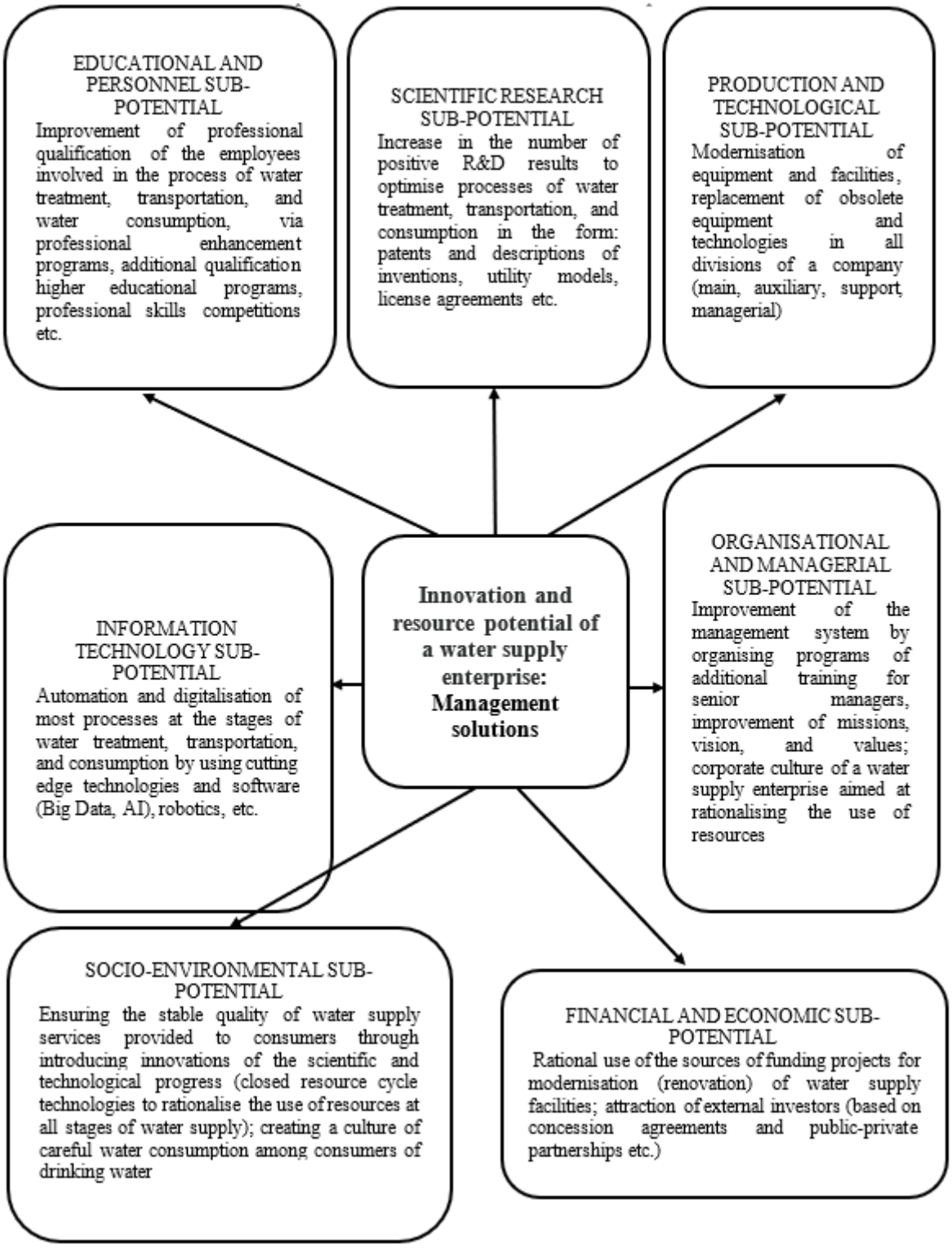

Figure 7. Recommendations for improving management of the innovation and resource potential of a water supply company in view of its sub-potentials

To drive the second direction, we recommend that stakeholders:

1. Increase the environmental friendliness of production efficiency of using resources by the water supply enterprise.

2. Reduce the release of pollutants generated by the water supply enterprise during production into water bodies.

3. Introduce the best accessible technologies into water supply systems that have a negative impact

on the environment.

4. Reduce water consumption and loss during production and transportation.

5. Adopt environmentally efficient waste management technologies at water supply enterprises.

The outcome of the research is the organisational and economic model of the innovation and resource potential management of the water supply enterprise, with content that is typical for such contexts. The specific features of this model that distinguish it from previous models are discussed below.

First, the focus of our model is on the complex category of the innovation and resource potential. A number of modern studies by other authors are devoted to the innovation and resource potential of the agro-industrial sector (Somkuwar et al., 2022; Fallah-Alipour et al., 2018), the fuel and energy sector (Dzikuć et al., 2021; Martins et al., 2018; Gutman and Brazovskaya, 2022; Hulio et al., 2017), and the chemical sector (Vasilieva et al., 2020). Fewer works dwell on resource potential. However, we must assume that there are no works devoted to innovation and resource potential. Overall, turning to the new category requires further in-depth methodological elaboration and substantiation to make scientific debates on this matter positive.

Second, the model considers a water supply enterprise as an economic research object and includes parameters unique to the enterprise. Such approaches to enterprise management, including the management of its potential, can be considered universal. For instance, the study, which is devoted to fundamentals of the enterprise's innovation potential management and to building a management model (Niewöhner et al., 2021), affirms that apart from developing products and services on a regular basis to remain competitive in the long run, companies should take advantage of the innovation potential of digital technologies. These technologies are the driving forces of innovation. The standard model of managing an enterprise's innovation potential is comprised of the innovative processes of an enterprise, innovation strategy, and culture.

The uniqueness of the model for managing the innovation and resource potential of a water supply company consists of the economic specifics of such companies and their core function, which is to provide the population with quality water. Therefore, the resultant indicators of this company's performance include not only conventional financial indicators but also indicators of water loss and consumption. This is correlated with Goal 6 of Sustainable Development Goals[1]. This aspect should be regularly updated, and the resultant management indicators should be constantly improved.

Further, the important role of taking measures to achieve sustainable development goals is the responsibility of financial institutions (Chen et al., 2022) as the source of tangible resources for the support of enterprises committed to green innovations, and offering such enterprises sustainable funding in the form of concessional loan programmes, subsidies, etc. (Wang et al., 2022). Through green funding, water supply companies can introduce innovative technologies –product and process innovations (Dhanora et al., 2018) – to provide customers with quality and safe drinking water supply services (Furtatova and Kamenik, 2020).

A debatable issue requiring further study is the analysis of a water supply enterprise, for example, SUE "Vodokanal of St. Petersburg" and similar companies, only in terms of water supply, without taking into account another component—sewerage. Both processes are closely linked, and they laid the ground for Goal 6 from the Sustainable Development Goals Report "Water and Sanitation". Considering water supply and sewerage in connection with the management of the enterprise's innovation and resource potential is a relevant further study.

6. Conclusion

This study constructed an organisational and economic model of managing innovation and resource potential, proposed by the authors, using classical laws. The model has specific features that characterise only water supply enterprises and the management specifics of such enterprises. Model testing

demonstrated the applicability of the model. The methodological part of the model enables assessment of the integral indicator of the innovation and resource potential of a water supply enterprise with an allowance for seven types of sub-potentials. It also enables the analysis of the links between innovation and resource potential and the resultant indicators of enterprise performance. This will help managers make reasonable decisions for managing innovation and resource potential. Testing the organisational and economic model on other water supply enterprises of the Russian Federation is of particular scientific interest. The given research focused on only one water supply enterprise, albeit a large one, targeted at innovative development.

References

Ahmed, W., Najmi, A., Ikram, M., 2020. Steering firm performance through innovative capabilities: a contingency approach to innovation management. Technology in Society 63, 101385. https://doi.org/10.1016/j.techsoc.2020.101385

Barykin, S.Y., Kapustina, I.V., Kirillova, T.V., Yadykin, V.K., Konnikov, Y.A., 2020. Economics of digital ecosystems. Journal of Open Innovation: Technology, Market, and Complexity 6 (4), 1–16. https://doi.org/10.3390/joitmc6040124

Canci, E., 2021. Economic growth and innovation: An estimation of the innovation possibilities function. Brazilian Journal of Political Economy 41, 155–175. https://doi.org/10.1590/0101-31572021-2932

Chen, Z., Mirza, N., Huang, L., Umar, M., 2022. Green banking - Can financial institutions support green recovery? Economic Analysis and Policy 75, 389–395. https://doi.org/10.1016/j.eap.2022.05.017

Dhanora, M., Sharma, R., Khachoo, Q., 2018. Non-linear impact of product and process innovations on market power: a theoretical and empirical investigation. Economic Modelling 70, 67–77. https://doi.org/10.1016/j.econmod.2017.10.010

Dzikuć, M, Gorączkowska, J., Piwowar, A., Dzikuć, M., Smoleński, R., Kułyk, P., 2021. The analysis of the innovative potential of the energy sector and low-carbon development: a case study for Poland. Energy Strategy Reviews, 38, 100769. https://doi.org/10.1016/j.esr.2021.100769

Fallah-Alipour, S., Boshrabadi, H.M., Mehrjerdi, M.R.Z., Hayati, D., 2018. A framework for empirical assessment of agricultural sustainability: The case of Iran. Sustainability 10, 4823. https://doi.org/10.3390/su10124823

Furtatova, A., Kamenik, L., 2020. Predictive analysis of water supply based on big data, in: Proceedings of the 33rd International Business Information Management Association Conference, IBIMA 2019: Education Excellence and Innovation Management through Vision 2020, 8762-8767. Available at: https://ibima.org/accepted-paper/predictive-analysis-of-water-supply-based-on-big-data/

Furtatova, A., Viktorova, N., Konnikov, E., 2021. Innovation and resource potential on key performance indicators of water supply enterprises. Sustainable Development and Engineering Economics 2, 2. https://doi.org/10.48554/SDEE.2021.2.2

Furtatova, A.S., Viktorova, N.G., 2020. Innovation-resource potential of water supply enterprise: terminology and meaning. Journal of Legal and Economic Studies 3, 187–196. https://doi.org/10.26163/GIEF.2020.72.76.031

Georgiev, I., Harvey, D.I., Leybourne, S.J., Robert Taylor, A.M., 2018. Testing for parameter instability in predictive regression models. Journal of Econometrics, 204 (1), 101–118. https://doi.org/10.1016/j.jeconom.2018.01.005

Gutman, S., Brazovskaya, V., 2022. Assessing the level of Russian energy security in the context of sustainable development. Publishing House Finance and Credit 18 (6), 1039–1058. https://doi.org/10.24891/ni.18.6.1039

Hulio, Z.H., Jiang, W., Rehman, S., 2017. Technical and economic assessment of wind power potential of Nooriabad, Pakistan. Energy, Sustainability and Society 7. https://doi.org/10.1186/s13705-017-0137

Kydyrbekova, A., Meiramkulova, K., Tolysbayev, B., Kydyrbekova, A., 2022. Investigation of different water-related innovation aspects within the past three decades: a case study of Kazakhstan and neighboring countries. Economies, 10 (8), 190. https://doi.org/10.3390/economies10080190

Martins, A.A., Simaria, M., Barbosa, J., Barbosa, R., Silva, D.T., Rocha, C.S., Mata, T.M., Caetano, N.S., 2018. Life cycle assessment tool of electricity generation in Portugal. Environment, Development and Sustainability 20– 129–143. https:// doi.org/10.1007/s10668-018-0179-y

Maryati, S., Azizah, D.M., 2022. Innovation during COVID-19 pandemic: water, sanitation, and hygiene in informal settlements. Pertanika Journal of Social Sciences and Humanities 30 (2), 835–857. https://doi.org/10.47836/pjssh.30.2.22

Niewöhner, N., Lang, N., Asmar, L., Röltgen, D., Kühn, A., Dumitrescu, R., 2021. Towards an ambidextrous innovation management maturity model. Procedia CIRP 100, 289–294. https://doi.org/10.1016/j.procir.2021.05.068

Puppim de Oliveira, J.A., Bellezoni, R.A., Shih, W.-Y., Bayulken, B., 2022. Innovations in urban green and blue infrastructure: tackling local and global challenges in cities. Journal of Cleaner Production 362, 132355. https://doi.org/10.1016/j.jclepro.2022.132355

Rakhmeeva, I., 2020. Assessment of sustainable development factors of the old industrial region: the case of the Ural Federal Okrug, in: E3S Web of Conferences. Yekaterinburg, Russia, 08002. https://doi.org/10.1051/e3sconf/202020808002

Rodionov, D.G., Konnikov, E.A., Konnikova, O.A., 2018. Approaches to ensuring the sustainability of industrial enterprises of different technological levels. Journal of Social Sciences Research 3, 277–282. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-85059040237&partnerID=MN8TOARS

Rudskaia, I., Rodionov, D., 2018. The concept of total innovation management as a mechanism to enhance the competitiveness of the national innovation system. In: International Conference on Internet and e-Business (ICIEB) 246–251. https://doi.org/10.1145/3230348.3230349

Rybicki, S.M., Schneider-Skalska, G., Stochel-Cyunel, J., 2022. Bio-Morpheme as innovative design concept for “Bio City” urban structure in the context of water-saving and human health. Journal of Cleaner Production 369, 133266. https://doi.org/10.1016/j.jclepro.2022.133266

Somkuwar, S.R., Sawant, R.C., Ingale, P.I., Masram, D.T., Chaudhary, R.R., 2022. 6 - Nanoparticles for sustainable agriculture: innovative potential with current and future perspectives. Biogenic Sustainable Nanotechnology 131–148. https://doi.org/10.1016/B978-0-323-88535-5.00013-5

Song, J., Li, B., 2021. Nonlinear and additive principal component analysis for functional data. Journal of Multivariate Analysis 181,

104675. https://doi.org/10.1016/j.jmva.2020.104675
Tashenova, L., Babkin, A., Mamrayeva, D., Babkin, I., 2020. Method for evaluating the digital potential of a backbone innovative active industrial cluster. International Journal of Technology 11 (8), 1499–1508. https://doi.org/10.14716/ijtech.v11i8.4537
Tereshko, E., Rudskaya, I., Dejaco, M.C., Pastori, S., 2021. Validation of factors for assessing the digital potential of the regional construction complex as a basis for sustainable development. Sustainable Development and Engineering Economics 1, 3. https://doi.org/10.48554/ SDEE.2021.1.3
Vasilieva, E., Kudryavtseva, T., Skhvediani, A., 2020. Managing the efficiency of an innovative project in the chemical sector. In: International Scientific Conference on Digital Transformation on Manufacturing, Infrastructure and Service 940, 012046. https://doi.org/10.1088/1757-899X/940/1/012046
Wang, K., Zhao, Y., Jiang, C., Li, Z., 2022. Does green finance inspire sustainable development? Evidence from a global perspective. Economic Analysis and Policy 75, 412–426. https://doi.org/10.1016/j.eap.2022.06.002
Wuijts, S., de Vries, M., Zijlema, W., Hin, J., Elliott, L.R., Breemen, L.D.-V., Scoccimarro, E., de Roda Husman, A.M., Külvik, M., Frydas, I.S., Grellier, J., Sarigiannis, D., Taylor, T., Gotti, A., Nieuwenhuijsen, M.J., Hilderink, H., 2022. The health potential of urban water: Future scenarios on local risks and opportunities. Cities 125, 103639. https://doi.org/10.1016/j.cities.2022.103639
Yashin, S.N., Koshelev, E.V., D.A. Sukhanov, D.A., 2021. Razrabotka Strategii Razvitiya Innovatsionno-industrial 'nogo Klastera Metodom Sostavnykh Real' nykh Optsionov [Articulating the development strategy for the innovation and industrial cluster by the compound option method]. Finance & Credit 27 (7), 1647–1671. https://doi.org/10.24891/fc.27.7.1647

Список источников

Ahmed, W., Najmi, A., Ikram, M., 2020. Steering firm performance through innovative capabilities: A contingency approach to innovation management. Technology in Society, 63, 101385, https://doi.org/10.1016/j.techsoc.2020.101385
Barykin, S.Y., Kapustina, I.V., Kirillova, T.V., Yadykin, V.K., Konnikov, Y.A., 2020. Economics of digital ecosystems. Journal of Open Innovation: Technology, Market, and Complexity, 6 (4), 1-16. https://doi.org/10.3390/joitmc6040124
Canci, E., 2021. Economic growth and innovation: An estimation of the innovation possibilities function. Brazilian Journal of Political Economy 41, 155–175. https://doi.org/10.1590/0101-31572021-2932
Chen, Z., Mirza, N., Huang, L., Umar, M., 2022. Green Banking - Can Financial Institutions support green recovery? Economic Analysis and Policy, 75, 389-395. https://doi.org/10.1016/j.eap.2022.05.017
Dhanora, M., Sharma, R., Khachoo, Q., 2018. Non-linear impact of product and process innovations on market power: A theoretical and empirical investigation. Economic Modelling, 70, 67-77. https://doi.org/10.1016/j.econmod.2017.10.010
Dzikuć, M, Gorączkowska, J., Piwowar, A., Dzikuć, M., Smoleński, R., Kułyk, P., 2021. The analysis of the innovative potential of the energy sector and low-carbon development: A case study for Poland. Energy Strategy Reviews, 38, 100769, https://doi.org/10.1016/j.esr.2021.100769
Fallah-Alipour, S., Boshrabadi, H.M., Mehrjerdi, M.R.Z., Hayati, D., 2018. A framework for empirical assessment of agricultural sustainability: The case of Iran. Sustainability 10, 4823. https://doi.org/10.3390/su10124823
Furtatova, A., Kamenik, L., 2020. Predictive analysis of water supply based on big data, in: Proceedings of the 33rd International Business Information Management Association Conference, IBIMA 2019: Education Excellence and Innovation Management through Vision 2020, 8762-8767. Available at: https://ibima.org/accepted-paper/predictive-analysis-of-water-supply-based-on-big-data/
Furtatova, A., Victorova, N., Konnikov, E., 2021. Innovation and resource potential on key performance indicators of water supply enterprises. Sustainable Development and Engineering Economics 2, 2. https://doi.org/10.48554/SDEE.2021.2.2
Furtatova, A.S., Viktorova, N.G., 2020. Innovation-resource potential of water supply enterprise: terminology and meaning. Journal of Legal and Economic Studies, 3, 187–196. https://doi.org/10.26163/GIEF.2020.72.76.031
Georgiev, I., Harvey, D.I., Leybourne, S.J., Robert Taylor, A.M., 2018. Testing for parameter instability in predictive regression models. Journal of Econometrics, 204 (1), 101-118. https://doi.org/10.1016/j.jeconom.2018.01.005
Gutman, S., Brazovskaya, V., 2022. Assessing the level of Russian energy security in the context of sustainable development. Publishing House Finance and Credit, 18 (6), 1039-1058. https://doi.org/10.24891/ni.18.6.1039
Hulio, Z.H., Jiang, W., Rehman, S., 2017. Technical and economic assessment of wind power potential of Nooriabad, Pakistan. Energy, Sustainability and Society 7. https://doi.org/10.1186/s13705-017-0137
Martins, A.A., Simaria, M., Barbosa, J., Barbosa, R., Silva, D.T., Rocha, C.S., Mata, T.M., Caetano, N.S., 2018. Life cycle assessment tool of electricity generation in Portugal. Environment, Development and Sustainability 20, 129–143. https:// doi.org/10.1007/s10668-018-0179-y
Niewöhner, N., Lang, N., Asmar, L., Röltgen, D., Kühn, A., Dumitrescu, R., 2021. Towards an ambidextrous innovation management maturity model. Procedia CIRP, 100, 289-294. https://doi.org/10.1016/j.procir.2021.05.068
Rakhmeeva, I., 2020. Assessment of sustainable development factors of the old industrial region: the case of the Ural Federal Okrug, in: E3S Web of Conferences. Yekaterinburg, Russia, 08002. https://doi.org/10.1051/e3sconf/202020808002
Rodionov, D.G., Konnikov, E.A., Konnikova, O.A., 2018. Approaches to ensuring the sustainability of industrial enterprises of different technological levels. Journal of Social Sciences Research, 3, 277-282. http://www.scopus.com/inward/record.url?eid=2-s2.0-85059040237&partnerID=MN8TOARS
Rudskaia, I., Rodionov, D., 2018. The concept of total innovation management as a mechanism to enhance the competitiveness of the national innovation system, in: International Conference on Internet and e-Business (ICIEB), 246–251. https://doi.org/10.1145/3230348.3230349
Somkuwar, S.R., Sawant, R.C, Ingale, P.I., Masram, D.T., Chaudhary, R.R., 2022. 6 - Nanoparticles for sustainable agriculture: innovative potential with current and future perspectives. Biogenic Sustainable Nanotechnology, 131-148. https://doi.org/10.1016/B978-0-323-88535-5.00013-5
Song, J., Li, B., 2021. Nonlinear and additive principal component analysis for functional data. Journal of Multivariate Analysis 181, 104675. https://doi.org/10.1016/j.jmva.2020.104675
Tashenova, L., Babkin, A., Mamrayeva, D., Babkin, I., 2020. Method for evaluating the digital potential of a backbone innovative active industrial cluster. International Journal of Technology 11(8), 1499–1508. https://doi.org/10.14716/ijtech.v11i8.4537

Tereshko, E., Rudskaya, I., Dejaco, M.C, Pastori, S., 2021. Validation of factors for assessing the digital potential of the regional construction complex as a basis for sustainable development. Sustainable Development and Engineering Economics 1, 3. https://doi.org/10.48554/ SDEE.2021.1.3

Vasilieva, E., Kudryavtseva, T., Skhvediani, A., 2020. Managing the efficiency of an innovative project in the chemical sector, in: International Scientific Conference on Digital Transformation on Manufacturing, Infrastructure and Service 940, 012046. https://doi.org/10.1088/1757-899X/940/1/012046

Wang, K., Zhao, Y., Jiang, C., Li, Z., 2022. Does green finance inspire sustainable development? Evidence from a global perspective. Economic Analysis and Policy, 75, 412-426. https://doi.org/10.1016/j.eap.2022.06.002

Яшин, С.Н., Кошелев, Е.В., Суханов, Д.А., 2021. Разработка стратегии развития инновационно-индустриального кластера методом составных реальных опционов. Финансы и кредит 27 (7), 1647–1671. https://doi.org/10.24891/fc.27.7.1647

The article was submitted 06.09.2022, approved after reviewing 18.11.2022, accepted for publication 20.11.2022.

Статья поступила в редакцию 06.09.2022, одобрена после рецензирования 18.11.2022, принята к публикации 20.11.2022.

About authors:

1. Alina Furtatova, Research assistant, Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, Russian Federation. https://orcid.org/0000-0002-2796-5174, alina_furtado@mail.ru

2. Natalia Viktorova, Doctor of Economics, professor, Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, Russian Federation. https://orcid.org/0000-0002-7355-3541, viktorova_ng@spbstu.ru

3. Diankai Wang, professor, Zhejiang International Studies University, Hangzhou, PRC. wangdiankai@zisu.edu.cn

Информация об авторах:

1. Алина Фуртатова, ассистент, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Российская Федерация. https://orcid.org/0000-0002-2796-5174, alina_furtado@mail.ru

2. Наталья Викторова, доктор экономических наук, профессор, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Российская Федерация. https://orcid.org/0000-0002-7355-3541, viktorova_ng@spbstu.ru

3. Дянькай Ван, преподаватель, Чжэцзянский университет международных исследований, Ханчжоу, КНР. wangdiankai@zisu.edu.cn

SECTION 3

SUSTAINABLE DEVELOPMENT OF REGIONAL INFRASTRUCTURE

РАЗДЕЛ 3

УСТОЙЧИВОЕ РАЗВИТИЕ РЕГИОНАЛЬНОЙ ИНФРАСТРУКТУРЫ

Research article
DOI: https://doi.org/10.48554/SDEE.2022.4.4

Diagnostics of Migration Processes for the Sustainable Development of the Economy of the Kyrgyz Republic

Ayganysh Sayakbaeva[1], Nelly Akylbekova[2*], Maria Taalaibek[1]

[1] Kyrgyz National University named after J. Balasagyn, Bishkek, Kyrgyz Republic
[2] International Academy of Management, Law, Finance and Business, Bishkek, Kyrgyz Republic
Corresponding author: nelly_a@bk.ru

Abstract

The article examines migration processes in the Kyrgyz Republic, analysing the dynamics of the population, natural increase, mortality, life expectancy of the population, and the level of poverty of the population. Diagnostics of changes in the demographic situation, as well as the intensification of migration processes, showed an increase in both quantitative and qualitative indicators of migration and in the forms and directions of movement of the migration vector. The findings suggest that migration processes have a significant impact on the socio-economic situation in the republic, the balance of the labour market, and changes in the economic and social situation of the population. These outcomes are often accompanied by a change in the vector of educational and professional training, and the expansion of the needs of people participating in migration.

Keywords: migration, sustainable development, demographic processes, population, natural increase, population mortality, life expectancy, poverty level, number of immigrants, number of emigrants, migration policy

Citation: Sayakbaeva, A., Akylbekova, N., Taalaibek, M., 2022. Diagnostics of Migration Processes for the Sustainable Development of the Economy of the Kyrgyz Republic. Sustainable Development and Engineering Economics 4, 4. https://doi.org/10.48554/SDEE.2022.4.4

This work is licensed under a CC BY-NC 4.0

© Sayakbaeva, A., Akylbekova, N., Taalaibek, M., 2022. Published by Peter the Great St. Petersburg Polytechnic University

Научная статья

УДК 314.7

DOI: https://doi.org/10.48554/SDEE.2022.4.4

Диагностика Миграционных Процессов в Кыргызской Республике

Айганыш Саякбаева[1], Нелли Акылбекова[2*], Мария Таалайбек[1]

[1] КНУ им. Ж. Баласагына, Бишкек, Кыргызская Республика
[2] Международная академия управления, права, финансов и бизнеса, Бишкек, Кыргызская Республика
Автор, ответственный за переписку: nelly_a@bk.ru

Аннотация

В статье исследуются миграционные процессы в Кыргызской Республике: проведен анализ динамики численности населения, естественного прироста, смертности, ожидаемой продолжительности жизни населения, уровня бедности населения, числа разводов, рассмотрены миграционные процессы. Диагностика изменения демографической ситуации, а также интенсификация процессов миграции показала рост как количественных, так и качественных показателей миграции и форм, и направлений передвижений вектора миграции. Делая вывод можно отметить, что миграционные процессы оказывают существенное влияние на социально-экономическую ситуацию в республике, сбалансированность рынка труда, изменяет экономическое и социальное положение населения, нередко сопровождается изменением вектора образовательной и профессиональной подготовки, расширением потребностей участвующих в миграции людей.

Ключевые слова: миграция, демографические процессы, население, естественный прирост населения, смертность населения, продолжительность жизни населения, уровень бедности, численность иммигрантов и эмигрантов, среднемесячная номинальная заработная плата, миграционная политика.

Цитирование: Саякбаева, А., Акылбекова, Н., Таалайбек, М., 2022. Диагностика миграционных процессов в Кыргызской Республике. Sustainable Development and Engineering Economics 4, 4. https://doi.org/10.48554/SDEE.2022.4.4

This work is licensed under a CC BY-NC 4.0

© Саякбаева, А., Акылбекова, Н., Таалайбек, М., 2022. Издатель: Санкт-Петербургский политехнический университет Петра Великого

1. Introduction

The collapse of the Soviet Union (USSR) and the integration of the Kyrgyz Republic into the world economy and further into the Eurasian Economic Union (EAEU) in the context of socio-economic chaos was due to problems and political crises that aggravated the crisis, especially in the labour market. As a result, the problem of migration has been associated with the collapse of the economy and the impoverishment of almost the entire population of the Kyrgyz Republic. The latter is what causes high migration of the population (Sayakbaeva et al., 2019). The high and uncontrolled migration of the population to the Kyrgyz Republic is a demographic and socio-economic risk, subsequently affecting the economic security of the country. Western European countries, Great Britain, and other economically highly developed countries face unregulated migration, which causes political and social crises due to large numbers. Thus, the problem requires the adoption of measures at the international level and the coordination of efforts of many countries around the world to resolve the migration crisis, especially in the field of the social protection of migrants.

Large-scale external and internal mobility of the population and labour resources occurs in various forms, including voluntary migrants who have legal and social support in choosing a place of residence and work. These include refugees and forced migrants from countries where local wars are taking place or under the pressure of certain circumstances. The content of a nation's migration policy can support the determination of the state of the socio-economic development of the country. Thus, the study of migration is relevant and necessary for assessing the processes of globalisation and their impact on the social processes in a particular country.

This study is diagnostic and based on statistical information. The purpose of this study is to deepen existing knowledge about the nature of migration processes for sustainable development of the economy, conduct diagnostics of modern migration processes in the Kyrgyz Republic, and evaluate their positive and negative impacts on the socio-economic development of the republic. The study diagnoses modern migration processes in the Kyrgyz Republic and evaluates their positive and negative impacts on the socio-economic development of the republic.

2. Literature review

The migration of the population is one of the main components of demographic development that determines the processes of the population as a whole (Massei, 2017). "Migration (of population, labour resources) (from Latin migratio) is the movement of people, workers, mainly associated with a change in place of residence and place of work. There are the following types of migration: internal – in the form of movements within the country; external – in the form of emigration outside the country and immigration into the country …" (Krasinets et al., 2004). A narrower definition is given in the Russian Encyclopedic Dictionary: "Migration (lat. migratio, from migro - I move, I move) population movements associated with a change of residence" (Rakovskaya et al., 2013).

De Haas (2021) elaborated on a theoretical framework that conceptualises migration as a function of people's capabilities and aspirations to migrate within given sets of perceived geographical opportunities. We agree with the author that not enough has been devoted to the theory of migration in the 21st century, although the ability to analyse and evaluate statistical data has grown with improvements in accounting for migration, especially in developed countries (de Haas, 2021). Other researchers have associated migrant integration policy with several factors: the number of asylum applications and the number of refugees (evidence-based point of view), GDP (per capita) and social security spending (institutionalist point of view), political ideology, and public opinion (party point of view) (Solano and Coninck, 2021, 2022). Further, some studies have considered the role and objectivity of information about migrants.

Researchers often study migration at their local level by studying the drivers of migration. For example, Kim and Lee (2022) investigated the size of the initial wage disadvantage and the patterns of subsequent labour market assimilation for immigrant workers in South Korea. Božič et al. (2022) ex-

amined the symbolic boundary work that sustains laypeople's understanding and use of specific labels. Salami et al. (2022) explored temporary foreign workers' access to and experiences with formal and informal support in Canada. Goksu and Leerkes studied (2022) political participation as transformative reactive mobilisation using a qualitative study of voter preferences among residents of Turkish origin in the Netherlands. Chan et al. (2022) studied five socio-political factors of migration.

Dumitru (2023) discussed the ethics of migration. When a basic principle in ethics is underdiscussed or absent from the ethics of immigration, the field is 'mildly biased'. Vermeulen (2019) discussed immigrant political participation in Europe. Vermeulen et al. (2020) considered the potential of immigrant parties, offering insights from the Dutch case. Simonsen (2021) raised the issue of the democratic consequences of anti-immigrant political rhetoric. Grzymala-Kazlowska et al. (2022) discussed bringing anchoring and embedding together, theorising migrants' lives over time. This study developed a theory of migrant behaviour. Wahab and Hamidi (2022) used the Nepal–Malaysia migration corridor as an example to explore the impact of the COVID-19 pandemic and the changing views of mobility. Comparative perspectives on migration, diversities, and the pandemic were offered by Cubas et al. (2022).

Thus, modern researchers consider migration in a single country or region. Often, these studies are analytical in nature. Considering migration at the global level reveals characteristics of global processes on migration as global coverage, non-homogeneous constituency, advisory nature of discussions, and greater reach of impact1.

3. Materials and methods

The theoretical basis of the study was the work of modern researchers on migration for the sustainable development of the economy. Extensive analysis made it possible to define the concept of migration. However, insufficient attention has been paid to the theoretical aspects of the problem under study by modern researchers. The official data of the National Statistical Committee of the Kyrgyz Republic (NSC KR), electronic resources, and databases of international organisations involved in the process of research and regulation of migration were used as analytical material.

In the process of this study, a wide range of methods was used, the main of which were the methods of generalisation and synthesis, abstract-logical, statistical, dynamic, and structural analysis, and graphical and tabular presentation of the results. The method of generalisation and synthesis created an opportunity to accumulate the entire range of scientific results obtained into a single concept that reflects the relevance, directions, goals, and tasks of the development of migration processes. The method of statistical, dynamic, and structural analysis made it possible to build a time series of indicators not only for migration, but also for the main demographic indicators of the development of the Kyrgyz Republic. The graphical and tabular presentation method offers a visualisation of the study's findings. The graphs illustrate the trend in changes and the rate of change in migration and demographic indicators. The abstract-logical method allowed us to draw conclusions based on the results of the study.

The presented scientific problem was solved in the following stages:

1. Extensive analysis of the special economic and statistical literature on population migration to determine the essence of migration and the factors influencing migration processes.

2. Diagnosis of the migration processes in the Kyrgyz Republic for the sustainable development of the economy. An analysis of population migration indicators and other demographic indicators of the development of the Kyrgyz Republic was conducted to determine the trends of migration processes.

3. Development of comprehensive measures to regulate migration for sustainable economic development.

[1] IOM 2022. Global processes on migration. Available at: https://www.iom.int/global-processes-migration (accessed January 4, 2023)

4. Results

Overall, the estimated number of international migrants has increased over the past five decades. The total estimated 281 million people living in a country other than their countries of birth in 2020 was 128 million more than in 1990 and over three times the estimated number in 19702. Although there has also been an increase in the share of international migrants in the world during this period, it is clear that the vast majority of people continue to live in the countries in which they were born.

Table 1. Number of international migrants for 1970–2020[2]

Year	Number of migrants, million people	Share of migrants in the world population. %
1970	84	2.3
1975	90	2.2
1980	102	2.3
1985	113	2.3
1990	153	2.9
1995	161	2.8
2000	174	2.8
2005	192	2.9
2010	221	3.2
2015	249	3.4
2020	281	3.6

In 2019, the majority of international migrants (about 74%) were of working age (20–64 years), and over the period 2000–2019, the share of migrants under 20 years of age decreased slightly (from 16.4% to 14%), while remaining unchanged from 2000. The share of international migrants aged 65 years and older was about 12%2. The population of the Kyrgyz Republic, according to the National Statistics Committee of the Kyrgyz Republic in 2021, increased to about 6 million 636 thousand people. against 5 million 477 thousand people. in 2011 (the number of men increased to 3 million 294 thousand people and women 3 million 342 thousand people)[3](Figure 1).

Modern demographic processes in the Kyrgyz Republic and their development trends are determined both by the external—globalisation, and the internal environment of the organisation—transformations in socio-economic development and changes in the political situation as a result of the collapse of the USSR.

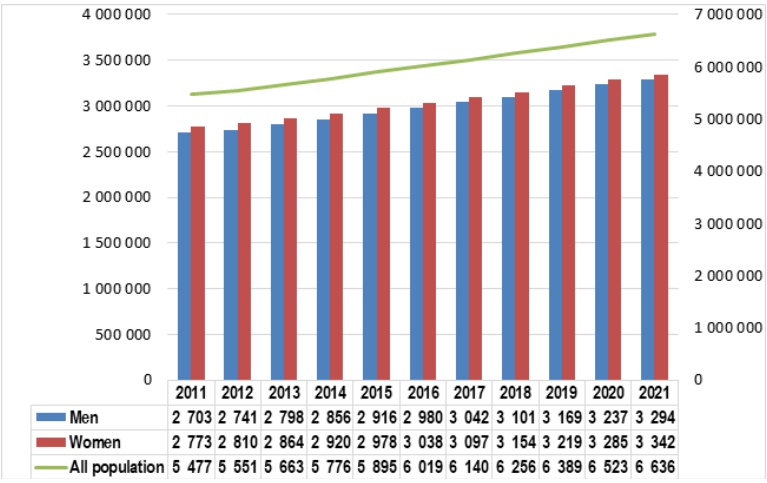

Figure 1. Population of the Kyrgyz Republic by sex for the period 2011-2021, people[3]

[2] World Migration Report 2022. Available at: https://worldmigrationreport.iom.int/wmr-2022-interactive/
[3] Population of the Kyrgyz Republic. Available at: http://www.stat.kg/ru/statistics/naselenie/

An analysis of a later retrospective period showed that the number of men grew at a faster rate than that of women. For example, the dynamics of population growth by sex for 1991–2021 showed that the growth rate in the number of men was 152.0%, and women was 148.0%3. The increase in the population of the Kyrgyz Republic has mainly been through natural growth, that is, the excess of the number of births over the number of deaths, and as shown in Figure 2, it is positive, although in some of its territories, there is a tendency to decrease, especially in the northern regions of the country[3].

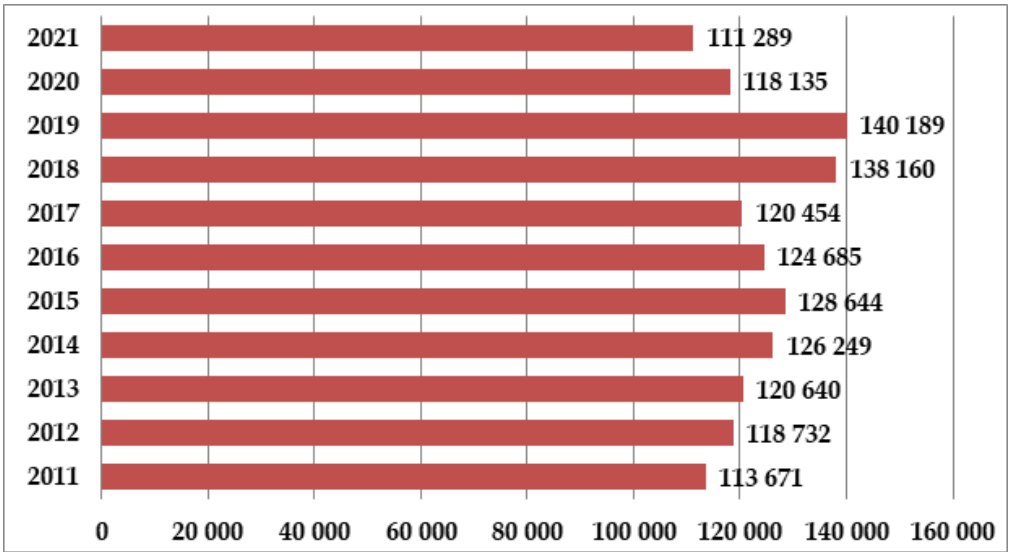

Figure 2. Natural population growth, people[3]

The COVID-19 pandemic has greatly affected the level of healthcare development and the quality of services provided to the population. In 2020–2021, due to its negative impact, the quantitative and qualitative indicators of healthcare services decreased. Even countries with developed economies could not cope with the high incidence of infection among the population. The health systems of the countries of the world faced the problems of providing medical workers, medicines, hospital beds, and financial resources, which caused high mortality during the peak periods of the pandemic.

Tracing the dynamics of mortality in the Kyrgyz Republic for 2019–2020, the medical services provided by healthcare organisations in the Kyrgyz Republic were of poor quality and led to a large number of deaths, and they were not enough to meet the needs of those in need. Thus, in 2020, 39,977 deaths were registered, including 2,448 deaths from COVID-19, against 33,295 deaths in 2019, or the growth rate of mortality was 20.1%, whereas for 2010-2019, the number of deaths ranged from 32,989 deaths in 2018 to 36,186 deaths in 2012[3] (Figure 3).

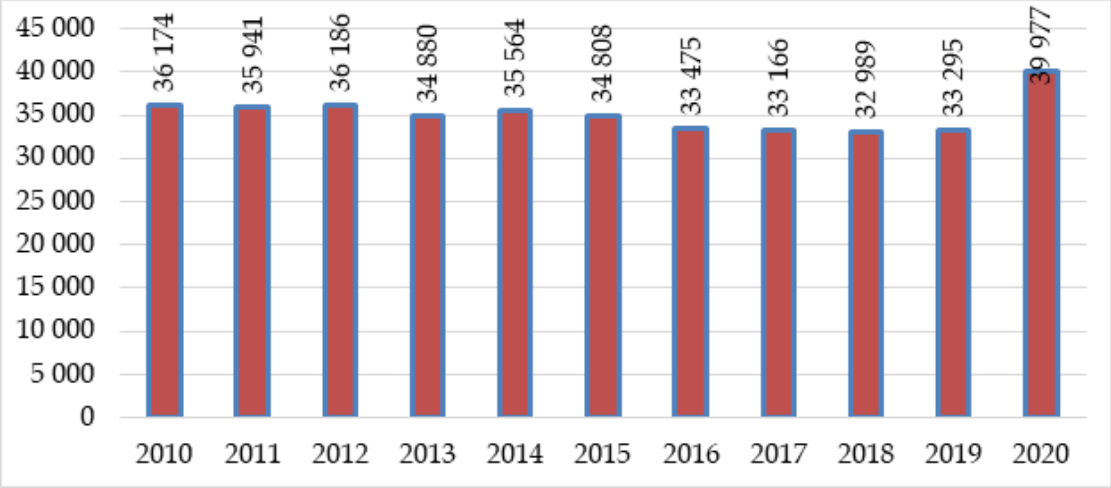

Figure 3. Mortality in the Kyrgyz Republic for 2010-2020, cases[3]

Further, the policy of regulating migration does not at all contradict the policy of encouraging the birth rate or reducing premature mortality. The gender imbalance in favour of women is explained by the higher mortality rates of men for various reasons, in particular, their biological characteristics. During the years of transition of the economy of the Kyrgyz Republic to market conditions and principles of functioning and its adaptation to new economic conditions, the indicator of life expectancy changed in accordance with these socio-economic conditions and acted as an indicator of the state of the country's human capital. Over the past decade, certain results have been achieved by the healthcare system in the provision of medical, preventive, rehabilitation, and health services, which is evidenced by the increase in life expectancy, which is evidenced by the increase in life expectancy.

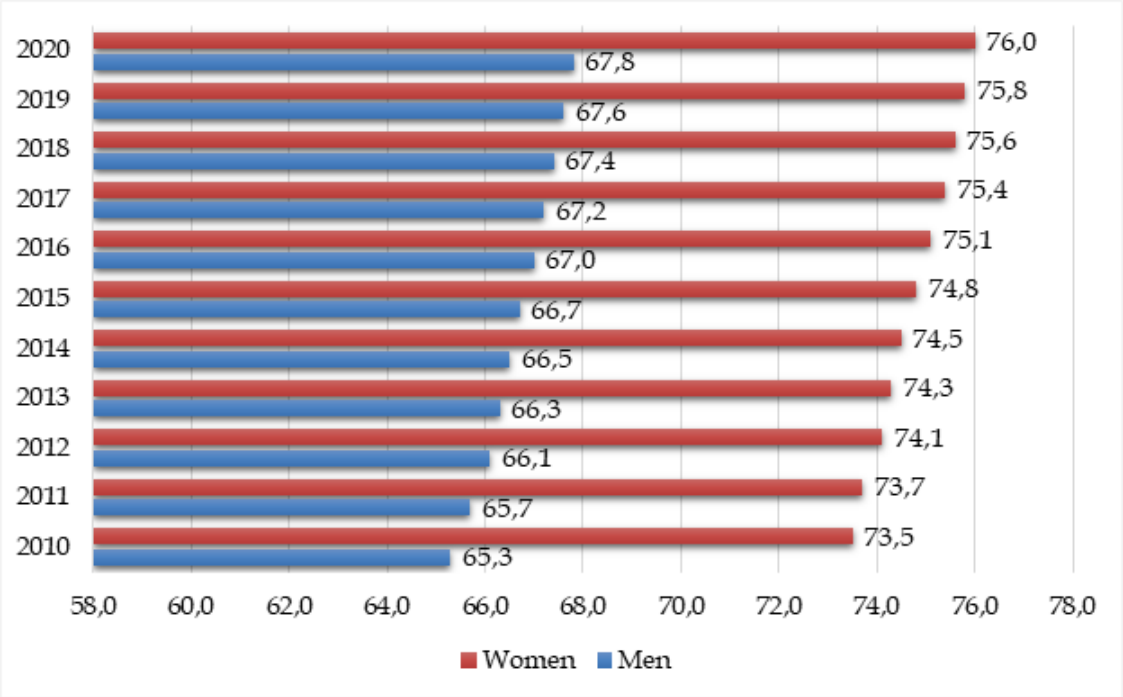

Figure 4. Dynamics of life expectancy of the population by sex in the Kyrgyz Republic, years[3]

The poverty level from 2012–2019 had a downward trend, which indicated an improvement in the economic situation in the republic and the effectiveness of social policy. However, the COVID-19 pandemic has caused significant damage to the economy of the republic and has caused a decline in indicators of the social sector and a deterioration in the standard of living of the population. This clearly confirms the poverty rate of the population for 2020, which was 25.3, which is 5.2% more than in 2019[3] (Figure 5).

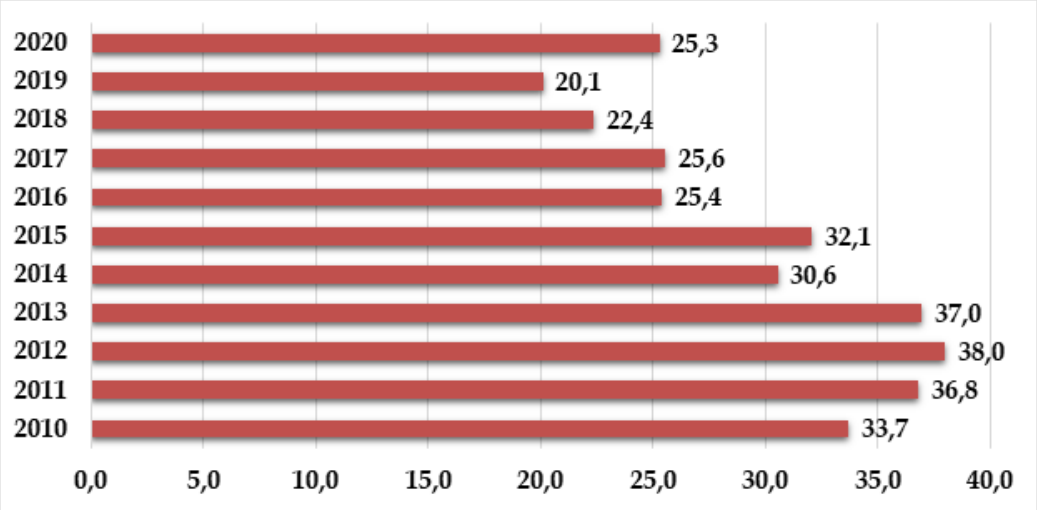

Figure 5. Poverty rate in the Kyrgyz Republic, %[3]

Sustain. Dev. Eng. Econ. 2022, 4, 4. https://doi.org/10.48554/SDEE.2022.4.4

In some regions of the republic, the level of poverty is much higher than in Bishkek. For example, in 2020, the Jalal-Abad region recorded the highest, at 37.2%, similar to that of the Naryn region (36.8%). A relatively high level of poverty was also observed in 2020 in the Batken region (34.7%), while the Talas region had the lowest (12.5%), which was 24.7 percentage points less than in the Jalal-Abad region. The cities of Bishkek and Osh also had low levels of poverty (16.8% and 14.7%, respectively)[3] (Figure 6).

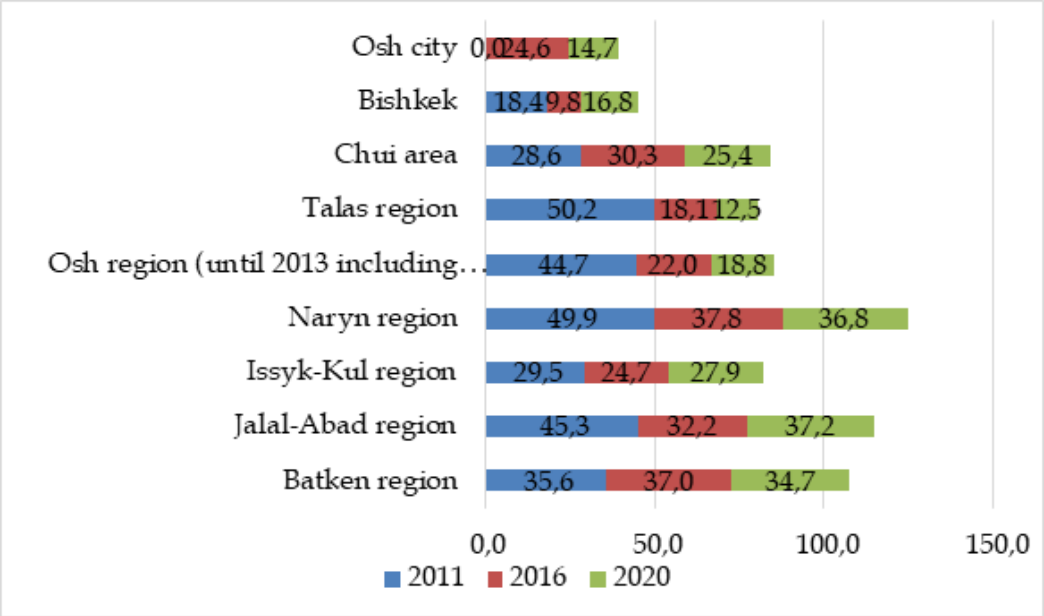

Figure 6. Poverty rate by territory of the Kyrgyz Republic, %[3]

The number of immigrants for 2011–2020 decreased by 6.6 times and amounted to 961 people in 2020 against 45,740 in (Figure 7)3. The number of emigrants for 2011–2020 also decreased by 7.9 times and amounted to 5822 people in 2020 against 6337 people (see Figure 7). At the same time, the number of emigrants in 2020 was 6 times more than immigrants. It is a fact that after the collapse of the USSR, the peak of migration occurred in 1993, when about 120 thousand people migrated from the country[3].

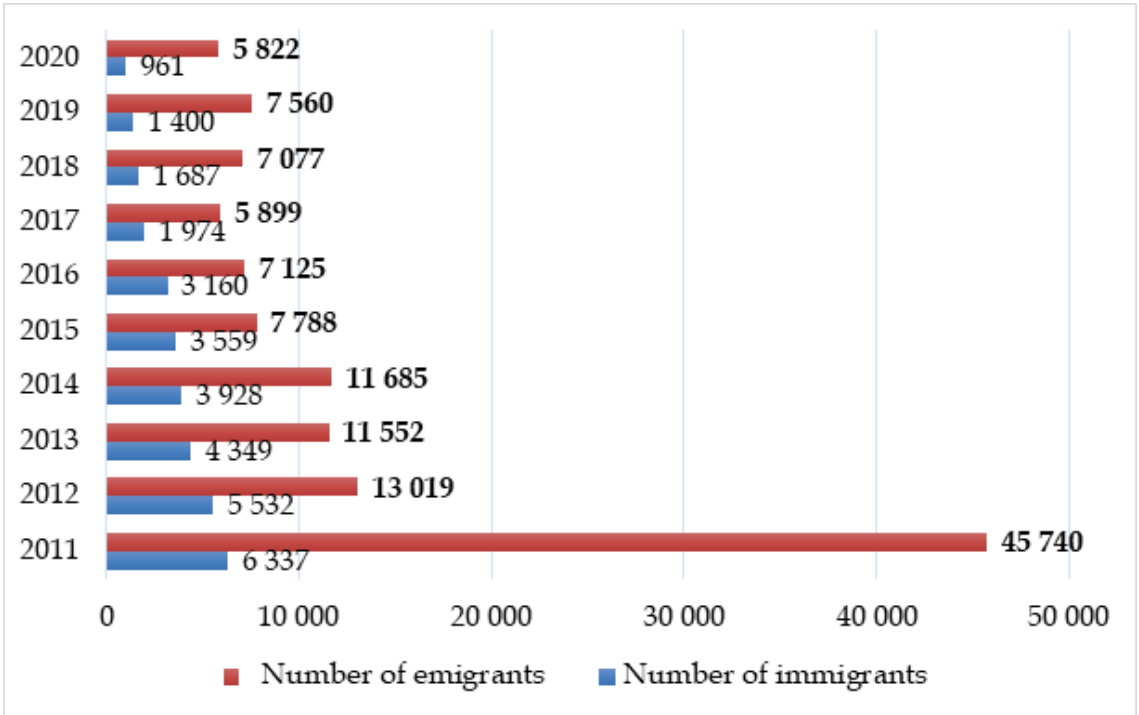

Figure 7. Number of immigrants and emigrants of the Kyrgyz Republic, pers.[3]

Diagnostics of external migration of the population of the Kyrgyz Republic by countries of departure for 2011–2020 showed that the number of emigrants from Kyrgyz Republic to the Commonwealth of Independent States (CIS) countries decreased by 8 times and amounted to 5649 people in 2020 against 45505 people in 20113. The number of people leaving the Kyrgyz Republic for countries outside the CIS decreased by 36.4%, or 62 people, and amounted to 173 people in 2020 compared to 235 people in 2011 (Figure 8)[3].

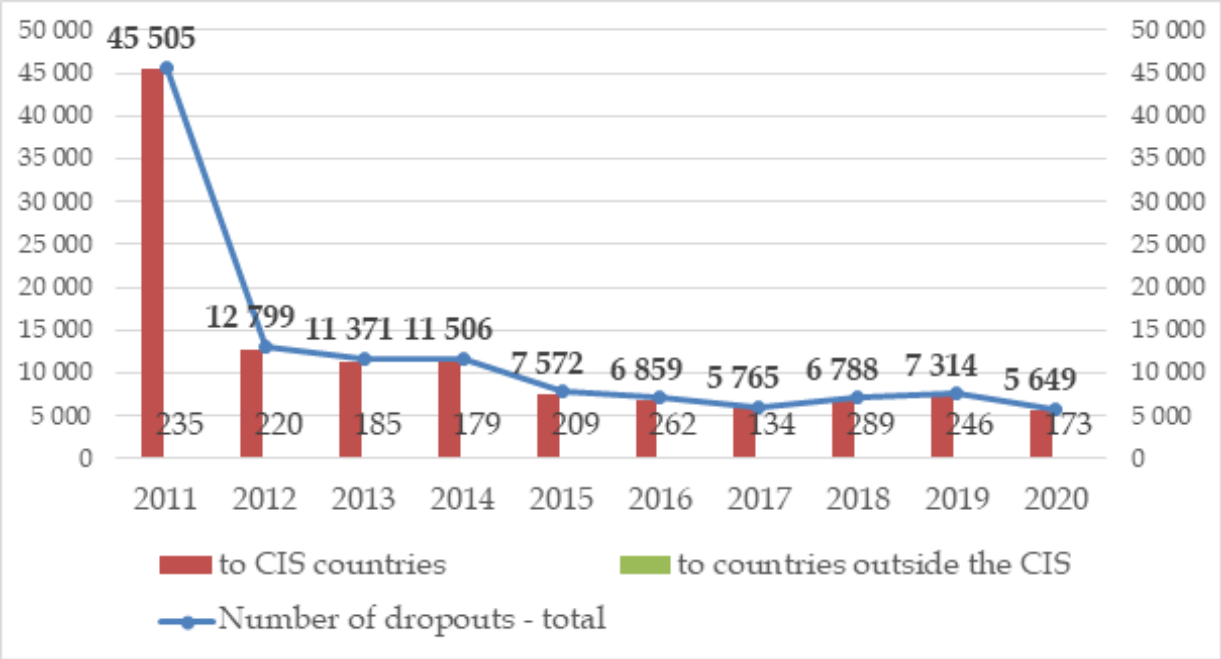

Figure 8. Dynamics of the number of those who left the Kyrgyz Republic, pers.[3]

The dynamics of the number of those who left the territory of the Kyrgyz Republic for other countries during 2011–2019, as shown in Figure 2.36, also showed a negative trend. The number of women who left the territory of the Kyrgyz Republic for other countries decreased by 79.7% and amounted to 4,799 people in 2019, compared to 23,619 people in 2011. Further, the number of men who left the territory of the Kyrgyz Republic from other countries decreased by 78.2% and amounted to 690 people in 2019 against 3162 people in 2011[3] (Figure 9).

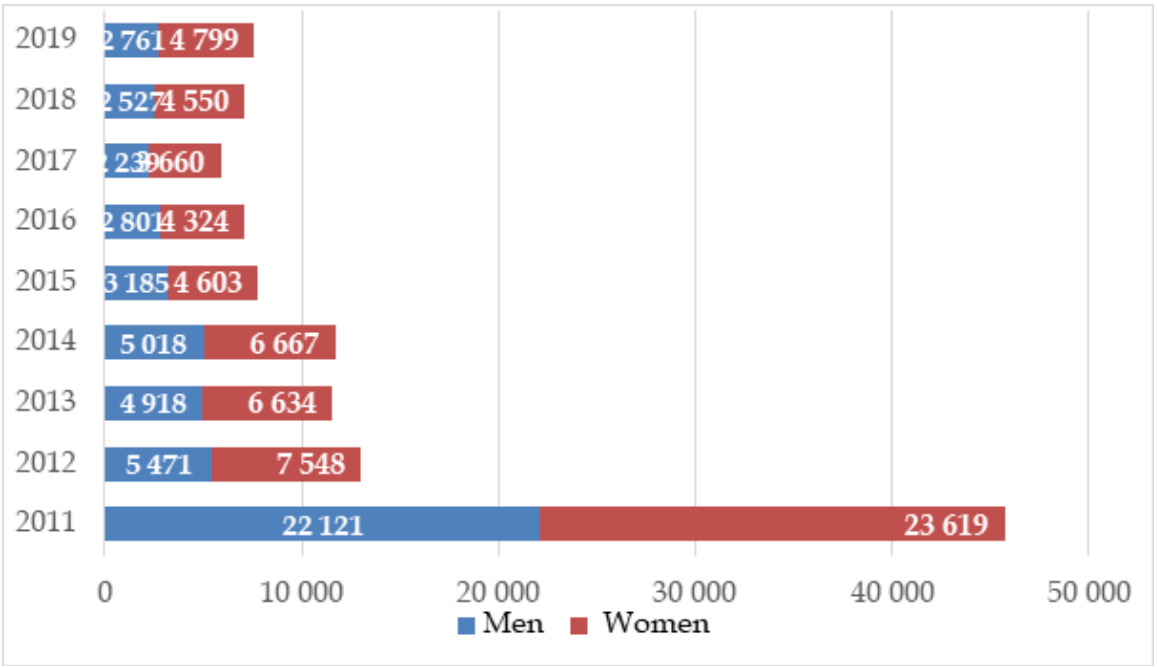

Figure 9. Dynamics of outward migration of the population by sex, pers.[3]

Sustain. Dev. Eng. Econ. 2022, 4, 4. https://doi.org/10.48554/SDEE.2022.4.4

The number of women who left the territory of the Kyrgyz Republic for other countries in 2019 was 2038 more than the number of men who did. The low income level of the population is due to low rates of economic development, entrepreneurship, and the creation of new jobs. Migration from the Kyrgyz Republic to Russia and Kazakhstan is caused by a lower standard of living of the population and a higher level of monetary income of the population and wages in these EAEU member states. Thus, in 2020, in the Russian Federation, the nominal wage was US$714, while it was US$516 in the Republic of Kazakhstan, compared to US$245 in the Kyrgyz Republic[4] (Figure 10).

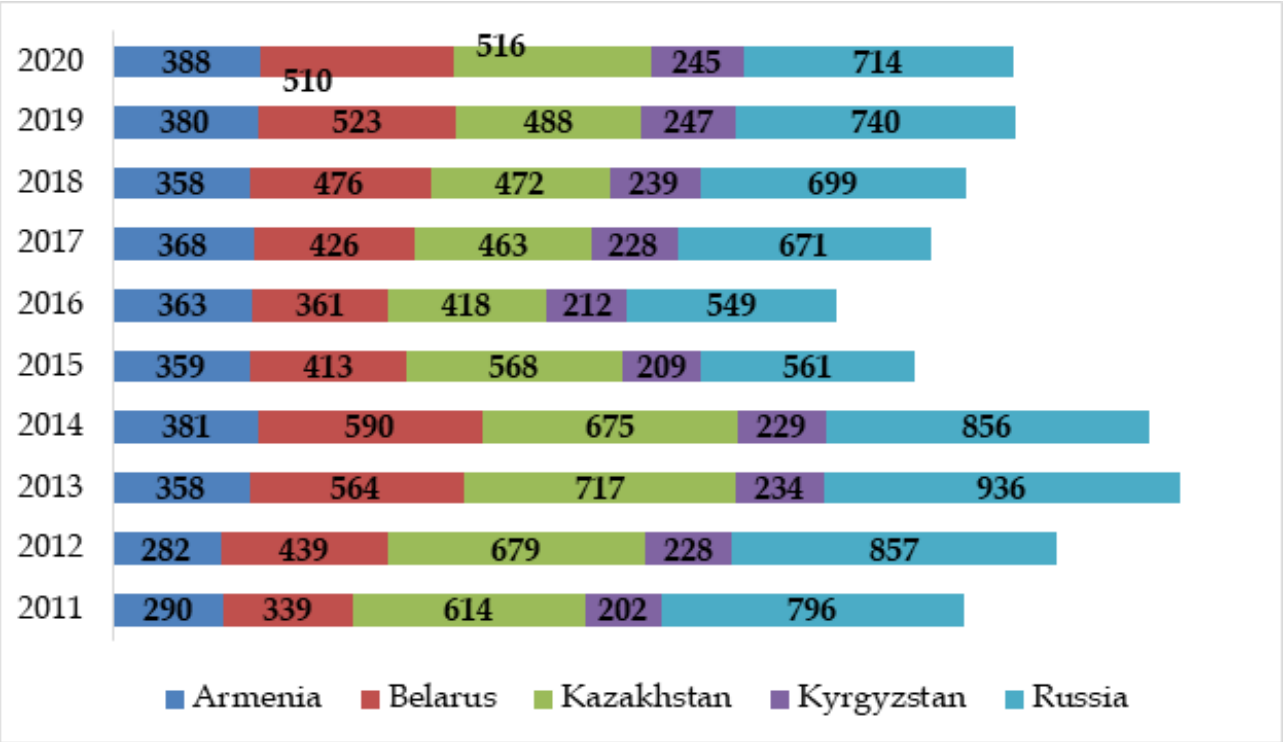

Figure 10. Average monthly nominal wages of the EAEU member states, USD[4]

Considering the dynamics of changes in the volume of remittances to the Kyrgyz Republic, there was an increase of 28.0%, amounting to 188,907.5 million soms in 2020, against 128,316.6 million soms from the Russian Federation3 (Figure 11). This resulted in a positive impact both on the quality of life of the population of the Kyrgyz Republic, and on the socio-economic development of the Kyrgyz Republic as a whole.

Despite the quantitative decrease in the number of emigrants, including in terms of gender, they are becoming feminised, which in the foreseeable future is fraught with a demographic risk that ultimately affects the national security of the Kyrgyz Republic. For example, the femininity of migrants leads to an increase in the number of divorces and, consequently, to a decrease in the birth rate and a gradual transition from expanded reproduction of the population to simple reproduction of the population. This is an example of such a small country as the Kyrgyz Republic.

Almost all countries in the world are developing a national migration policy based on regulatory legal acts, financial opportunities, etc. in order to regulate emigration and immigration. For example, some are creating a system of social protection and legal support for the citizens of the country during their residence and work abroad. The Law of the Kyrgyz Republic "On external labour migration" dated January 13, 2006 No. 4 defines the legal norms of protection and regulates the procedure for carrying out the activities of migrant workers, taking into account the legal norms and standards enshrined in the documents of international organisations, ratifying international conventions governing the process labour migration, including the ILO, which provides for "regulation of intercountry migration of the population".

[4] Socio-economic statistics of the EAEU countries. Available at: http://www.eurasiancommission.org/ru/act/integr_i_makroec/dep_stat/union_stat/Pages/default.aspx

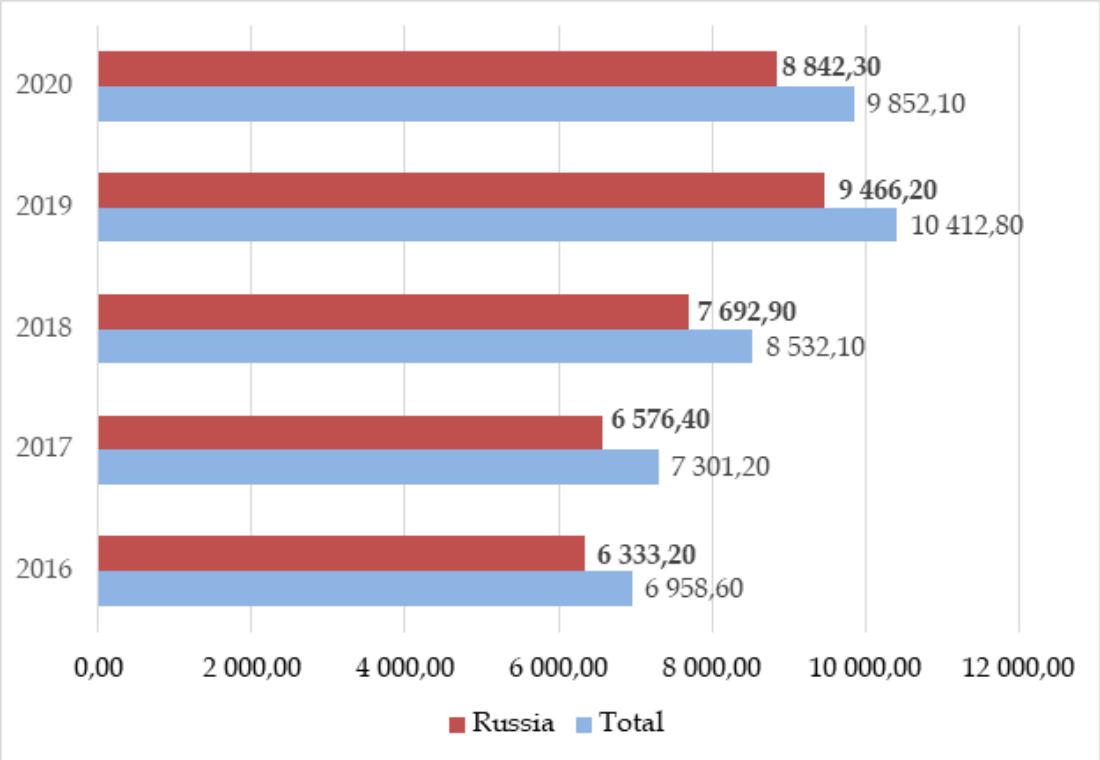

Figure 11. Volumes of remittances in the Kyrgyz Republic, million soms[3]

In connection with the entry of the Kyrgyz Republic into the EAEU in 2015, separate regulatory legal acts on the legal and social support of migrants are being developed and adopted, which will subsequently play a positive role for the Kyrgyz Republic on the return of labour migrants to the country (Sayakbaeva et al., 2020).

5. Discussion

Our diagnostic analysis of the migration processes in the Kyrgyz Republic offers several outcomes. The findings point to the positive impact of migration on socioeconomic processes in the Kyrgyz Republic, including remittances from emigrants making up a significant part of the GDP of many countries of the world, attraction of additional investments, increasing knowledge and skills among the population, reducing the unemployment rate, and improving the standard of living of the population while reducing the level of poverty of the population of the Kyrgyz Republic as a whole. Some of the negative impacts of migration on socio-economic processes in the Kyrgyz Republic are changes in the age, sex, ethnic, and social structure of the population, leading to a demographic imbalance that negatively affects the formation of human capital; the feminisation of external labour migrants increases the impact on the increase in divorce rates, and, consequently, on the number of children born in the family, and labour shortage.

Intercountry labour migration in modern conditions is a global process caused mainly by wars (Syria, Libya, etc.), interethnic conflicts and the collapse of entire countries, such as the USSR, socio-economic and other motives, to stop, restrain, or optimise it in practice impossible. The main motives, both external and internal in the Kyrgyz Republic, are the poverty of the population and the stratification of society, political instability, and the inadequate policy of income and wages. The high and uncontrolled migration of the population to the Kyrgyz Republic is a demographic and socio-economic risk that subsequently affects the economic security of the country. However, despite certain problems in one country, labour migration in another country provides benefits to the latter.

Diagnostics of changes in the demographic situation, as well as the intensification of migration processes, showed an increase in both quantitative and qualitative indicators of migration and in the

forms and directions of movement of the migration vector. Large-scale external and internal mobility of the population and labour resources occurs in various forms, including voluntary migrants who have legal and social support in choosing a place of residence and work. These include refugees and forced migrants from countries where local wars are taking place (Syria, Libya, Afghanistan, etc.) or under pressure from certain circumstances.

The primary task of the state is to create a favourable environment for the population within the country, both for the development of the economy as a whole and for the formation of human capital. This must be done through a whole range of economic, social, and legal measures. The development of agriculture, healthcare, and cultural and social life should help reduce the flow of labour migrants abroad and consolidate the population in the areas of its traditional residence. In addition, it is necessary to protect the rights of labour migrants and to provide all social guarantees for those who have already found themselves abroad.

6. Conclusion

To summarise our findings on population migration in the Kyrgyz Republic, we observed that this socio-economic process has a significant impact on the balance of the labour market and changes the economic and social situation of the population. The process is often accompanied by an increase in educational and professional training, and an expansion of the needs of people participating in migration. To regulate migration for the sustainable development of the economy, efforts should be made to implement comprehensive measures, including the following:

- Form a system for recording and analysing information about migrants in order to develop an optimal migration policy.

- Create a system of pre-departure training for migrant workers, using various forms of information and legal and resource centres for the protection of rights and raising legal awareness, language training, and cultural adaptation of migrant workers.

- Create a system of vocational training and retraining taking into account the needs of the labour market of the countries of employment, and the gender factor, stimulating the participation of the private sector, employers, and educational institutions.

- Create a flexible system of health insurance for migrant workers and members of their families using various types, including voluntary insurance of citizens, the possibility of paying contributions after returning from migration, etc.

- Develop and implement programmes for the social and professional reintegration of returned migrants to enhance the participation of migrant workers and members of their families in the socio-economic development of the country.

- Develop public–private partnerships in order to attract labour migrants as investors in the economy.

- Coordinate activities of private employment agencies, providing them with methodological, informational, and legal support from the state.

- Ensure control over the implementation of legislation by intermediaries in terms of movement, employment of citizens, and protection of their rights in the host country.

- Collaborate with non-governmental organisations, associations of labour migrants, and trade unions to create an infrastructure to support labour migrants abroad.

- Use the open interaction of diasporas and local governments to solve problems of employment, family problems, and observance of the rights of labour migrants.

- Coordinate countries of destination on the issues of introducing a system of certification of skills

acquired by labour migrants in countries of destination.

- Ensure the safety of labour migrants of the Kyrgyz Republic in the process of their emigration to adaptation in recipient countries by familiarising emigrants with legal rights and obligations in countries of arrival.

Based on the findings of this study, the labour market in the Kyrgyz Republic and the impact of migration on the labour market need to be further studied to understand and identify current trends in the economy's labour needs.

References

Bodström, E., 2022. Illusions of objectivity: The two functions of country of origin information in asylum assessment. Migration Studies, mnac033. https://doi.org/10.1093/migration/mnac033

Božič, I.R, Klvaňová, R., Jaworsky, B.N., 2022. Foreigner, migrant, or refugee? How laypeople label those who cross borders. Migration Studies, mnac035. https://doi.org/10.1093/migration/mnac035

Chan, A.K.Q., Cheung, L.T.O, Chong, E.K-m., Lee, M.Y.K, Wong, M.Y.H., 2022. Hong Kong's new wave of migration: socio-political factors of individuals' intention to emigrate 10, 49. Comparative Migration Studies. https://doi.org/10.1186/s40878-022-00323-y

Cubas, A., Paul, A.M., Ramírez, J. et al., 2022. Comparative perspectives on migration, diversities and the pandemic. Comparative Migration Studies 10, 38. https://doi.org/10.1186/s40878-022-00306-z

de Haas, H., 2021. A theory of migration: The aspirations-capabilities framework. Comparative Migration Studies 9, 8. https://doi.org/10.1186/s40878-020-00210-4

Dumitru, S., 2023. The ethics of immigration: How biased is the field? Migration Studies, mnac042. https://doi.org/10.1093/migration/mnac042

Goksu, F., Leerkes, A., 2022. Political participation as transformative reactive mobilization: A qualitative study of voter preferences among Turkish origin residents in the Netherlands. Comparative Migration Studies 10, 47. https://doi.org/10.1186/s40878-022-00318-9

Grzymala-Kazlowska, A., Ryan, L., 2022. Bringing anchoring and embedding together: Theorising migrants' lives over-time. Comparative Migration Studies 10, 46. https://doi.org/10.1186/s40878-022-00322-z

Kim, H., Lee, C., 2022. The immigrant wage gap and assimilation in Korea. Migration Studies, mnac031. https://doi.org/10.1093/migration/mnac031

Krasinets, E., Tyuryukanova, E., Shevtsova, T., 2004. Migration of the population in the Russian Federation: development trends and problems of regulation. Power 10, 63-69.

Massei, D., 2017. Synthetic theory of international migration. International population migration: Russia and the modern world. The World in the Mirror of International Migration 10, 132.

Rakovskaya, V.S., Solovyova, N.N., Tumanova, I.A., 2013. Labor migration: implications for donor and recipient countries. Modern problems of science and education. Modern problems of science and education 3. Available from: http://www.science-education.ru/ru/article/view?id=9443 (accessed November 23, 2022).

Salami, B., Tulli, M., Alaazi, D.A., Juen, J., Khasanova, N., Foster, J., Vallianatos, H., 2022. Formal and informal support networks as sources of resilience and sources of oppression for temporary foreign workers in Canada. Migration Studies, mnac038. https://doi.org/10.1093/migration/mnac038

Sayakbaeva, A.A., Akylbekova, N.I, Temirlan, T., 2020. Problems of human capital development in the Kyrgyz Republic. Human Capital in the Digital Economy, 23–31.

Sayakbaeva, A.A., Akylbekova, N.I, Temirlan, T., 2021. The impact of the COVID-19 pandemic on the socio-economic development of Kyrgyzstan. Reform 3 (91), 6–12.

Simonsen, K.B., 2021. The democratic consequences of anti-immigrant political rhetoric: A mixed methods study of immigrants' political belonging. Polit Behav 43, 143–174. https://doi.org/10.1007/s11109-019-09549-6

Solano, G., De Coninck, D., 2022. Explaining migrant integration policies: A comparative study across 56 countries. Migration Studies, mnac032, https://doi.org/10.1093/migration/mnac032

Solano, G., de Coninck, D., 2022.Correction to: Explaining migrant integration policies: A comparative study across 56 countries. Migration Studies, mnac036. https://doi.org/10.1093/migration/mnac032

Vermeulen, F., 2019. The Paradox of Immigrant Political Participation in Europe Amidst Crises of Multiculturalism. New York: OUP, pp. 801–816.

Vermeulen, F., Harteveld, E., van Heelsum, A., et al., 2020. The potential of immigrant parties: insights from the Dutch case. Acta Polit 55, 432–453. https://doi.org/10.1057/s41269-018-0123-z

Wahab, A., Hamidi, M., 2022. COVID-19 pandemic and the changing views of mobility: the case of Nepal–Malaysia migration corridor. Comparative Migration Studies 10, 44. https://doi.org/10.1186/s40878-022-00320-1

Список источников

Bodström, E., 2022. Illusions of objectivity: The two functions of country of origin information in asylum assessment. Migration Studies, mnac033. https://doi.org/10.1093/migration/mnac033

Božič, I.R, Klvaňová, R., Jaworsky, B.N., 2022. Foreigner, migrant, or refugee? How laypeople label those who cross borders. Migration Studies, mnac035. https://doi.org/10.1093/migration/mnac035

Chan, A.K.Q., Cheung, L.T.O, Chong, E.K-m., Lee, M.Y.K, Wong, M.Y.H., 2022. Hong Kong's new wave of migration: socio-political factors of individuals' intention to emigrate 10, 49. Comparative Migration Studies. https://doi.org/10.1186/s40878-022-00323-y

Cubas, A., Paul, A.M., Ramírez, J. et al., 2022. Comparative perspectives on migration, diversities and the pandemic. Comparative Migration Studies 10, 38. https://doi.org/10.1186/s40878-022-00306-z

de Haas, H., 2021. A theory of migration: The aspirations-capabilities framework. Comparative Migration Studies 9, 8. https://doi.org/10.1186/s40878-020-00210-4

Dumitru, S., 2023. The ethics of immigration: How biased is the field? Migration Studies, mnac042. https://doi.org/10.1093/migration/mnac042

Goksu, F., Leerkes, A., 2022. Political participation as transformative reactive mobilization: A qualitative study of voter preferences among Turkish origin residents in the Netherlands. Comparative Migration Studies 10, 47. https://doi.org/10.1186/s40878-022-00318-9

Grzymala-Kazlowska, A., Ryan, L., 2022. Bringing anchoring and embedding together: Theorising migrants' lives over-time. Comparative Migration Studies 10, 46. https://doi.org/10.1186/s40878-022-00322-z

Kim, H., Lee, C., 2022. The immigrant wage gap and assimilation in Korea. Migration Studies, mnac031. https://doi.org/10.1093/migration/mnac031

Krasinets, E., Tyuryukanova, E., Shevtsova, T., 2004. Migration of the population in the Russian Federation: development trends and problems of regulation. Power 10, 63-69.

Massei, D., 2017. Synthetic theory of international migration. International population migration: Russia and the modern world. The World in the Mirror of International Migration 10, 132.

Salami, B., Tulli, M., Alaazi, D.A., Juen, J., Khasanova, N., Foster, J., Vallianatos, H., 2022. Formal and informal support networks as sources of resilience and sources of oppression for temporary foreign workers in Canada. Migration Studies, mnac038. https://doi.org/10.1093/migration/mnac038

Sayakbaeva, A.A., Akylbekova, N.I, Temirlan, T., 2020. Problems of human capital development in the Kyrgyz Republic. Human Capital in the Digital Economy, 23–31.

Sayakbaeva, A.A., Akylbekova, N.I, Temirlan, T., 2021. The impact of the COVID-19 pandemic on the socio-economic development of Kyrgyzstan. Reform 3 (91), 6–12.

Simonsen, K.B., 2021. The democratic consequences of anti-immigrant political rhetoric: A mixed methods study of immigrants' political belonging. Polit Behav 43, 143–174. https://doi.org/10.1007/s11109-019-09549-6

Solano, G., De Coninck, D., 2022. Explaining migrant integration policies: A comparative study across 56 countries. Migration Studies, mnac032, https://doi.org/10.1093/migration/mnac032

Solano, G., de Coninck, D., 2022.Correction to: Explaining migrant integration policies: A comparative study across 56 countries. Migration Studies, mnac036. https://doi.org/10.1093/migration/mnac032

Vermeulen, F., 2019. The Paradox of Immigrant Political Participation in Europe Amidst Crises of Multiculturalism. New York: OUP, pp. 801–816.

Vermeulen, F., Harteveld, E., van Heelsum, A., et al., 2020. The potential of immigrant parties: insights from the Dutch case. Acta Polit 55, 432–453. https://doi.org/10.1057/s41269-018-0123-z

Wahab, A., Hamidi, M., 2022. COVID-19 pandemic and the changing views of mobility: the case of Nepal–Malaysia migration corridor. Comparative Migration Studies 10, 44. https://doi.org/10.1186/s40878-022-00320-1

Раковская, В.С., Соловьева, Н.Н., Туманова, И.А., 2013. Трудовая миграция: последствия для стран-доноров и стран-получателей помощи. Современные проблемы науки и образования. Современные проблемы науки и образования 3. Режим доступа: http://www.science-education.ru/ru/article/view?id=9443 (Ноябрь 23, 2022).

The article was submitted 21.11.2022, approved after reviewing 12.12.2022, accepted for publication 14.12.2022.

Статья поступила в редакцию 21.11.2022, одобрена после рецензирования 12.12.2022, принята к публикации 14.12.2022.

About authors:

1. Ayganysh Sayakbaeva, Doctor of Economics, professor, head of the "Finance" department, Kyrgyz National University named after J. Balasagyn, Bishkek, Kyrgyz Republic. https://orcid.org/0000-0002-8015-5061, aas51@mail.ru

2. Nelly Akylbekova, , Doctor of Economics, senior lecturer, Vice Rector for Research, International Academy of Management, Law, Finance and Business, Bishkek, Kyrgyz Republic. https://orcid.org/0000-0002-8829-0094, nelly_a@bk.ru

3. Maria Taalaibek, doctoral student, Kyrgyz National University named after J. Balasagyn, Bishkek, Kyrgyz Republic

Информация об авторах:

1. Айганыш Апышевна Саякбаева, д.э.н., профессор, зав. кафедрой «Финансы» Кыргызского национального университета (КНУ) им. Ж. Баласагына, Бишкек, Кыргызская Республика. https://orcid.org/0000-0002-8015-5061, aas51@mail.ru

2. Нелли Ильинична Акылбекова, д.э.н., доцент, проректор по научной работе Международной академии управления, права, финансов и бизнеса (МАУПФиБ), Бишкек, Кыргызская Республика. https://orcid.org/0000-0002-8829-0094, nelly_a@bk.ru

3. Мария Таалайбек, докторант, КНУ им. Ж. Баласагына, Бишкек, Кыргызская Республика

SECTION 4

MANAGEMENT OF KNOWLEDGE AND INNOVATION FOR SUSTAINABLE DEVELOPMENT

РАЗДЕЛ 4

УПРАВЛЕНИЕ ЗНАНИЯМИ И ИННОВАЦИЯМИ В ИНТЕРЕСАХ УСТОЙЧИВОГО РАЗВИТИЯ

Research article
DOI: https://doi.org/10.48554/SDEE.2022.4.5

Development of Methodological Provisions for Rational Material Cutting in Lean Manufacturing at Mechanical Engineering Enterprises

Artem Smirnov[1,2*], Vladimir Kobzev[1*], Cholpon Nuralieva[3]

[1] Peter the Great St. Petersburg Polytechnic University, Saint-Petersburg, Russia
[2] Vologda State University, Vologda, Russia
[3] Kyrgyz-Russian Slavic University named after B.N. Yeltsin
Corresponding author: smirnov.artem.a@yandex.ru

Abstract

In the market economy, mechanical engineering enterprises require continuous improvement of business processes to ensure their competitiveness and sustainable development. Improving business processes based on lean manufacturing and management accounting allows for gaining competitive advantages in the value-creating flow for the consumer and increasing the economic efficiency of the enterprise's operations. This study takes into account the need to improve the management of material resources being cut at mechanical engineering enterprises with single and serial production types. The main direction for improving the cutting process of industrial materials is to increase their utilisation rate through the use of rational cutting methods. However, this study identifies unresolved problems in theory and practice related to managing business and non-business material resources obtained after cutting, which affect the elimination of material and time losses arising in the process of cutting. Among the main study results are advanced terminological apparatus in the field of cutting industrial materials, advanced techniques for sorting material resources obtained after cutting and methodological provisions for their valuation, methodological approach to assessing economic efficiency of the sorting decision, and software package prototype with elements of the decision-making support system for sorting materials obtained after cutting. The implications of these results are discussed, and directions for future research are suggested.

Keywords: lean manufacturing, managerial accounting, material resource management, mechanical engineering enterprises, development of rational material cutting, business material resources, sorting technique

Citation: Smirnov, A., Kobzev, V., Nuralieva, Ch., 2022. Development of methodological provisions for rational material cutting in lean manufacturing at mechanical engineering enterprises. Sustainable Development and Engineering Economics 4, 5. https://doi.org/10.48554/SDEE.2022.4.5

This work is licensed under a CC BY-NC 4.0

© Smirnov, A., Kobzev, V., Nuralieva, Ch., 2022. Published by Peter the Great St. Petersburg Polytechnic University

Научная статья
УДК 658.5
DOI: https://doi.org/10.48554/SDEE.2022.4.5

Развитие методических положений рационального раскроя материалов в бережливом производстве на предприятиях машиностроения

Артем Смирнов[1,2*], Владимир Кобзев[1], Чолпон Нуралиева[3]

[1] Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия
[2] Вологодский государственный университет, Вологда, Россия
[3] Кыргызско-Российский Славянский университет им. Б.Н. Ельцина, Бишкек, Кыргызская Республика
Автор, ответственный за переписку: smirnov.artem.a@yandex.ru

Аннотация

В условиях рыночной экономики на предприятиях машиностроения для обеспечения конкурентоспособности и устойчивого развития требуется непрерывное совершенствование бизнес-процессов. Совершенствование бизнес-процессов на основе бережливого производства и управленческого учета позволяет получить конкурентные преимущества в потоке создания ценности для потребителя и повысить экономическую эффективность операционной деятельности предприятия. В исследовании принята во внимание необходимость совершенствования управления материальными ресурсами при их раскрое на предприятиях машиностроения с единичными и серийным типами производства. Основным направлением совершенствования раскроя промышленных материалов является увеличение коэффициента их использования через применение рациональных методов раскроя. Однако в ходе работы выявлены нерешенные в теории и практике проблемы, связанные с управлением деловыми и неделовыми материальными ресурсами, полученными после раскроя, которые влияют на устранение возникающих материальных и временных потерь в процессе раскроя Также основными результатами исследования являются: развитый терминологический аппарат в области раскроя промышленных материалов; разработанные методика сортировки материальных ресурсов, полученных после раскроя, и методические положения их стоимостной оценки; предложены методический подход к оценке экономической эффективности принимаемого решения по сортировке и прототип программного комплекса с элементами системы поддержки принятия решений по сортировке материалов, полученных после раскроя. В статье проведен анализ полученных результатов и определены направления дальнейших исследований.

Ключевые слова: бережливое производство, управленческий учет, управление материальными ресурсами, предприятия машиностроения, развитие рационального раскроя материалов, деловые материальные ресурсы, методика сортировки

Цитирование: Смирнов, А., Кобзев, В., Нуралиева, Ч., 2022. Развитие методических положений рационального раскроя материалов в бережливом производстве на предприятиях машиностроения. Sustainable Development and Engineering Economics 4, 5. https://doi.org/10.48554/SDEE.2022.4.5

This work is licensed under a CC BY-NC 4.0

© Смирнов, А., Кобзев, В., Нуралиева, Ч., 2022. Издатель: Санкт-Петербургский политехнический университет Петра Великого

1. Introduction

Mechanical engineering enterprises with single or serial types of production, using lean manufacturing tools as one of the directions of their development, were chosen as the study objects. The relevance of the study is grounded in its focus on the concept of lean manufacturing aimed at eliminating all types of losses while improving processes in the organisation, which ensures an increase in the economic efficiency of production and in the consumer properties of products, and the emergence of competitive advantages as a result. The solution to multiple problems in modern science and technology development requires an interdisciplinary approach that provides synergistic effects. The current practice of implementing lean manufacturing confirms the need to consider the identified problems from different perspectives.

Shichkov et al. (2016, 2019) confirmed that the study of the problems applied in the field of production organisation, managerial accounting and innovation management ensures the development of the theoretical aspects of industrial economics. Managerial accounting should include the adoption of prompt and reasonable managerial decisions, so it is advisable to consider its competent combination with lean manufacturing. Suloeva et al. (2017) emphasised that in the overall mechanical engineering enterprise management system, special attention should be paid to cost management, since achieving the required consumer product properties and competitive advantages can be guaranteed by increasing the economic efficiency of production processes.

In the field of lean manufacturing, Turovets et al. (2016), for example, substantiated the need to consider the specifics of the object of study, which can improve business processes. The development of lean manufacturing tools is driven by their validation by many manufacturing enterprises (Safronova et al., 2020). Business processes associated with material resources management at mechanical engineering enterprises require constant managers' attention, since these are material resources that form the largest share of costs, and the technology of their processing and organisational and economic management mechanisms determine the economic efficiency of their activities. The task of increasing the utilisation rate of industrial materials in order to reduce material costs, optimise costs of improving product consumer properties, and increase net income is set when organising the process of material cutting, which is a significant share in operating costs at many mechanical engineering enterprises.

The main direction of increasing the utilisation rate of industrial materials is the promotion of rational cutting algorithms, which are widely considered by national and international researchers. The issues of rational cutting are handled by the Euro Special Interest Group on Cutting and Packing (ESICUP), the Ufa School of Science, etc. The analysis of the scientific and practical literature on the issues of rational cutting led to the following conclusions:

Scientific and practical studies consider the issues of developing rational cutting techniques that provide optimal blank location on a given material resource and optimal material resource choice for making blanks from it to increase the material utilisation rate.

The issue of the reasonable sorting of material resources into business and non-business resources obtained after cutting at mechanical engineering enterprises has not been addressed. The relevance of this issue is confirmed by the fact that reasonable sorting of material resources after cutting reduces the cost of storage and transportation of non-business materials, which, under empirical sorting, could be classified as business materials, and will increase the material utilisation rate during manufacturing products made from business material resources, which, under empirical sorting, could be classified as non-business materials. This task is especially relevant for mechanical engineering enterprises with single or serial production types, since the range and completeness of blanks and material resources obtained after cutting vary depending on the consumer properties of the product.

Thus, to address these gaps, this study focuses on managerial relations that arise in the process of providing lean production with material resources when cutting materials in mechanical engineering

enterprises with single or serial production types. The purpose of this study is to develop methodological provisions for improving the tools to manage material resources in lean manufacturing when cutting materials in mechanical engineering enterprises with single or serial production types. Methodological provisions are understood in the study as a set of tools (e.g. terminology, techniques, methodological approaches) that help to achieve the main goal (e.g. improving the process under study, existing technologies). The study is aimed at:

Assessing theoretical and practical aspects of rational material cutting.

Forming a terminological apparatus in the field of material cutting.

Developing a methodology for classifying material resources as business and non-business after cutting and practical recommendations for the methodology application.

Developing methodological provisions to determine the possible price of material resources obtained after cutting.

Developing a methodological approach to assess the economic efficiency of the sorting process during decision making.

Developing the prototype software package with elements of decision support for sorting material resources.

2. Literature review

A central issue in the rational cutting of industrial materials, according to the scientific and practical literature, is the 'cutting and packing problem'. The solution to this problem is aimed at reducing the cost of resources (Valiakhmetova et al., 2014). One-dimensional (1D), two-dimensional (2D), and three-dimensional (3D) cutting and packing problems are distinguished based on the geometry of the initial resource. In addressing these problems, researchers have identified nesting problems arising from placing parts of the complex geometry in specified areas of the material resource. In solving these issues, particular attention is paid to informational problems of shape setting, accounting, and ensuring their non-intersection. Within the framework of 3D packing problems, objects are rectangular parallelepipeds placed either in a rectangular container with one unfixed face, or in several containers with given linear dimensions. Table 1 shows the main varieties of one-dimensional and two-dimensional problems within the framework of the general cutting and packing problem (Filippova et al., 2013).

Table 1. Basic one-dimensional and two-dimensional problems of cutting and packing

Problem name	Content
1D cutting and packing problems	
Knapsack packing (KP)	The dimensions (e.g. weight, length) and the values (price, other estimate) of certain elements are known, and the capacity of the knapsack is also known. A combination of elements that allows the cost of the knapsack to reach its maximum is identified.
1D cutting stock (1DCS)	The strip must be cut into blanks of certain sizes with the lowest cost of the source material.
Multi cutting stock (MCS)	A more complex version of the previous problem of cutting material of various lengths.
1D bin packing (1DBP)	A special case of the one-dimensional cutting problem in which each blank is required in a single copy.
2D cutting and packing problems	

2D strip packing (2DSP)	One of the strip dimensions (e.g. width) is specified, the second dimension (e.g. length) is variable. A package must fit within a strip of a minimum length.
2D bin packing (2DBP)	Both dimensions (width, length) are set. The minimum number of containers in which all rectangular elements are packed must be specified.
2D area packing (2DAP, quadrant)	Both dimensions (width, length) are variable for a rectangular object. A pack of elements must fit into an angle formed by coordinate axes that coincide with the width and length of the area for which the area of the envelope element of the rectangle reaches its minimum.
Guillotine cutting	Only through cuts of the source material are possible; Generalises the 1DCS problem to a two-dimensional version.
2D guillotine strip cutting (2DGSC)	A guillotine roll must be cut into specified rectangular elements that will provide the minimum length of the used part of a strip.
2D guillotine bin cutting (2DGBC)	A set of guillotine cuts must be identified to ensure the minimum consumption of sheets.

Table 2 reflects the research directions in the field of solving problems of cutting industrial materials.

Table 2. Research in the field of solving problems of cutting and packing

Authors	Main research directions in solving problems of cutting industrial materials
L.V. Kantorovich and V.A. Zalgaller	Soviet scientists, founders of solving the problems of rational cutting of industrial materials. L.V. Kantorovich proposed the method of resolving indices, which was finalised in practice by V.A. Zalgaller, who proposed his method for selecting integer indices. The researchers described the developed techniques, which were practically tested at the Leningrad Carriage Works in 1948–1949 in their Rational Cutting of Industrial Materials book. The first edition was published in 1951. In this paper, the authors mainly considered techniques for solving problems of rational (with the highest material utilisation factor) cutting of linear materials (long products, pipes, bars) and sheet materials (rolled sheets, plywood, glass) into blanks of simple shapes. It should be noted that the issues of cutting sheet material into curvilinear elements have not been studied. (Kantorovich and Zalgaller, 1971)
E.A. Mukhacheva	The Ufa Scientific School was found based on the cutting and packing studies by E. A. Mukhacheva (a student of G. Sh. Rubenstein, who worked with L. V. Kantorovich. Her paper, Rational Cutting of Industrial Materials. Application in Automated Control Systems, which was published in 1984, reflects the theory and practice of rectangular cutting within the framework of a computer-aided design system for the technological preparation of cutting in cold stamping production. The main attention was paid to the theory and practice of rational cutting of rectangular sheets into rectangular blanks. (Mukhacheva, 1984)
V.M.Kartak	Development of the ‘branches and boundaries’ technique for solving packing problems by introducing iteration reduction procedures; study of the problems of linear cutting, packing, and assessing packing density of rectangles in a semi-infinite strip. (Kartak, 2009, 2019)

M.A. Mesyagutov	An exact technique of solving the problem of one-dimensional continued packing was proposed, based on dominance criteria and cut-off rules to reduce the process of iteration (Filippova et al., 2013)
Yu.I. Valiakhmetova	Research of layer-by-layer algorithms for solving problems of rectangular guillotine cutting of sheet materials; development of the concept of hyperheuristic algorithms for solving optimisation problems (Valiakhmetova et al., 2012, 2013, 2014)
A.S. Filippova	Research is aimed at developing solutions to orthogonal packing problems (Filippova et al., 2013)
A.A. Petunin	A scheme is proposed for automatic selection of the optimisation algorithm for cutting materials depending on the task type (Petunin, 2010)
H. Dyckhoff, G. Wascher, H. Haubner, H. Schumann	Classifications development of cutting and packing problems (Dyckhoff, 1990; Wascher et al., 2007)
Euro Special Interest Group on Cutting and Packing (ESICUP)	The organisation was founded in 1988 to bring together practitioners and researchers interested in cutting and packing problems. The goal of ESICUP is to improve the interactions between people working in this field.

The issues of rational cutting of industrial materials in combination with reasonable material costs for manufacturing were considered by Tolstobrov (2019) and Salkova (2019). The analysis of scientific publications and practical work on the problem of cutting and packing showed that national and international researchers have developed mathematical methods and approaches to organising rational cutting of industrial materials in terms of the optimal location of blanks on a given material resource and the optimal choice of a material resource for manufacturing blanks from it. This ensures an increase in the material utilisation rate, change in the indicators of the enterprise's operating activities (production volume in physical and value terms, unit technological costs, depreciation deductions from tangible and intangible assets, and operating profit).

However, in the reviewed works on the rational cutting of industrial materials, no attention has been paid to the issue of sorting the material resources obtained after cutting, with the goal of classifying them into groups of business or non-business materials. The relevance of reducing the amount of recycling of industrial waste from the point of view of environmental problems and increasing the economic efficiency of the enterprise was confirmed by Demidenko and Malevskoy-Malevich (2013, 2014).

3. Methods and materials

The research methodology is based on the concept of lean production, which is focused on the formation of a continuous value-creating flow for the consumer, continuous improvement of organisational processes through the involvement of personnel, and elimination of all types of losses. The study explores the issues of lean production related to reducing material costs through the use of business materials, the cost of storing and transporting business or non-business material resources, and reducing the time spent searching for and transporting business material resources in the manufacturing process.

The developed toolkit for managing the material resources obtained after cutting takes into account some components of supply chain management (demand forecasting, stock and replenishment management in relation to the allocated classes of material resources, and visualisation of information on material residues in the context of their nomenclature with allowance for business and non-business material resources). The proposed methods are based on the provisions of managerial accounting, since timely collecting, processing, analysing, and interpreting diverse information is required for making

prompt and informed decisions, according to the enterprise specifics.

The authors used the following general research techniques:

Analysis (theoretical and practical aspects of rational cutting, lean production, and managerial accounting were analysed)

Synthesis (methodological provisions for sorting the material resources obtained after cutting were synthesised)

Formalising (graphic description of the studied processes using the activity diagram (UML language) was given; dependence of the analysed economic indicators was described using mathematical formulas).

The analysis of production processes at mechanical engineering enterprises manufacturing capacitive equipment in the city of Vologda and the analytical materials presented in the studied literature constitute the empirical aspects of the study.

4. Results

4.1. Identifying the problems of material resource management

The costs and process of cutting sheet metal analysis at mechanical engineering enterprises in the city of Vologda, with a single and small-scale type of capacitive equipment manufacturing, were considered to determine the problems of managing material resources in terms of the theoretical and practical foundations of rational materials cutting at mechanical engineering enterprises:

The cost of sheet metal is approximately 70% in the structure of material costs, and the sheet metal utilisation rate is approximately 0.8. The selling price of non-business material resources is significantly lower than the purchase price of the source material (by about 80–85%). Thus, the enterprise increases the cost of production with an increase in the number of non-business material resources.

Disparate design of sheet metal cutting maps prevails; therefore, there is less opportunity to place blanks more densely, and the material utilisation rate decreases.

Sheet metal cutting is carried out on the basis of the technologist's empirical perception; there are no regulations, reducing the possibility of increasing the sheet metal utilisation rate.

Classification of material resources after cutting into business and non-business ones is carried out empirically with no methodology, which is reflected in the growth of material costs (business materials can be classified as non-business materials), storage costs, and transport and procurement works (non-business materials can be classified as business materials).

There is no marking equipment or procedures for marking business material resources after cutting, which complicates their accounting.

There is no reasoned design of cutting maps with an allowance for business materials, which is reflected in increased material costs.

Sheet metal is accounted for in terms of the original nomenclature in kilograms, which is reflected in the inability to analyse data on the residues of solid sheets, variety of business material resources, and number of non-business ones. This complicates the operational design of cutting charts with allowance for business materials, and planning the correct purchase.

Information support has the possibility of more detailed accounting, but the necessary actions of the process participants are not defined.

There is no regulation of the accounting of materials after cutting.

There is no technique for defining the selling price of material resources after cutting. Non-business materials are sold for recycling at the price of scrap metal.

Based on a cause-and-effect analysis of the lack of data on business material resources in the accounting system, it can be concluded that the main reasons for shortcomings of management accounting for business materials are related to accounting techniques and accounting equipment. Consequently, it is necessary to adjust the existing rules for managing material and information flows within the accounting process and warehousing business and non-business material resources after cutting. The identified organisational and economic aspects, and problems of managing material resources in the field of cutting industrial materials are relevant, since managerial decisions affect enterprise performance and value stream for the consumer. It is necessary to improve the tools for managing material and information flows associated with material resources received after cutting. The set of managerial tools and regulated business processes aimed at managing material resources in an enterprise is understood in this study as the toolkit for managing material resources.

4.2. Developing a terminological apparatus in the field of cutting industrial materials

This study introduces the concept of 'multilevel cutting', that is, the cutting of material resources at the 0 level or *n* level (n are natural numbers from 1 to infinity) when considering the set of material resources obtained after cutting source materials as a system of material resources that have different indicator values characterising them.

The 0-level material resource is the material resource that was not used to produce blanks. The *n*-level material resource is the material resource that was the initial resource for the cutting chart design *n* times. The level of cutting is understood as cutting from the material resource of the 0 level or from the material resource of the *n* level of cutting. Material resources of the *n* levels are obtained as a result of *n*-1 level cutting and represent a set of material resources for further product manufacturing or selling to external consumers. From a technological point of view, interchangeable material resources at different levels can be used in the development of cutting charts. However, preference should be given to those that are more cost-effective for making blanks. Such a material resource has substitutive properties.

Integrated design of cutting charts is the design of blank cutting charts for the entire range of products manufactured at the enterprise, taking into account the available range of material resources. It is necessary to identify the resulting material resources of the *n*+1 level into groups of 'business' and 'non-business' material resources when cutting from material resources of the 0 or *n* level. Business material resources of the *n* level are resources that are technically possible and economically feasible to use for *n* level cutting. Non-business material resources are resources of the *n* level that are not economically feasible to use for *n*-level cutting. Assessment of the *n*-level material resource is determination of the indicator values and characterising the material resource of the *n* level, based on which identification of the material resource of the *n* level is carried out to justify the feasibility of manufacturing products from it.

Identification of the material resource of the *n* level is a comparison of the indicator values characterising the material resources of the *n* level with the reference indicator values of the corresponding classes of material resources. The expediency of allocating classes of material resources is substantiated in the framework of the developed sorting technique described in the next segment. Sorting of the *n*-level material resource is a categorisation of the material resource of the *n*-th level into the group of business or non-business material resources, taking into account changes in costs and net income, and the ratio of supply and demand for the corresponding class of material resources.

This study developed **a technique for sorting the material resources obtained after cutting into business or non-business material groups** (Smirnov et al., 2019). The technique is represented by a set of sequential actions for assessing the indicator values characterising consumer properties of material resources after cutting, identifying them with the corresponding classes, and classifying them as business and non-business ones with an allowance for changes in unit costs and net income from the enterprise's operating activities.

1. Designing cutting charts

When designing a cutting chart for a reasonable and prompt selection of the optimal option, it is advisable to use software tools (CAD/CAM-systems) developed on the rational cutting techniques proposed in the theory.

2. Classifying material resources

Since material resources can be interchangeable after cutting, it is advisable to determine their classes in accordance with their similarities in terms of assessed indicators in a certain range of values. If there are classes, the software tool can sufficiently analyse templates of the generated classes in the process of designing a cutting chart, taking into account business material resources. It is necessary to keep quantitative records of the material resources being cut in terms of classes, not only in kilograms but also in pieces, so that the cutting chart design programme can determine the choice of material resources, taking its availability into account. Thus, the indicator values characterising the material resources should be obtained after cutting and identified with the corresponding classes.

3. Pre-sorting

We propose assessing the estimated demand (Qsm, pcs./month) for classes of material resources, the value of which is compared with the quantity of material resources in the class (Nsm, pieces) at the time of sorting, since it is not advisable to store materials suitable for making blanks, but there is no need for manufacturing at the moment. The assessed demand should be carried out on the basis of a statistical assessment of the average consumption volume of the corresponding class. Depending on the managerial tasks, the values of the enterprise average monthly performance indicators can be assessed for different periods, for example, quarter, half a year, or a year. The seasonality factor has a significant impact on production activities for a number of mechanical engineering enterprises in single and serial production. Therefore, it is advisable to use the average monthly value for the past year (starting from the month preceding the month of assessment) when assessing the average consumption volume of the corresponding class of business material resources, in order to smooth the seasonality factor and use the most relevant data.

4. Final sorting

Sorting decisions must be based on the assessment of the storage and transportation of material resource cost changes when they are classified in the group of business materials in comparison with the uncovered costs of purchasing raw material when selling non-business material resources at a reduced price.

5. Reassessment of business material resources

A monthly reassessment of stored business material resources should be carried out, since the range of manufactured blanks may change due to possible changes in the production programme. The number of stored business material resources in the respective classes should be determined monthly, and the data should be compared with the average monthly consumption. It is expedient to implement this use of the appropriate software in the format of a monthly scheduled job. In addition, the demand for business materials should be monitored daily using the appropriate reports of the software package to promptly adjust inventory management parameters. The decision support system (DSS), CAD/CAM system, and accounting system (such as ERP) should be used to make operational decisions on sorting due to the complexity of assessing and identifying material resources when performed by a staff member.

Based on the developed proposals, Figure 1 presents a graphical interpretation of the process of organised material cutting in mechanical engineering enterprises, considering the business material resources. Changes are proposed at the stages of designing cutting charts, sorting, marking, and managerial accounting of material resources after cutting.

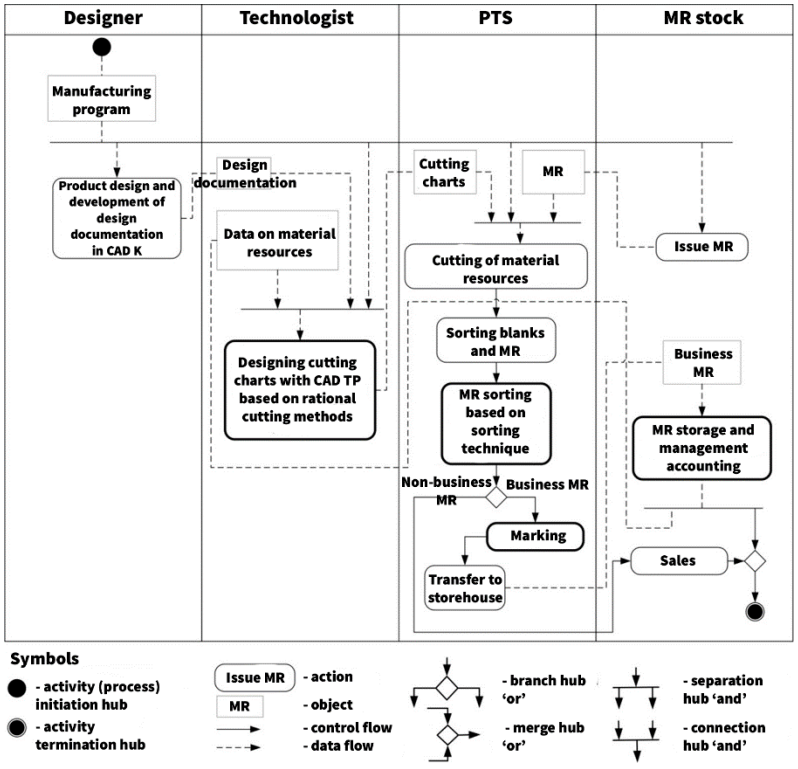

Figure 1. The process of organising material rational cutting taking with allowance for business material resources

Figure 2 shows a graphical interpretation of the process of sorting the material resources obtained after cutting.

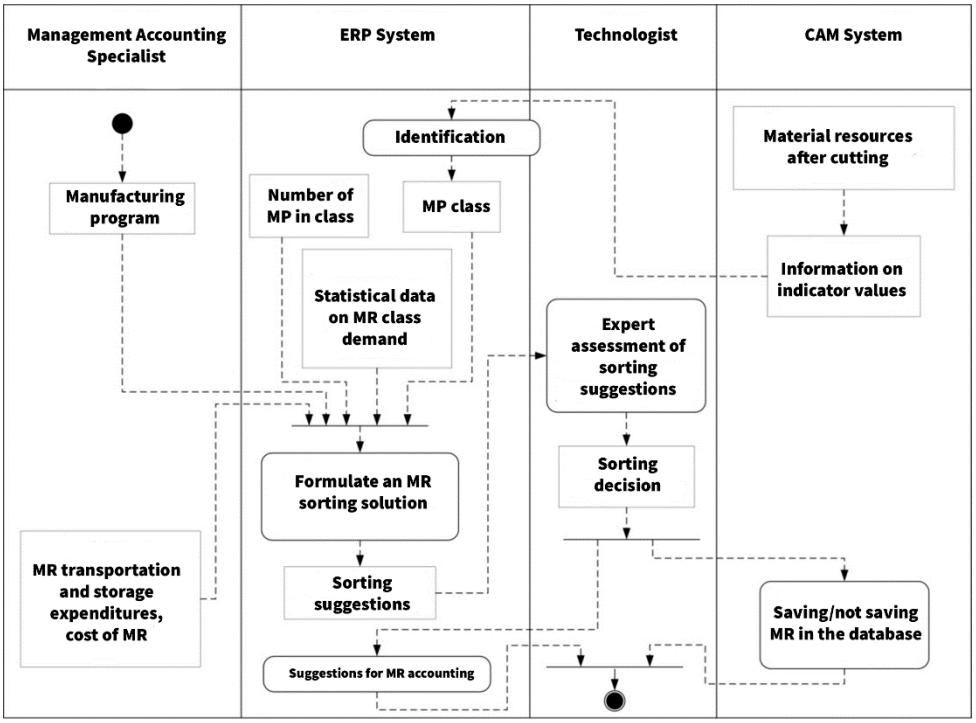

Figure 2. The process of sorting material resources after cutting when allocating them into groups of business or non-business materials

The technique of sorting material resources into business and non-business types and practical guidelines of its development are designed to reduce losses in the value-creating flow (operational and

time costs), optimise the cost structure, improve consumer properties of products and increase net income at mechanical engineering enterprises.

4.3. Techniques for defining the possible selling price of material resources after cutting

As part of the cutting process, it is advisable to assess the transfer price of the material resources after cutting to organise a cost transfer or a possible selling price for external organisations. In this case, the price of the n-level material resource (Vscm, rub./kg) involved in the cutting process cannot be lower than the price of scrap metal (Vscm, rub./kg), since this is the minimum metal price formed by the market, and is generally lower than the market grade metal price (Vsm0, rub./kg) or actual metal costs (Wsmc, rub./kg). It should also be noted that the transfer price of material resources after cutting is equal to the possible selling price, as it is defined based on the actual purchase price of the source material. Therefore, it is proposed to define the material resource transfer price after cutting by its possible selling price.

The material resource selling price may differ depending on the changing indicator value characterising the consumer properties of material resources, and it decreases depending on the increase in the indicator level. This helps to form a customer-centric price in the consumer value-creating flow. Therefore, it is proposed to determine the possible selling price according to Formula (1):

$$\mathrm{Vsm}_i = \mathrm{Vsm}_0\left(1-\left(\sum_{i=1}^{n} w_i k_i\right)\right) \quad (1)$$

where *wi* is the weight factor, *ki* is a coefficient that takes into account price decrease with the change of indicators characterising the consumer properties of the material, *i* is a coefficient index, serial number, and *n* is the total number of coefficients.

Depending on the production specifics, the use of coefficients can be considered in cutting sheet metal, taking into account: (1) the length deviation of the rectangle, formed by the material resource minimum addition, from the length of the 0 level material resource; (2) deviation of the rectangle width, formed by the material resource minimum addition, from the width of the 0 level material resource; (3) value of the fill factor (the ratio of the material resource area to the area of the rectangle formed by the material resource minimum addition); (4) deformation of the material resource plane; (5) change in the material resource edge roughness after cutting; (6) change in the deviation angle of the edge plane from the plane perpendicular to the sheet plane; and (7) mechanical damage to the surface; corrosion of the material resource.

The following conditions should be met when defining a possible selling price of the material resource after cutting according to formula (1): the sum of the weight coefficients *wi* is equal to one; Vsmi cannot be less than the selling price of the corresponding type of scrap metal Vscm. Methodological provisions for determining the material resource selling price after cutting, based on the assessment of changes in indicators characterising consumer properties, allow organising the cost transfer in value terms when manufacturing products from business material resources and increasing the net income when selling non-business material resources. From the point of view of lean manufacturing, allowance for changes in the consumer properties of the material resources obtained after cutting allows for forming a customer-oriented price in the value-creating flow for the consumer.

4.4. Methodological approach to assessing the economic efficiency of decision making in sorting material resources after cutting

The proposed technique of sorting material resources after cutting is considered in the example of sheet metal. The following geometric and technical indicators for identifying the material resources obtained after cutting are proposed: steel grade of sheet metal, thickness, area of the material resource, length of the rectangle formed by the material resource minimum addition, width of the rectangle formed by the material resource minimum addition, area of the rectangle formed by the material resource minimum addition, and fill coefficient. Further, sorting is influenced by such accounting indicators as the

potential demand (Qsm, pcs/month) and amount (Nsm, pcs) of business material resources in a class stored at the time of new material resources identification.

The final sorting decision is made on the basis of an economic assessment of cost changes and net income from the operating activities of the enterprise, taking into account changes in transportation and storage costs of the material resources obtained after cutting the source material. To assess an increase in storage costs, storage time should be assessed through forecasted demand. We propose assessing the maximum allowable and expected storage times of material resources after cutting. The maximum acceptable storage time of business material resources (Tmax) is the storage time at which the change in net income from the sales of products by manufacturing them from business material resources (taking into account the increase in transportation and storage costs) is equal to the increase in net income when selling non-business material resources to external organisations without adding consumer properties. After cutting, material resources should be recognised as business resources if the expected storage time is lower than the permissible one. The estimated material resource storage time can be determined by the data on the values of Qsm and Nsm.

The assessment of the maximum material resource storage time should be carried out when comparing two manufacturing options, relying on possible solutions for sorting material resources (Smirnov, 2017):

Products are made from business material resources.

Products are made from 0-level material resources, and after cutting residues are recognised as non-business and are sold to external organisations. The cost of pre-sale storage is assumed to be insignificant, and the transportation of material resources is organised by the consumer.

During comparison, it is logical to assume that there is no restriction on the source material purchase in ideal market economy conditions in terms of the commodity market supply (which is confirmed in practice). Consequently, the enterprise will receive the same sales at different costs, regardless of the option of using material resources after cutting. The first option will require fewer costs of the source material, since part of the blanks will be made from business material resources. The second option will require more source material, since material resources at the *n* level will be sold to external organisations.

The net income change in blank production from business material resources (the first option) is assessed by Formula (2), taking into account additional transportation and storage costs (natural units of measurement on the example of sheet metal):

$$\Delta D_0 = D_i \cdot \mathrm{Gsm} - \left(1 - \mathrm{Np}\right)\left(\mathrm{Wt} \cdot \mathrm{Gsm} + \mathrm{Ws} \cdot \mathrm{Gsm} \cdot T\right) \quad (2)$$

where ΔD0 is the increase in the net income from the product sales, rub./piece;

Di is the net income per 1 kg (e.g. sheet metal the product is made from), rub./kg;

Np is an income tax rate;

Gsm is the volume of the 0 or n level material resources, from which products are manufactured or which are sold to external organisations, kg/piece;

Wt is specific costs for transportation of material resources after cutting, rub./kg;

Ws is specific costs for storage of material resources after cutting, rub./kg·days;

T is the storage time of material resources, days.

When selling residues after cutting, external organisations are reimbursed for part of the source material costs (second option); therefore, the net income change is assessed by Formula (3):

$$\Delta \mathrm{D}_0 = D_i \cdot \mathrm{Gsm} - \left(1 - \mathrm{Np}\right)\left(\mathrm{Wsmc} - \mathrm{Vsm}_i\right)\mathrm{Gsm} \quad (3)$$

where Vsmi is the selling price of the material resources obtained after cutting, rub./kg; and Wsmc is the specific costs of the source material (which are equal to the purchase price at the first cutting), rub./kg.

Then, under conditions of an unlimited amount of source material purchase, Tmax is assessed by Formula (4):

$$T\max = \frac{\mathrm{W\ smc} - V\ \mathrm{sm}_i - \mathrm{Wt}}{\mathrm{Ws}} \tag{4}$$

Thus, the time is defined in which the increase in transportation and storage costs is equal to the unreimbursed part of the costs (Wsmc′ rub./kg, the difference in the purchase price of the source material (Wsmc, rub./kg) and the selling price of non-business material resources (Vsmi, rub./kg)) when selling the material resources to external organisations at a reduced market price. Formula (5) presents requirements for the decision-making on attributing the material resources obtained after cutting to the group of business materials in economic terms:

$$\mathrm{Wt} + \mathrm{Ws} \cdot T < \mathrm{Wsmc} - \mathrm{Vsm}_i \tag{5}$$

Thus, the economic aspects of the sorting technique were determined with allowance for loss reduction, which arises in the bottlenecks of the cutting process.

4.5. Prototype of the software package with elements of the decision support system for sorting the material resources obtained after cutting

With the current development of information technologies and the need for prompt and justified managerial decision making, a software package should be developed for managing material resources. It was emphasised earlier that the corresponding programme relating to CAD/CAM systems is tasked with managing rational material cutting. The accounting of material resources is also maintained in a certain ERP system. With the developed proposals, it is essential to develop a software package with elements of the DSS to determine the manufactured material resources after cutting into groups of business and non-business materials according to the proposed sorting technique.

It is necessary to ensure cross-system data synchronisation since certain information on materials will be transferred from the CAD/CAM system to the ERP system (e.g. nomenclature of material resources and values of indicators characterising material resources after cutting), and from the ERP system to the CAD/CAM system (e.g. nomenclature of source material purchased from the supplier and sorting results). To implement the developed proposals, the model structure of the ERP system should be supplemented with a subsystem that implements the management of procurement production. This will expand the functionality of the software package in terms of implementing the DSS for sorting the material resources obtained after cutting and revaluing material resources stored in warehouses, as well as the CAD/CAM and ERP systems interaction.

It is proposed to develop the ‘Procurement production management’ subsystem based on interacting software modules, each performing its own function. The structure of this subsystem and its place in the ERP system are presented in Figure 3. This study considered DSS development based on fuzzy logic, the relevance of which is reflected in Kroshilin et al.’s (2010) and Skorodumova’s (2014) studies.

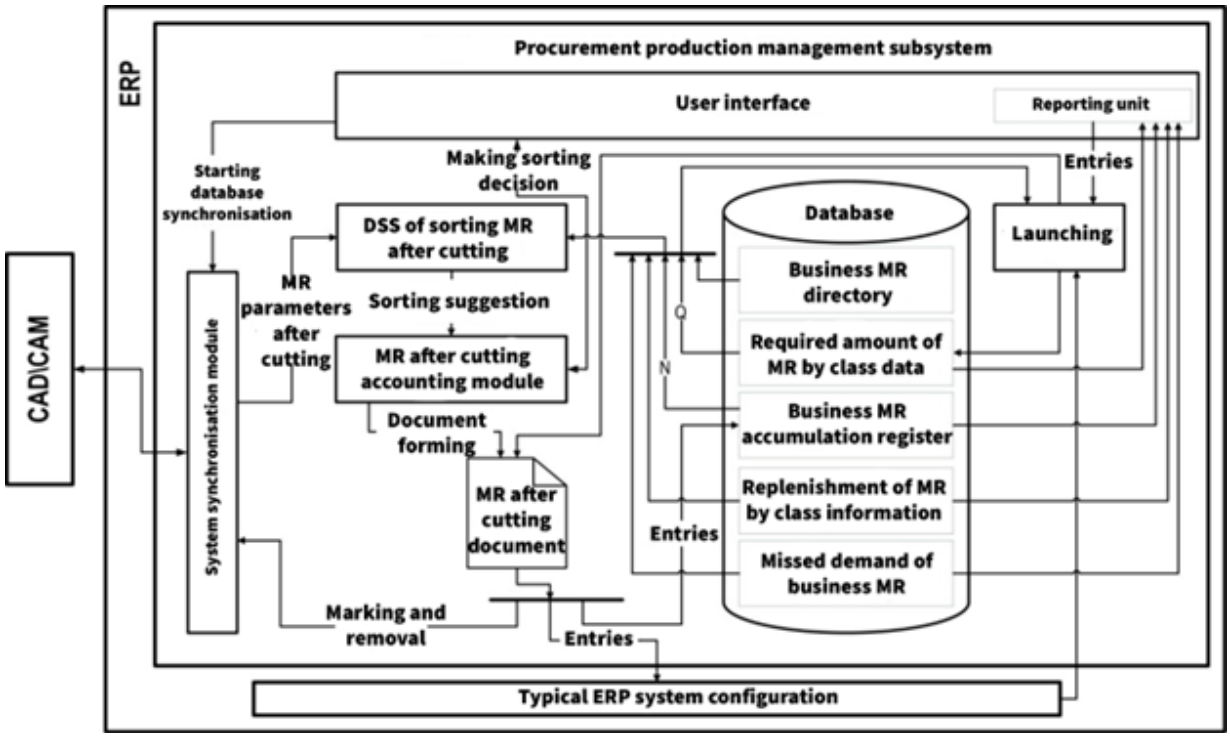

Figure 3. Structure of the 'Procurement production management' subsystem within the framework of the ERP system

Information is processed in the accounting system based on the decision made after the operational proposal for sorting material resources is formed by the DSS and approved by the user.

5. Discussion

The study focuses on the development of mechanical engineering enterprises with single or serial production types. Given that these production types have specific characteristics, the features of the obtained research outputs were not singled out in each of the selected production types. This is because the production types have similar features that equally affect the study results, for example, diverse product range, frequently changing customer requirements for technical characteristics of the existing product line of the enterprise, and inaccurate expected production programme for the expected period before business acquisition.

The study is based on the basic idea of lean manufacturing, namely improving business processes and eliminating various types of losses in the flow of value creation for the consumer. In connection with the identified applied features of the studied problems, the main emphasis was placed on the development of material resources management tools that are aimed at reducing material and time costs, as well as storage costs, when organising rational cutting of industrial materials at mechanical engineering enterprises. More in-depth studies are needed to apply and improve the existing lean manufacturing tools.

The study proposes a methodological approach to the value assessment of materials obtained after cutting, which can be used not only to define a possible selling price but also for transfer pricing. However, there are no specific ranges of the proposed coefficients that affect the price formation of material resources when the values of the assessed indicators change. This is because not all coefficients can be applied at each enterprise, and the range of their values can be different because of production specifics. That is, universal values are quite difficult to choose, but more detailed testing of examples will enhance the practical value of the results. In assessing the cost change in the option of assigning the material resources obtained after cutting to the group of business materials, transportation costs refer to the costs of internal micro-logistic movements from production to warehouse and back to production when necessary. However, the results obtained do not define the technique for assessing these costs, which is

certainly necessary for the final sorting of the materials obtained after cutting, and thus requires further research.

When developing the methodological approach to assessing the economic efficiency of assigning material resources to an appropriate group, we assumed that transportation costs are imposed on the consumer when selling non-business material resources to third-party organisations. On the one hand, the introduced condition is a special case. On the other hand, the study proceeded from the fact that separate payment for the service or its inclusion in the price of the materials sold is mainly provided in the case of material resource sale to external organisations on the delivery by the supplier terms. In this regard, it is logical not to take into account delivery costs to the consumer when making a decision on sorting, since they are compensated by the corresponding income. Further, there are no supplier's delivery costs in the self-delivery by the buyer terms. However, delivery costs are mainly borne by the supplier if materials are sold as scrap metal. Therefore, the indicator of the scrap metal delivery cost should be taken into account. If material resources are recognised as scrap metal, they should be added to the formula for assessing the change in the net income, determining the maximum storage time of materials after cutting, and comparing costs in the corresponding sorting options (Formulas 3–5) to increase the versatility of the methodological approach to assessing the economic efficiency of the sorting decision. These shortcomings should be considered in future research.

6. Conclusion

The study made several contributions to material resource management in lean manufacturing at mechanical engineering enterprises. We revealed the problems of material resources management in organising sheet metal cutting and proposed a terminological apparatus that can allow the exploration of a combination of material resources after cutting as a multi-level system. We developed a technique for sorting material resources after cutting to reduce the cost of source material and offer practical recommendations for its development. Methodological provisions for assessing the possible selling price of the material resources obtained after cutting were developed, which allows for organising the managerial accounting of business and non-business material resources in value terms. We also proposed a methodological approach to assessing the economic efficiency of the decision made when sorting the material resources after cutting was proposed. Notably, the study developed a software package prototype with elements of DSS sorting, which allows for making prompt and reasonable managerial decisions when assigning the material resources to the group of business or non-business materials.

Thus, the goal of the study was achieved, i.e., methodological provisions were developed to improve the management tools of material resources in lean manufacturing when cutting materials at mechanical engineering enterprises with single or serial production types. The following managing tools of the material resources were developed: technique for sorting the material resources obtained after cutting into business and non-business resources, software package prototype with elements of the DSS sorting, and managerial accounting regulations for the business process of the material resources received after cutting.

The toolkit developed in this study can help improve the process of rational material cutting at mechanical engineering enterprises and reduce losses in unreasonable sorting of the material resources obtained after cutting from the point of view of lean production. By applying this toolkit, material costs are reduced due to the use of business material resources, which could be recognised as non-business under empirical sorting. Further, the costs of storage and transportation of non-business material resources that could be recognised as business ones are reduced, and less time is spent finding and transporting business material resources in case of the production need. This allows enterprise managers to increase the net income or optimise the cost structure in the customer value-creating flow, offer a customer-oriented price, increase competitiveness, and promote lean and responsible use of natural resources in manufacturing, which ensures sustainable development of the enterprise.

Future studies should focus on developing proposals for organising the storage process and mark-

ing the material resources received after cutting.

References

Demidenko, D.S., Malevskaia-Malevich, E.D., 2014. The industrial waste utilization as an economic challenge. St. Petersburg State Polytechnical University Journal. Economics 209 (6), 90–97.

Demidenko, D.S., Malevskaya-Malevich, E.D. 2013. Increasing production efficiency through increased use of secondary resources in enterprises of St. Petersburg. St. Petersburg State Polytechnical University Journal. Economics 175 (4), 84–89.

Dyckhoff, H., 1990. A typology of cutting and packing problems. European Journal of Operational Research 44 (2), 145–159.

Filippova, A.S., Valiakhmetova, Yu.I., 2013. L.V. Kantorovich's theory of optimal resource utilization in scientific papers of Ufa school. Omsk Scientific Bulletin 1, 39–42.

Kantorovich, L.V., Zalgaller, V.A., 1971. Rational cutting of industrial materials. Novosibirsk: Nauka.

Kartak, V.M., Mesyagutov M.A., Mukhacheva E.A., Filippova A.S., 2009. Local search of orthogonal packings using the lower bounds. Automation and Remote Control 70 (6), 1054–1066.

Kartak, V.M., Ripatti A.V., 2019. Large proper gaps in bin packing and dual bin packing problems. Journal of Global Optimization 74 (3), 467–476.

Kroshilin, A.V., Babkin, A.V., Kroshilina, S.V., 2010. Features of building decision support systems based on fuzzy logic. St. Petersburg State Polytechnical University Journal. Informatics. Telecommunications. Management 97 (2), 58–63.

Mukhacheva, E.A., 1984. Rational cutting of industrial materials. Application of ACS. M.: Mashinostroenie.

Petunin, A.A., 2010. Automatic technique selection of assessing the figured cutting using comparative algorithm analysis. Bulletin of the Tomsk Polytechnic University. Geo Asset Engineering 316 (5), 169–171.

Safronova, K.O., Tsvirkunov, D.I., 2020. Maturity level study of applying lean manufacturing at Russia's enterprises. Bulletin of Moscow University. Series 6: Economics, 2, 106–122.

Salkova, O.S., Sokolovskiy, M.V., Kononova, S.A., Kolotova, Ye.A., Organization of accounting the motion of metal at chemical engineering enterprises: Problems and opportunities. Fundamental Research 11, 163–168.

Shichkov, A., Gluhov V., 2019. Model and toolkit for the formation of the production enterprise digital platform. IOP Conference Series: Materials Science and Engineering 497, 012093. https://doi.org/10.1088/1757-899X/497/1/012093

Shichkov, A.N., 2016. Designing manufacturing technological systems. Scientific Israel-Technological Advantages 1, 89–106.

Shichkov, A.N., 2016. Innovative enhancement of an engineering business: Operation cycle method. Scientific Israel-Technological Advantages 4, 100–111.

Shichkov, A.N., Borisov, A.A., Kremleva, N.A., 2019. Digital platform of controlling applied tasks in engineering business. Digital Economy and Industry 4.0: Trends 2025. Proceedings of scientific and practical conference with international participation. Edited by A.V. Babkin, 652–664.

Skorodumov, P.V., 2014. Modelling of economic systems with Petri nets. Economic and Social Changes: Facts, Trends, Forecast 4, 253–259.

Smirnov, A., Kobzev, V., Skvortsov, S., 2019. Sheet metal material resources management in lean production. E3S Web of Conferences 110, 01029. https://doi.org/10.1051/e3sconf/201911001029

Smirnov, A.A., 2017. Economic aspects of making managerial decisions in the identification of material resources of sheet metal at an engineering enterprise. St. Petersburg State Polytechnical University Journal. Economics 6, 195–204.

Suloeva, S.B., Gultseva, O.B., 2017. Cost management system: Conceptual provisions. Organizer of Production (theoretical and scientific-practical journal) 25(3), 47–58.

Tolstobrov, D.A., 2019. Operational assessment of the probability of order fulfillment in the conditions of uncertainty of consumer demand. Applied Mathematics and Control Sciences 3, 133–157.

Turovets, O.G., Rodionova, V.N., 2016. On some problems of ensuring effective organization of high-tech production. Organizer of Production (theoretical and scientific-practical journal) 68 (1), 47–53.

Valiakhmetova, Yu.I, Filippova, A. S., 2014. Theory of optimum resource utilization by L. V. Kantorovich in cutting-packing problems: overview and history of development of solving methods. Vestnik UGATU (scientific journal of Ufa State Aviation Technical University) 18 (62), 186–197.

Valiakhmetova, Yu.I, Telitskiy, S.V., 2012. Application of computer-aided design of cutting charts in shipbuilding. Bulletin of Voronezh State Technical University 6, 38–43.

Wascher, G., Haubner, H., Schumann, H., 2007. Improved typology of cutting and packing problems. European Journal of Operational Research 183(3), 1109–1130.

Список источников

Dyckhoff, H., 1990. A typology of cutting and packing problems. European Journal of Operational Research 44(2), 145-159.

Kartak V.M., Mesyagutov M.A., Mukhacheva E.A., Filippova A.S., 2009. Local search of orthogonal packings using the lower bounds. Automation and Remote Control 70(6), 1054-1066.

Kartak V.M., Ripatti A.V., 2019. Large proper gaps in bin packing and dual bin packing problems. Journal of Global Optimization 74(3), 467-476.

Shichkov A. N., 2016. Designing manufacturing technological systems. Scientific Israel-Technological Advanteges 1, 89-106.

Shichkov A., Gluhov V., 2019. Model and toolkit for the formation of the production enterprise digital platform. IOP Conference Series: Materials Science and Engineering 497, 012093. https://doi.org/10.1088/1757-899X/497/1/012093

Shichkov A.N., 2016. Innovative Enhancement of an Engineering Business: Operation Cycle Method. Scientific Israel-Technological Advanteges 4, 100-111.

Skorodumov P.V., 2014. Modelling of economic systems with Petri nets. Economic and Social Changes: Facts, Trends, Forecast 4, 253-259.

Smirnov A., Kobzev V., Skvortsov S., 2019. Sheet metal material resources management in lean production. E3S Web of Conferences 110, 01029. https://doi.org/10.1051/e3sconf/201911001029

Wascher G., Haubner H., Schumann H., 2007. An improved typology of cutting and packing problems. European Journal of Operational Research 183(3), 1109-1130.

Валиахметова Ю.И., Телицкий С.В., 2012. Применение систем автоматизированного проектирования карт раскроя в судостроении. Вестник Воронежского государственного технического университета 6, 38-43.

Валиахметова Ю.И., Филиппова А.С., 2014. Теория оптимального использования ресурсов Л. В. Канторовича в задачах раскроя-упаковки: обзор и история развития методов решения. Вестник Уфимского государственного авиационного технического университета 1, 186-197.

Демиденко Д.С., Малевская-Малевич Е.Д., 2013. Повышение эффективности производства на основе расширения использования вторичных ресурсов на предприятиях Санкт-Петербурга. Научно-технические ведомости СПбГПУ. Экономические науки 175 (4), 84-89.

Демиденко Д.С., Малевская-Малевич Е.Д., 2014. Экономическая задача эффективного использования производственных отходов предприятием. Научно-технические ведомости СПбГПУ. Экономические науки 209(6), 90-97.

Канторович Л.В., Залгаллер В.А., 1971. Рациональный раскрой промышленных материалов. Новосибирск: Наука, 300 с.

Крошилин А.В., Бабкин А.В., Крошилина С.В., 2010. Особенности построения систем поддержки принятия решений на основе нечёткой логики. Научно-технические ведомости Санкт-Петербургского государственного политехнического университета. Информатика. Телекоммуникации. Управление 97(2), 58-63.

Мухачева Э. А., 1984. Рациональный раскрой промышленных материалов. Применение АСУ. М.: Машиностроение, 176 с.

Петунин А.А., 2010. Автоматический выбор метода расчета фигурного раскроя с использованием сравнительного анализа алгоритмов. Известия Томского политехнического университета. Инжиниринг георесурсов 316(5), 169-171.

Салькова О.С., Соколовский М.В., Кононова С.А., Колотова Е.А., 2019. Организация учета движения металла на предприятиях химического машиностроения: проблемы и возможности. Фундаментальные исследования 11, 163-168.

Сафронова К.О., Цвиркунов Д.И., 2020. Исследование уровня зрелости применения бережливого производства на российских предприятиях. Вестник Московского университета. Серия 6: Экономика 2, 106-122.

Смирнов А.А., 2017. Экономические аспекты принятия управленческих решений при идентификации материальных ресурсов листового металла на машиностроительном предприятии. Научно-технические ведомости СПбГПУ. Экономические науки 6, 195-204.

Сулоева С.Б., Гульцева О.Б., 2017. Система управления затратами: концептуальные положения. Организатор производства 25(3), 47-58.

Толстобров Д.А., 2019. Оперативная оценка вероятности выполнения заказа при условии неопределенности потребительского спроса. Прикладная математика и вопросы управления 3, 133-157.

Туровец О.Г., Родионова В.Н., 2016. О некоторых проблемах обеспечения эффективной организации высокотехнологичного производства. Организатор производства 68(1), 47-53.

Филиппова А.С., Валиахметова Ю.И., 2013. Теория оптимального использования ресурсов Л. В. Канторовича в работах Уфимской научной школы. Омский научный вестник 1, 39-42.

Шичков А.Н., Борисов А.А., Кремлёва Н.А., 2019. Цифровая платформа контроллинга прикладных задач инженерного бизнеса: Цифровая экономика и Индустрия 4.0: тенденции 2025. Сборник трудов научно-практической конференции с международным участием. Под редакцией А.В. Бабкина, 652-664.

The article was submitted 11.09.2022, approved after reviewing 14.12.2022, accepted for publication 23.12.2022.

Статья поступила в редакцию 11.09.2022, одобрена после рецензирования 14.12.2022, принята к публикации 23.12.2022.

About authors:

1. Artem Smirnov, postgraduate, Graduate School of Production Management, Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia; senior lecturer, Vologda State University, Vologda, Russia. https://orcid.org/0000-0001-5431-4150, smirnov.artem.a@yandex.ru

2. Vladimir Kobzev, Doctor of Economics, Professor, Graduate School of Production Management, Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia. https://orcid.org/0000-0002-4144-4287, kobzev_vv@mail.ru

3. Cholpon Nuralieva, Doctor of Economics, Deputy Head of the Department of Accounting, Analysis and Audit, Professor, Kyrgyz-Russian Slavic University named after B.N. Yeltsin, Bishkek, Kyrgyz Republic. https://orcid.org/0000-0001-8005-054X, nur-cholpon@mail.ru

Информация об авторах:

1. Артём Смирнов, соискатель, Высшая школа производственного менеджмента, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия; старший преподаватель, Вологодский государственный университет, Вологда, Россия. https://orcid.org/0000-0001-5431-4150, smirnov.artem.a@yandex.ru

2. Владимир Кобзев, доктор экономических наук, профессор Высшей школы производственного менеджмента, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия. https://orcid.org/0000-0002-4144-4287, kobzev_vv@mail.ru

3. Чолпон Нуралиева, доктор экономических наук, зам. зав. кафедрой бухгалтерского учета, анализа и аудита, профессор, Кыргызско-Российский Славянский университет им. Б.Н. Ельцина, Бишкек, Кыргызская Республика. https://orcid.org/0000-0001-8005-054X, nur-cholpon@mail.ru