Lecture Notes in Information Systems and Organisation 61

Vikas Kumar
Grigorios L. Kyriakopoulos
Victoria Akberdina
Evgeny Kuzmin *Editors*

Digital Transformation in Industry

Sustainability in Uncertain Dynamics

Springer

Lecture Notes in Information Systems and Organisation

Volume 61

Lecture Notes in Information Systems and Organization—LNISO—is a series of scientific books that explore the current scenario of information systems, in particular IS and organization. The focus on the relationship between IT, IS and organization is the common thread of this collection, which aspires to provide scholars across the world with a point of reference and comparison in the study and research of information systems and organization. LNISO is the publication forum for the community of scholars investigating behavioral and design aspects of IS and organization. The series offers an integrated publication platform for high-quality conferences, symposia and workshops in this field. Materials are published upon a strictly controlled double blind peer review evaluation made by selected reviewers.

LNISO is abstracted/indexed in Scopus

Vikas Kumar · Grigorios L. Kyriakopoulos ·
Victoria Akberdina · Evgeny Kuzmin
Editors

Digital Transformation in Industry

Sustainability in Uncertain Dynamics

Springer

Editors
Vikas Kumar
Faculty of Business, Law and Social Sciences
Birmingham City University
Birmingham, UK

Grigorios L. Kyriakopoulos
School of Electrical and Computer Engineering
National Technical University of Athens
Athens, Greece

Victoria Akberdina
Department of Regional Industrial Policy and Economic Security
Institute of Economics of the Urals Branch of the Russian Academy of Sciences
Ekaterinburg, Russia

Evgeny Kuzmin
Department of Regional Industrial Policy and Economic Security
Institute of Economics of the Urals Branch of the Russian Academy of Sciences
Ekaterinburg, Russia

ISSN 2195-4968 ISSN 2195-4976 (electronic)
Lecture Notes in Information Systems and Organisation
ISBN 978-3-031-30350-0 ISBN 978-3-031-30351-7 (eBook)
https://doi.org/10.1007/978-3-031-30351-7

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

About This Book

This book offers a selection of the best papers presented at the annual International scientific conference "Digital Transformation in Industry: Trends, Management, Strategies", held by the Institute of Economics of the Ural Branch of the Russian Academy of Sciences (Ekaterinburg, Russia) on October 28, 2022.

The purpose of the conference is to evaluate trends and prospects for digital transformation in the industry and industrial markets, create an idea of introduction mechanisms for digitalization processes, and substantiate successful strategies of digital transformation in sectors and at industrial enterprises. In 2022, DTI Conference focused on assessing the digital transformation sustainability of the industry in an uncertain environment, digital solutions for the connectivity of industrial markets, and adaptation of ESG metrics to the digital transition of industry. The scope of the conference also covers issues, including the development of digital design to increase competitiveness, digital logistics, digital solutions for the connectivity of industrial markets, organizational mechanisms for supporting digital transformation in the industry, etc. The experience of countries, regions, and various enterprises implementing IT and other technological innovations is also included.

The book contains seven sections. The first section is devoted to the best regional practices of the industry's digital transition. The studies of the second section are united by a common theme of the digital transition of industries and reveal challenges and barriers to development. The third section is related to adapting ESG values to the digital transition. The fourth section informs about the connectivity of industrial markets and digital logistics. The fifth section includes papers on digital technologies and decision support for industrial enterprises. The sixth section draws attention to the internal environment of industrial enterprises and discusses the digital transition's potential, management, and strategies. The seventh section concludes the book with studies on human capital change under digital transformation.

This is a timely book in which researchers, university academia, managers of industrial enterprises, economists, and financial experts can benefit from the scientific pluralism of the topics covered.

Contents

About the Editors

Dr. Vikas Kumar is an Associate Dean for Research, Innovation, and Enterprise and Professor of Operations and Supply Chain Management at the Faculty of Business, Law and Social Sciences, Birmingham City University, Birmingham, UK. He serves on the editorial board of several international journals, including the International Journal of Physical Distribution and Logistics Management, the Journal of Business Logistics, International Journal of Mathematical, Engineering and Management, and International Journal of Supply Chain and Operations Resilience. Prof. Kumar's current research focuses on sustainable supply chain management and Supply Chain 4.0. His other research interests include supply chain improvement, short food supply chains, operations strategy, and circular economy.

Dr. Grigorios L. Kyriakopoulos (2 Ph.Ds.) is a teaching and research associate at the School of Electrical and Computer Engineering, National Technical University of Athens (NTUA), Greece. He accumulated 30 years of research and teaching service at NTUA, Hellenic Naval Academy (2 years), Hellenic Merchant Marine Academy (2 years), School of Pedagogical and Technological Education of Athens (4 years). Dr. Kyriakopoulos accomplished 22 university qualifications during the period 1991-2022. He is a reviewer for more than 5000 papers in a wide spectrum of scientific fields and he (co)authored numerous papers at journals and conferences. Dr. Kyriakopoulos was included in the list of "World's top 2% of highly cited scientists" in the main field of "Enabling & Strategic Technologies" (2020, 2021), subfields of "Energy" (2020, 2021), "Environmental Sciences" (2020), "Business and Management" (2021), by the Stanford University's list for the years 2020 and 2021. He currently serves as (co)editor for books and special issues in the fields of engineering, environment, business and management, renewable energy sources, education, and behavioral ecology. His CV is included at the international Who's Who eds.

Dr. Victoria Akberdina is Deputy Director of the Institute of Economics of the Ural Branch of the Russian Academy of Sciences and Head of the Department of Regional Industrial Policy and Economic Security. She performs fundamental and applied research on the problems of industrial policy formation, forecasting methodology, and modeling the evolution of the economic and technological development of industrial complexes, and conducts research on the structural proportions of economic development. In 2019, she was awarded the title of Corresponding Member of the Russian Academy of Sciences.

Evgeny Kuzmin is a researcher (Academic) at the Department of Regional Economic Policy and Economic Security of the Institute of Economics of the Ural Branch of the Russian Academy of Sciences. He is a reviewer of high impact international journals including the Journal of Cleaner Production (Elsevier), Entrepreneurship and Sustainability Issues, etc. He has over 150 published scientific papers. Mr. Kuzmin has participated in the implementation of more than 10 research projects supported by grants from the Russian Foundation for Basic Research, the Russian Humanitarian Science Foundation, the Russian Science Foundation, and the Ministry of Education and Science of Russia. His research interests are risk, uncertainty, economic crises, sustainability, public–private partnerships, investments, business planning, industrialization, industrial policy, industry markets, modeling, economic growth and development, entrepreneurship, and business activity.

Editorial: What Does Industry's Digital Transition Hold in the Uncertainty Context?

Victoria Akberdina, Vikas Kumar, Grigorios L. Kyriakopoulos, and Evgeny Kuzmin

Abstract The chapter summarizes the best research published in the book of contributions from the International scientific conference "Digital Transformation in Industry: Trends, Management, Strategies" (DTI2022), held by the Institute of Economics of the Ural Branch of the Russian Academy of Sciences on October 28, 2022. The Editors evaluate the background and trends that have the impetus to the research. This year's main topic of discussion was "Sustainability of Digital Transformation in Uncertain Dynamics". We see how uncertainty has greatly changed business processes, posing new economic challenges. From the position of Digital Tools, researchers select options for effectively solving urgent problems in the field of logistics and transport systems, industrial production, artificial intelligence, etc. Finally, a brief overview of the contribution of each chapter is given, and the main conclusions made by researchers in the relevant field are noted.

Keywords Digital economy · Smart manufacturing · Industrial policy

V. Akberdina (✉) · E. Kuzmin
Department of Regional Industrial Policy and Economic Security, Institute of Economics of the Urals Branch of the Russian Academy of Sciences, 29 Moskovskaya St, 620014 Ekaterinburg, Russian Federation
e-mail: akberdina.vv@uiec.ru

E. Kuzmin
e-mail: kuzmin.ea@uiec.ru

V. Kumar
Faculty of Business, Law and Social Sciences, Birmingham City University, City Centre Campus, Curzon Building, 4 Cardigan Str, Birmingham B4 7BD, UK
e-mail: Vikas.Kumar@bcu.ac.uk

Department of Management Studies, Graphic Era Deemed to Be University, Bell Road, Clement Town Dehradun, Uttarakhand, India

University of Economics Ho Chi Minh City (UEH), A.016—59C Nguyen Đinh Chieu Dist. 3, Ho Chi Minh City, Vietnam

G. L. Kyriakopoulos
School of Electrical and Computer Engineering, National Technical University of Athens, 15780 Zografou Campus, Athens, Greece
e-mail: gregkyr@chemeng.ntua.gr

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_1

The active development of the contemporary economy is increasingly associated with an equally rapid increase in uncertainty. And the search for determinants of sustainability becomes the cornerstone of both fundamental and applied scientific research. The challenges of recent times—the technological gap, the global pandemic, and economic sanctions—have given special importance to digital tools. Therefore, the solution to many urgent problems is seen by researchers in the context of the digital economy. Approaches based on digital twins, digital platforms, and models have found their application in various fields of production, logistics and supply chains, transport systems, etc.

The sustainability of digital transformation will depend on the nature and speed of the digital transition. Therefore, it is important to analyze the current digitalization processes, evaluate the effectiveness of digital tools, and justify their implementation strategy.

These and other relevant issues were discussed at the International scientific conference "Digital Transformation in Industry: Trends, Management, Strategies" (DTI2022), held by the Institute of Economics of the Ural Branch of the Russian Academy of Sciences. The prerequisites of the economic situation in 2022 identified the key topic of scientific discussion: "Sustainability of Digital Transformation in Uncertain Dynamics". DTI2022 became a platform for its participants to present their vision of the ongoing economic transformation and describe new patterns and trends.

This book presents the best scientific reports of the conference. The book contains seven sections. The first section is devoted to the best regional practices of the industry's digital transition. The studies of the second section are united by a common theme of the digital transition of industries and reveal challenges and barriers to development. The third section is related to adapting ESG values to the digital transition. The fourth section informs about the connectivity of industrial markets and digital logistics. The fifth section includes papers on digital technologies and decision support for industrial enterprises. The sixth section draws attention to the internal environment of industrial enterprises and discusses the digital transition's potential, management, and strategies. The seventh section concludes the book with studies on human capital changed under digital transformation.

What are the conclusions the studies gave us?

The first important conclusion is that our subject area is no longer considered a simple process of introducing ICT into production. We clearly distinguish between "digitalization" and "digital transformation" concepts. By *digitalization*, we mean using digital technologies in companies' business models to create additional value. At the same time, we define *digital transformation* as the process of a system transition of the industry from one technological mode to another through the large-scale use of digital and ICT in order to significantly increase its efficiency and competitiveness. Digital transformation is a more holistic concept of change. Moreover, today we are talking about such a concept as "digital transition in industry", referring to the paradigm shift of the business model. And we argue that the *digital transition* is based not only on significant technological changes, but also on structural, organizational, and financial changes, as well as the transformation of the value created in the industry itself.

In the last decade, management and organizational scientists have been paying increasing attention to the relationship between digital transformation and innovation management. In our opinion, technological and organizational changes associated with the use of digital technologies differ significantly from traditional innovations since digital technologies have the character of "end-to-end" technologies, and the process of their implementation is complex, multilevel, and nonlinear.

The second significant conclusion: an important aspect of any country's development is not just the introduction of digital technologies and large-scale digital transformation of the industry, but the powerful development of the digital development sector in the country and the placement of microelectronic production. This is the key to *technological sovereignty* and the long-term competitiveness of many nations today. Ensuring the country's sovereignty has turned from a purely political problem into a technological problem since virtual digital technologies are used to manage and control production in the physical world. Therefore, in the context of ensuring the successful development of industry, they are increasingly talking about *digital sovereignty* at three levels—hardware, software, and communication technologies.

Technological, including digital, sovereignty of the country requires a holistic state policy, ranging from support for research, transfer of research, development of the education system, qualification of scientists and specialists, etc., and to initiatives for standardization and the creation of a regulatory framework. Developed countries use the selective principle of supporting digital technologies. State programs and projects are formed both for implementing one prospective group of digital technologies in several industries and for the digital transformation of one industry through introducing a variety of technologically heterogeneous digital solutions.

The third important conclusion: digital transformation in industry is a sustainable trend regardless of the degree of uncertainty created by disruptive innovations, politics, economics, financial markets, pandemics, etc. A digital transition is a non-alternative option for industrial development since the change of the business paradigm does more than simply oblige companies to optimize the existing business models: it allows tapping into the hitherto untapped value-enhancing potential.

The sustainability of the digital transformation's vector is also due to the unprecedented growth in demand for digital technologies. In the near future, a new stage of digital transformation in the industry is expected, associated with the combination of various technological developments in one digital solution. Convergent digital technologies will lead to a new breakthrough based on more mature technologies.

And *the fourth conclusion*: the digital transformation processes in industries are not proceeding evenly. This is largely due to the prerequisites for the digitalization of industries, the industry's readiness for digital transition, and of course, the financial capabilities of enterprises. A lot of research is devoted to the *problems that hinder digital transformation.* Among the main barriers in the industry remain the insufficient maturity of the company's business processes, the low level of digital competencies, and the inconsistency of the business strategy and the strategy of digital transformation. At the same time, the financial capabilities of industrial enterprises play an important but not leading role in the digital transition of industries.

The book includes the best papers from the International scientific conference "Digital Transformation in Industry: Trends, Management, Strategies" (DTI2022) to introduce readers to some of the latest research in the field of the digital economy and its applied aspects. Researchers, managers of industrial enterprises, economists, financial experts, and managers alike, can benefit from the results of the topics covered.

The Best Regional Practices of Digital Industry Transition

Regional Digital Space and Digitalisation of Industry: Spatial Econometric Analysis

Victoria Akberdina, Ilya Naumov, and Sergey Krasnykh

Abstract The heterogeneous development of digital space in the regions is accounted for by many factors, which predetermine the spatial features of digital infrastructure development and its use. In turn, the formation and expansion of the digital space have an impact on the productive capacity of the regions. Accordingly, the hypothesis of the research is an assumption that there exists a bilateral relationship between the digital space formed in the regions and the level of digital transformation of a region. To test this hypothesis, the objective was to assess the specifics of digital space formation in the regions and, using the methods of regression analysis, to assess the factors of its development and the cause-effect relationship with the industrial digitalisation indices in regional territories. The paper presents a methodological approach that takes into account the spatial heterogeneity of digital space formation and development, which helps to identify the factors of its development in different regional groups and to ascertain the impact of territorial digital space on the industry digitalisation level. The use of the given methodology resulted in the identification of three groups of regions in terms of the digital space development level, with ascertainment of the key factors of its development. It was proved that the high level of digital space development in the first group of regions was due to the active use of advanced production technologies in the industry. The study of cause-effect relationships using the Granger test made it possible to reveal the inverse impact of the digital space on the industry digitalisation indices, thus confirming the proposed hypothesis.

Keywords Regional digital space · Digital spatial heterogeneity · Digitalisation of industry · Regression analysis · Granger test · Moran's spatial autocorrelation

V. Akberdina (✉) · I. Naumov · S. Krasnykh
Institute of Economics of the Ural Branch of Russian Academy of Sciences, 29 Moskovskaya Str., Ekaterinburg 620014, Russian Federation
e-mail: akberdina.vv@uiec.ru

I. Naumov
e-mail: naumov.iv@uiec.ru

S. Krasnykh
e-mail: krasnykh.ss@uiec.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_2

1 Introduction

Industry is a key sector of material production that generates a significant share of GDP in most countries in the world. Digital transformation of industry is at the core of the digital transition of a country's entire economy. In turn, digital transformation processes in the regions within the country are highly differentiated, resulting in significant unevenness in the digital density of the entire country.

The relevance of the study of regional digital space development is accounted for by the following factors: additional incentives for economic development are needed in the conditions of different-nature cyclical crises, while the active introduction of digital technologies secures the reduction of transactional, logistic, operational, and other costs. In turn, digital technologies represent a basis for the development of a high-tech, new industrial economy, which falls within the development priorities of any country and meets the need to form digital sovereignty in the conditions of the formation of the new world economic order.

With this in mind, the *aim of the research* was the assessment of the specifics of digital space formation in the regions, as well as the econometric analysis of the cause-effect relationship between the digital space and local industry digitalisation indices.

The key hypothesis of the research is the assumption that there is a two-way relationship between the established digital space in the regions and the indices of digital transformation of industry. The present study will help to realise the differentiated approach to assessing the factors of digital space development in the regions.

2 Theoretical Overview

The study of digitalisation processes in various spheres of economic activity has been at the forefront of scientific publications in recent decades. The researchers are developing the theoretical foundations of digitalisation as a process of ubiquitous penetration of information and communication technologies in industry, as well as the methodology for studying digital transformation as a process of qualitative change in the system properties of industry [1]. At the same time, the number of scientific articles devoted to the concept of the digital space of a region is not numerous at present.

The authors propose to treat digital space as a set of territorial characteristics that integrate digital processes, means of digital interaction, information resources, as well as a set of digital infrastructural conditions on a territory, as based on regulatory norms, mechanisms of organisation, management, and use.

Currently, various approaches are used to assess the level of development of digital space in territorial systems; most often, methods of calculating integral indices are used. For instance, Sadyrtdinov used an integral index including four blocks of factors: digital mobility, digital equality, digital economy, and digital interaction [2];

Novikova and Strogonova applied a methodology based on calculating a business digitalisation index comprising 12 parameters [3]; Lysenko et al. used a methodology evaluating three elements of the digital space of a territory: enterprises of different economic profiles, the population, and public authorities [4].

The International Telecommunication Union (ITU) used the Information and Communication Technology Development Index [5]. Initially, the index included only 11 parameters grouped into sub-indices that reflected access to information and communication technologies (ICT), ICT use, and ICT skills. In 2018, the index was supplemented by three new indices, namely: mobile broadband Internet subscription, the share of mobile phone owners, and those with ICT skills [6]. The principal limitation of this index is that it shows only basic parameters of ICT penetration across the country [7] and it cannot be scaled to the regional level.

Among the existing methodological approaches to assessing the digital space development level, the methodological toolkit developed by the National Research University Higher School of Economics [8] is worth mentioning. It assesses the country's digital space by the level of availability of human resources dealing in the digital economy, the telecommunications market development level, and the indices characterising the ICT sector activity. This index quite extensively characterises the extent of the country's digital infrastructure development and, to a lesser extent, assesses the level of its use. The business digitalisation index, proposed by a team of authors, characterises the rate of business adaptation to digital transformation, the use of broadband Internet, cloud services, RFID technologies, and ERP systems, as well as business involvement and organisation of electronic commerce [9]. The main limitation of the methodological approach proposed by the Higher School of Economics is the impossibility of its application at the regional level.

There exist methodologies for calculating the digital space development index, which also uses non-quantitative indices derived from sociological surveys and rankings—for instance, the Digital Economy and Society Index (DESI) developed by the European Union. This index assesses the territorial digital space development level in terms of several elements: communications, human capital, the use of Internet services, integration of digital technologies, and digital public services [10]. The key limitation of this index is that the digital space development level is calculated only for the countries of the European Union.

The Digital Evolution Index developed by Mastercard and Fletcher School of Law and Diplomacy takes into account a country's digital development potential, whereby every state is evaluated on the basis of more than 170 parameters. In the aggregate, they describe 4 key elements of a country's digital space, which include: the digital infrastructure development level, consumer demand for digital goods and services, government policy in the sphere of digitalisation, and innovation climate. The main drawback of this rating is that it shows the state of a country's digital space and is not applicable at the regional level [11].

The studies assessing the impact of regional digital space on territorial socio-economic development point out that: digital space has a positive impact on economic growth [12], trade [13, 14], and labour productivity [15]; curtails labour and intermediary costs and provides due financial development of territorial systems [16, 17] and sought export volume of the regional high-tech products [18], etc.

Thus, the theoretical review of scientific publications showed the need to develop a systemic methodological approach assessing the specifics of digital space, the factors of its development in different regions, and its relationship with the industry digitalisation level in these territories.

3 Methods and Data

To assess the regional digital space development level, the authors used the index comprising three elements characterising the digitalisation level of enterprises, households, and public administration (formula 1).

$$SDI = \sqrt[3]{DI_I \cdot DI_H \cdot DI_G q} \tag{1}$$

where SDI is the Digital space index of a region; DI_I is the Enterprise digitalisation index; DI_H the is Household digitalisation index; DI_G is the Public administration digitalisation index.

The first element of this index assessed *the digitalisation level of enterprises* through the use of a geometric mean under the indices normalised against the reference values for Russian regions, namely: the share of organisations using servers; local computation networks, cloud services, broadband Internet access, special software for scientific research, design and management of automated production, as well as individual technical means and technological processes; the share of organisations using special software for CRM, ERP, SCM systems; electronic document management systems, electronic data exchange between own and external information systems using exchange formats; RFID technologies. Each indicator's maximum value for the surveyed regions was equated to one, and the values for the remaining regions were normalised relative to it.

The *household digitalisation index* was calculated in a similar way. The geometric mean was calculated under normalised indices characterising the proportion of households using a personal computer, having access to the Internet and using it; the number of active mobile broadband Internet subscribers.

In addition to enterprises and households, the *public administration digitalisation level* was assessed in order to correctly evaluate the digital space development level in the regions. For this purpose, the authors applied the geometric mean for specific values describing the share of households using official websites of state and municipal service providers; organisations using special software for access to databases through the global information networks, including the Internet; electronic legal reference systems.

At the next stage of the survey, in order to assess the differentiation of regions by the digital space development level, the authors calculated the weighted average value for each region for the last 5–6 years, which made it possible to exclude too high and too low values that are not characteristic of its dynamics. To group the regions, the authors applied the method of calculating the average value using the surveyed index values and a standard deviation therefrom.

Three groups of regions were formed:

- with a high digital development level exceeding the upper limit of regional data spread—standard deviation from the mean ($SDI_i > SDI_{max}$);
- with a midrange digital development level exceeding the regional average ($SDI_i \geq SDI_l$);
- with a low digital development level—below the regional average ($SDI_i < SDI_l$).

This grouping will allow further identification of factors contributing to the development of digital space in different groups of regions, as well as obtaining more credible and reliable results of modelling to be carried out at the next stage of the research.

In order to substantiate the correctness of the implemented regional grouping by digital space development level, spatial autocorrelation analysis, according to Moran's methodology, using a different spatial weights matrix [19, 20], should be undertaken. In order to identify the factors contributing to the development of digital space in territorial systems, a regression model using panel data will be constructed for each group of regions at the next stage of the research. The selection of optimal model will be based on panel diagnostics results; assessment of the statistical significance of regression parameters; Schwartz, Akaike, and Hannan-Quinn's information criteria; model examination for multicollinearity, autocorrelation of residuals, heteroscedasticity, and Gaussian error distribution normality.

In order to confirm the relationships established in the course of regression modelling and to assess the impact of the regional digital space on the socio-economic development of the local institutional sectors (manufacturing enterprises, households, and public administration), Granger causality tests are envisaged at the final stage of the study.

With a view to explore the regional industry digital transformation level, a unique computer model [21], designed to determine the type of region by the level of digital transformation of its industrial complex, will be used. The model classifies each of the regions as one of six local entities, being based on two calculated criteria—the digital transformation coefficient value (DTI coefficient) and the share of manufacturing enterprises in the gross regional product.

The research is based on the *Russian region's data for the period of 2015–2020*, as provided by the Russian Federation Federal State Statistics Service.

4 Results and Discussion

4.1 Grouping of Regions by the Digital Space Index

The regional digital space, which is interpreted as the digitalisation level of enterprises of different economic profiles, households, the public administration sector, as well as the development level of local digital infrastructure, is characterised by minor spatial heterogeneity.

The authors have identified the regions characterised by a higher digital space development level (Table 1). The digital space index in these regions exceeds one standard deviation from the average—above 0.73. A large proportion of businesses and households had access to digital technologies and were actively using them. These regions are characterised by a high digitalisation level of households and the public administration sector. The high digitalisation level of enterprises, households, and the public administration sector was not only characteristic of these regions in 2020, but has also been observed over the past six years.

This dynamics of the digital space development index confirms the results of the implemented regional grouping. The values of this index for all regions forming the first group did not change significantly and exceeded one standard deviation from the average all-Russia value. The regions of this group are also distinguished by high levels of industrial digitalisation. These regions also have significant financial resources for progressive socio-economic development. All of the above, in the authors' opinion, contributes to the active development of digital space in these areas. Below is a detailed study of this regional group implemented with a view to ascertain, using the econometric model, the existence of a close relationship between the digital space development level and the industry digitalisation level.

4.2 Spatial Autocorrelation Analysis

The spatial autocorrelation analysis according to Moran's modified method showed that Russia was distinguished by spatial regional clustering in terms of the digital space development level, i.e. it is possible to identify some groups of regions that are similar according to this parameter. The disposition towards their clustering is confirmed by the positive Global Moran's Index values calculated using different spatial weight matrices (Table 2).

The calculated Moran's global index values obtained through inverse distance matrices between regional administrative centres and their standardised (normalised) values are statistically significant; their *p-value* is within acceptable values, and standard errors of calculated indices tend to zero. Moran's scatter plot formed for different spatial weight matrices also confirmed the conclusions on possible clustering of the regions according to the digital space development level (Table 3). Summarising the results of spatial autocorrelation analysis obtained under the previously mentioned

Table 1 Grouping of Russian regions by the digital space development index

	Regions	Mean level of the digital space index over the period of 2015–2020
The first regional group—having a high level of digital space development	Moscow	0.87
	Moscow region	0.80
	Tula region	0.73
	Yamalo-Nenets autonomous area	0.81
	Khanty-Mansiysk autonomous area	0.81
	Republic of Tatarstan	0.80
	St. Petersburg	0.78
	Tyumen region without regard for autonomous areas	0.75
	Republic of Bashkortostan	0.73
The second regional group—having a midrange level of digital space development	Regions: Nizhny Novgorod, Yaroslavl, Voronezh, Sverdlovsk, Astrakhan, Lipetsk, Chelyabinsk, Belgorod, Leningrad, Novgorod, Rostov, Murmansk, Sakhalin, Smolensk, Kaliningrad, Tomsk, Orenburg, Vladimir, Ivanovo, Kaluga, Arkhangelsk, Penza, Kemerovo, Samara; Perm, Kamchatka, Stavropol, Krasnodar, Khabarovsk, Primorye, Krasnoyarsk; Komi Republic, Altai, Karelia, Chuvashia, Udmurtia	0.73 < DI < 0.65
The third regional group—having a below-average level of digital space development	All other regions	DI < 0.64

matrices, two clusters composed of similar regions were identified: those with high and low values of the digital space development index.

The HH quadrant of this diagram shows aggregately the regions with higher values of the analysed index—above the average level, i.e. the regions of the first and second groups singled out earlier on the basis of their digital space development level. At the same time, this quadrant identifies two regional subgroups: the areas with a high level of spatial synergy, which have already formed into a spatial cluster with close interregional ties (the regions around Moscow and St. Petersburg), and those with

Table 2 Summary results of Moran's spatial autocorrelation analysis for the digital space development level of Russia's regions in 2020

	Road distance matrix	Road distance matrix (Norm)	Linear distance matrix	Linear distance matrix (Norm)	Adjacent boundaries matrix	Adjacent boundaries matrix (Norm)
Moran's index	0.1728	0.1730	0.1783	0.1907	0.2032	0.1718
sd(Ii)	0.0004	0.0004	0.0004	0.0005	0.0005	0.0005
E(Ii)	0.000024	0.000024	0.000025	0.000026	0.000028	0.000024
Z-score	452.073	452.642	425.250	409.110	387.257	340.538
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 3 Aggregate Moran's scatter plot for the digital space development level of Russia's regions in 2020

LH—reciprocal influence zones		HH—Spatial clusters	
High level of spatial synergy	Low level of spatial synergy	High level of spatial synergy	Low level of spatial synergy
Regions: Kirov, Kostroma, Orel, Tver, Ulyanovsk; Republic of Mordovia, Chuvashia	Regions: Kaliningrad, Pskov, Omsk, Kurgan, Bryansk, Kursk, Volgograd; Altai, Krasnoyarsk; Republic of Mari El, Udmurtia, Komi; Nenets Autonomous Area	*Moscow, St. Petersburg*; Regions: *Tula,* Vladimir, Kaluga, Leningrad, Moscow, Nizhny Novgorod, Novgorod, Ryazan, Smolensk	Regions: *Tyumen*, Arkhangelsk, Belgorod, Vologda, Voronezh, Ivanovo, Kemerovo, Lipetsk, Murmansk, Novosibirsk, Orenburg, Penza, Samara, Saratov, Sverdlovsk, Tambov, Tomsk, Chelyabinsk, Yaroslavl; Perm; *Republic of Tatarstan, Bashkortostan*, Karelia; *Yamalo-Nenets Autonomous Area, Khanty-Mansiysk Autonomous Area*
LL—Regions with a low level of digital development		HL—Regions with a higher level of digital development relative to other areas	
Remaining regions of Russia		Regions: Astrakhan, Rostov, Sakhalin; Primorye, Stavropol; Republic of Khakassia, Altai; Krasnodar	

a low level of spatial synergy, with the being-formed interregional synergy, that are quite remote from the digital technology development centres.

The LL quadrant, on the contrary, brings together the regions with a very low digital space development level; below the average Russian level (the regions of the third group). Some regions of the third group have been included in the LH quadrant and have become a zone prone to the impact of spatial clusters with a higher digital space development level (Table 3). These regions, due to the closer interregional relations and spatial proximity to the regions with highly developed digital infrastructure, such as Moscow, St. Petersburg, and the Republic of Tatarstan, can significantly increase their digital space development level in the future. The remaining regions of the third group, located in quadrant LH and characterised by a lower level of spatial synergy, have a lower potential for the development of digital space, since they are spatially distant from the digital infrastructure development centres.

In order to investigate the factors contributing to the digital space development of the outlined regional groups, regression modelling with the use of panel data was carried out. The source data analysis shows that the most appropriate functional criterion describing the relationship between the regional digital space index and the tested factors is the exponential function. In the course of the research, a number of models with random and fixed effects were constructed with the use of the joint least-squares method, with allowance for heteroscedasticity. Following the estimation of the statistical significance of the model parameters, the information criteria and determination coefficient, as well as the Hausman test results, the regression model with fixed effects was recognised to be the optimal model for all region groups.

The regression analysis revealed that the digital space development of the first-group regions was significantly influenced by the scope of advanced production technologies used in them and their gross regional product:

$$SDI_1 = -1.646 + 0.081 \cdot \text{Ln}(GRP) + 0.143 \cdot \text{Ln}(IT) \quad (2)$$

where SDI_1 is the Digital space index of the first-group regions, with values from 0 to 1; *GRP* is the Gross regional product values of the Russian Federation entity, million roubles; *IT* is the Scope of advanced production technologies used in the region, pcs.

The main model parameters and the results of validity tests are presented in Table 4. The determination coefficient in the model has a low, but sufficient value for acknowledging the existence of a close relationship between the variables. The regression coefficients are statistically significant; the model shows no multicollinearity, autocorrelation of errors or heteroscedasticity and demonstrates the normal distribution of errors.

It should be noted that the regions under study are the main centres of economic growth in the country, having a well-developed industrial complex; therefore, it is quite natural that these factors are determinants for the expansion of their digital space. These regions have a high financial potential, attract a significant amount of investment in the technological renewal of fixed assets, and have due intellectual and scientific potential; therefore, the development of their digital space relies not on new advanced production technologies, but on their use.

The Granger causality test showing the relationship between the explored indices made it possible to confirm the influence of the gross regional product volume on the digital space development level of the regions forming this group (Table 5).

Table 4 Results of regression modelling of factors influencing the digital space development of the first-group regions (with fixed effects)

	Factor	Statistical error	t-statistics	P-value
Const	−1.646	0.528	−3.116	0.0033***
Gross regional product	0.081	0.036	2.206	0.0328**
IT	0.143	0.034	4.234	0.0001***
LSDV R-squared		0.688	Within R-square	0.424
LSDV F (10, 43)		9.502	P-value (F)	4.33e-08***
Logical plausibility		104.7	Akaike criterion	−187.4
Schwartz criterion		−165.6	Hannan-Quinn criterion	−179.1
Rho parameter		0.361	Durbin-Watson statistic	1.459
Wald test for heteroscedasticity (null hypothesis—observed homoscedasticity—the observations have a common error variance)			Chi-square (9) = 234.4	0.928
Chi-square test (null hypothesis—normal distribution of residuals)			Chi-square (2) = 4.977	0.083
Wooldridge test (null hypothesis—presence of autocorrelation of residuals)			Test statistics: F (1, 8) = 35.2	0.345
Hausman test statistics: H = 5.234; p-value = 0.0004 (The low p-value points to the optimality of the fixed-effects model)				
Pesaran CD test for cross-sectional dependence (Null hypothesis: no cross-sectional dependence): Asymptotic test statistic: z = 1.082; p-value = 0.279				

Note Compiled by the authors; *statistical significance at 10%; **statistical significance at 5%; ***statistical significance at 1%

In addition, a positive influence of other factors was also established, namely: the average per capita income of the population, employment rate, and the scope of telecommunication services provided to the population. Thus, one can conclude that the digital space development level in the regions of this group is accounted for not only by the active development of the production sector but also by the specific high socio-economic condition of its households and their financial security.

The Granger causality test made it possible to reveal as well an inverse effect of the digital space development index on the volume of goods shipped by manufacturing enterprises and on the level of industrial employment.

5 Conclusions and Implications

The methodological approach proposed in the study for assessing the regional digital space, modelling the factors contributing to its development, and evaluating its impact on the digitalisation of industry in the regions made it possible to reveal an insignificant spatial heterogeneity of the digital space formed in Russia.

Table 5 Granger causality test results showing the correlation between the digital space development level in the regions of the first group and the factors contributing to its development

Null hypothesis	F-Statistic	Probability	Conclusion
ID_1 does not have an impact on the gross regional product of the Russian Federation constituent entities	2.719	0.081*	Has an impact
ID_1 does not have an impact on the employment rate	3.56	0.041**	Has an impact
ID_1 does not have an impact on the retail turnover	5.333	0.011**	Has an impact
ID_1 does not have an impact on the volume of shipped goods, performed work, and rendered services in manufacturing industries	3.968	0.029**	Has an impact
The gross regional product volume of the Russian Federation constituent entities does not have an impact on ID_1	9.003	0.0008**	Has an impact
The average per capita income of the population does not have an impact on ID_1	4.423	0.021**	Has an impact
The employment level of the population does not have an impact on ID_1	7.189	0.003***	Has an impact
The scope of telecommunication services to the population does not have an impact on ID_1	4.229	0.024**	Has an impact

Note Coefficient values rejecting the null hypothesis of the test supposing no causality: *$0.05 < p < 0.1$; **$0.01 < p < 0.05$; ***–$p < 0.01$

Several spatial centres with well-developed digital space and their active use by manufacturing enterprises stand out clearly (Moscow and St. Petersburg, Moscow, Tula, and Tyumen regions, Republics of Tatarstan and Bashkortostan, Yamalo-Nenets and Khanty-Mansi Autonomous Areas). The regression analysis revealed that the development of digital space in the regions of this group was significantly influenced by the scope of advanced production technologies used in them and the volume of their gross regional product. The regions under study are the main centres of economic growth in the country and have a developed industrial complex; therefore, it is quite natural that these factors are determinants for the expansion of their digital space. The study of cause-effect relationships using the Granger test made it possible to reveal an inverse impact of the digital space on the volume of goods shipped by manufacturing enterprises and on the level of industrial employment in the regions of the first group. The research showed that the development of digital space in these regions not only contributed to the progressive development of their industry, but also secured their socio-economic growth.

The methodological approach to studying the digital space development factors realised in this paper, as well as the obtained results, can be subsequently used for searching the optimal mechanisms for its development with a view to achieve well-balanced and progressive socio-economic development of the territorial systems.

Acknowledgements The research was supported by Russian Science Foundation grant No. 22-28-01674, https://rscf.ru/project/22-28-01674/

References

1. Akberdina, V. V. (2018). Digitalization of industrial markets: Regional characteristics. *The Manager, 9*(6), 78–87. https://doi.org/10.29141/2218-5003-2018-9-6-8
2. Sadyrtdinov, R. R. (2020). Digitalisation level of Russia's regions. *Bulletin of Chelyabinsk State University, 10*(444), 230–235. https://doi.org/10.47475/1994-2796-2020-11029
3. Novikova, N. V., & Strogonova, E. V. (2020). Regional aspects of studying the digital economy in the system of economic growth drivers. *Journal of New Economy, 2*(21), 76–93. https://doi.org/10.29141/2658-5081-2020-21-2-5
4. Lysenko, A. N., Afanasyeva, N. A., & Rakhmeeva, I. I. (2021). Assessing the digitalisation level of central federal district regions. *Bulletin of Perm National Research Polytechnic University. Socio-Economic Sciences, 3*, 171–182. https://doi.org/10.15593/2224-9354/2021.3.12
5. Karyshev, M. Yu. (2011). *Socio-economic efficiency of information and communication technologies: International statistical comparison methodology: monograph*. Finansy i Statistika (160 p.).
6. Ministry for Digital Development, Communications and Mass Media of the Russian Federation. (n.d.). *ICT development index*. https://www.digital.gov.ru/ru/activity/statistic/rating/indeks-razvitiya-informacionno-kommunikacionnyh-tehnologij-ict-development-index/tabs/Compare:Place. Retrieved 10 Sep 2022.
7. Dobrota, M., Jeremic, V., & Markovic, A. (2013). A new perspective on the ICT development index. *Information Development, 28*(4), 271–280. https://doi.org/10.1177/0266666912446497
8. Higher School of Economics. (n.d.). *Digital economy indicators*. https://www.hse.ru/data/2018/08/20/1154812142/ICE2018.pdf. Retrieved 3 Sep 2022.
9. Kevesh, M. A., & Filatova, D. A. (2019). *Business digitalisation index*. Higher School of Economics. https://issek.hse.ru/data/2019/10/03/1543029709/NTI_N_121_27022019.pdf. Retrieved 10 Sep 2022.
10. European Commission. (n.d.). *The digital economy and society index (DESI)*. https://ec.europa.eu/digital-single-marketB/en/desi. Retrieved 10 Sep 2022.
11. Mastercard. (2017). *Mastercard and fletcher school of law and diplomacy presented digital evolution index 2017*. https://newsroom.mastercard.com/ru/press-releases/mastercard-и-школа-права-и-дипломатии-им-флетче/. Retrieved 9 Sep 2022.
12. Niebel, T. (2018). ICT and economic growth – comparing developing, emerging and developed countries. *World Development, 104*, 197–211. https://doi.org/10.1016/j.worlddev.2017.11.024
13. Adeleye, B. N., Adedoyin, F., & Nathaniel, S. (2021). The criticality of ICT-trade nexus on economic and inclusive growth. *Information Technology for Development, 27*(2), 293–313. https://doi.org/10.1080/02681102.2020.1840323
14. Ha, L. T., & Thanh, T. T. (2022). Effects of digital public services on trades in green goods: Does institutional quality matter? *Journal of Innovation & Knowledge, 7*(1), 100168. https://doi.org/10.1016/j.jik.2022.100168
15. Cardona, M., Kretschmer, T., & Strobel, T. (2013). ICT and productivity: Conclusions from the empirical literature. *Information Economics and Policy, 25*, 109–125. https://doi.org/10.1016/j.infoecopol.2012.12.002
16. Herzog, K., Winter, G., Kurka, G., Ankermann, K., Binder, R., Ringhofer, M., Maierhofer, A., & Flick, A. (2017). The digitalization of steel production. *BHM Berg- Und Hüttenmännische Monatshefte, 162*(11), 504–513. https://doi.org/10.1007/s00501-017-0673-9
17. Pop, L. D. (2020). Digitalization of the system of data analysis and collection in an automotive company. *Procedia Manufacturing, 46*, 238–243. https://doi.org/10.1016/j.promfg.2020.03.035
18. Andreeva, E. L., Glukhikh, P. L., & Krasnykh, S. S. (2020). Assessing the impact of digitalisation processes on the development of Russian regions' technological exports. *Economy of Regions, 2*(16), 612–624.
19. Naumov, I. V., Otmakhova, Yu. S., & Krasnykh, S. S. (2021). Methodological approach to modelling and forecasting the impact of spatial heterogeneity of COVID-19 distribution

processes on economic development of Russian regions. *Computer Research and Modeling, 3*(13), 629–648. https://doi.org/10.20537/2076-7633-2021-13-3-629-648
20. Naumov, I. V., Otmakhova, Yu. S., & Krasnykh, S. S. (2022). Scenario forecasting of the socio-economic consequences of the COVID-19 pandemic in Russian regions. *R-Economy, 1*(8), 5–20. https://doi.org/10.15826/recon.2022.8.1.001
21. Akberdina, V. V., & Krasnykh, S. S. (2021). *State registration certificate for computer programme no. 2021611446, Russian Federation. Digital Transformation of Regional Industries: No. 2021610631.*

Formation of a System of Statistical Indicators of Digitalization and Reindustrialization of Small and Medium-Sized Cities

Irina Turgel and Aleksandr Pobedin

Abstract Digital transformation of socio-economic processes, the development of the urban environment, and smart cities are important trends in the transformation of the economic system at all levels of territorial structure—global, national, regional, and individual municipalities. Small and medium-sized cities of the Russian Federation are currently experiencing a transformational challenge—whether the city will be able to integrate into the modern system of digital society will determine both the further pace of economic development and the level of well-being of the population. In this study, the authors analyze existing approaches to assessing the development of smart cities and reindustrialization of old industrial areas, highlighting the most significant factors and criteria used in the analysis of the processes of digital transformation and reindustrialization. The authors consider the experience of such an assessment taking into account the peculiarities of the system of statistical indicators available in the Russian Federation.

Keywords Digital transformation · Smart city · Urban environment

1 Introduction

Every year, the influence of digital technology increases both on the structure of production and technological processes in individual enterprises, and on the development of countries, regions, and cities, the standard of living of citizens, and the range of produced and consumed goods and services.

I. Turgel (✉)
Ural Federal University, 19 Mira St., Ekaterinburg 620002, Russian Federation
e-mail: i.d.turgel@urfu.ru

A. Pobedin
Ural Institute of Management—Branch of the Russian Presidential Academy of National Economy and Public Administration (RANEPA), 66 8-March St., Ekaterinburg 620144, Russian Federation
e-mail: pobedin-aa@ranepa.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_3

The attention of public authorities to the processes of digital transformation is increasing. Following the Strategy for the Development of Information Society in the Russian Federation for 2017–2030 (approved by Presidential Decree of May 9, 2017 No. 203, further—Strategy 2017–2030), the main goal is defined as "creating conditions for the formation of the Russian Federation knowledge society", which will allow approaching such national goals as human development, security of citizens and the state, increasing the role of Russia in the global humanitarian and cultural space, the development of interaction between citizens, organizations, and public authorities, the growth of public administration efficiency, the development of the economy and social field, the formation of a digital economy. Following the priority scenario for the development of a digital society outlined in the Strategy 2017–2030, it is planned to create, with government support, national technology platforms in the areas of education and medicine, a national digital library, and a unified infrastructure of e-government. The implementation of the Strategy 2017–2030 is necessarily ensured by coordinated actions of state authorities, local government, and several organizations, including funds and development institutions.

In addition to the federal and regional levels of public authority, digitalization processes are also implemented at the local government level. To implement the goals of the national program "Digital Economy of the Russian Federation" (program passport approved by the minutes of the meeting of the Presidium of the Presidential Council for Strategic Development and National Projects on June 4, 2019 No. 7) and the state program "Affordable and Comfortable Housing and Public Services to citizens of the Russian Federation" (approved by the Government of the Russian Federation on December 30, 2017, Dec. No 1710), in pursuance of the Federal Project "Formation of a Comfortable Urban Environment" (approved by the minutes of the meeting of the Project Committee on the national project "Housing and Urban Environment" dated December 21, 2018 No. 3), the departmental project of digitalization of urban economy "Smart City" was developed (project passport approved by the Order of the Russian Ministry of Construction dated December 27, 2021 No. 1014/pr, hereinafter—"Smart City" project), which envisages the development of methods and tools to assess the progress and effectiveness of the digital transformation of the urban economy in cities of the Russian Federation, the formation of an index of digitalization of the urban economy in cities of the Russian Federation, the creation of methodological and organizational framework for the formation of the Smart City ecosystem, and the development and launch of the online resource "Smart City Solutions Bank" from 2024.

For small and medium-sized cities of the Russian Federation, the support and development of digitalization processes are of particular importance due to the single-industry nature of the economic structure. Digital transformation, on the one hand, contributes to the creation of additional competitive advantages for city-forming enterprises, on the other hand, creates the preconditions for the emergence of new types of economic activity, ensuring the soft reindustrialization of cities and the inclusion of residents and businesses of these territories in the digital environment of the region and the country.

One of the basic conditions for successful reindustrialization and digital transformation of cities is the system of reliable statistical indicators that allow both monitoring of the implementation of state and municipal projects and digitalization programs, and a comprehensive expert assessment of the processes including small and medium-sized cities in the digital environment. The purpose of this paper is to analyze the existing approaches and prerequisites for the creation and operation of such a system of indicators.

2 Literature Review

The theoretical development of the digital economy, digital society, and Industry 4.0 have recently been the focus of attention among both foreign and domestic authors. A study by Pedersen and Wilkinson [1] discusses the processes associated with the digitalization of services, online access to information, and decision-making based on big data analysis; the authors state that the development of a digital society reveals a new model of service delivery to citizens. Popkova et al. [2] examines the impact of digital society on the development of the Russian economy. The authors assess the prospects for optimizing socio-economic development by managing the processes of the digital transformation of society. A theoretical and methodological summary of the changes in society caused by digital transformation is presented in the study by Vertakova et al. [3], which analyzes digital transformation in the economic system, especially in industries. The authors distinguish the following levels of digital transformation: the level of existence (change of objects and social consciousness of subjects), the level of manifestation (change of conditions, values), and the level of implementation (realized changes). Glezman et al. [4] analyzes the basic properties of digital technologies and the main stages of digitalization. Also, the problems of digital transformation and its impact on the state and citizens are developed in the studies by Zvereva et al. [5], Goisauf et al. [6], Ma et al. [7], Malin et al. [8], MiCiC [9], Myovella [10], Niebel [11], Posu [12], Shahbaz et al. [13], etc.

Separately, it is worth noting the layer of work aimed at studying the digitalization of the urban environment and the development of “smart cities”. Caragliu and Nijkamp [14] summarize the concept of smart cities from the perspective of covering modern production factors of the city, including the development of information and communication technologies. The authors analyze data on urban development in the EU countries, determining the efficiency of development and the quality of the urban environment, taking into account the presence of the creative class, the level of education, and the availability of modern technology. Hollands [15] attempts to develop clear criteria for a smart city comparing them to the concept of entrepreneurial cities. This problem is also developed in the studies by Albino et al. [16], Wang et al. [17], Aziz et al. [18], and several other works.

The phenomenon of reindustrialization has also been highlighted by many researchers. Nassif [19] and his co-authors analyze the processes of industrialization, deindustrialization, and reindustrialization, considering the regulatory activities of the state through monetary, fiscal instruments, wage, and exchange rate regulation. The article by Reznikova et al. [20] discusses the social consequences of reindustrialization. The authors state the relationship of value attitudes to the level of education and age, as well as other characteristics of residents. Singh [21], using a cluster approach, studies the phenomena of urbanization, industrial agglomeration, and labor productivity, identifying a group of regions in the stage of reindustrialization.

In the context of the active policy of digitalization pursued in the Russian Federation, there is a lack of research integrating the concepts of reindustrialization and smart cities.

3 Material and Methods

The information base of the study consisted of data from the Scopus database, as well as statistical information published on the official website of the Federal State Statistics Service (https://rosstat.gov.ru/). The methodological basis of the work was formed by the concepts of the smart city, digital transformation, and reindustrialization.

The general algorithm of the study consisted of the following steps:

1. Forming a pool of publications on the topic in question by issuing queries in the Scopus information system. This system was used in the study, first, due to the high quality of the research material, and second, due to the limitation of access to another scientific publication site—the Web of Science database was unavailable at the time of the study.
2. Quantitative evaluation of the selected list of publications, and refinement of search queries.
3. Generalization of the results of found publications, and the formation of a system of approaches and indicators following the chosen topic of research.
4. Assessment of the existing system of municipal statistics in the Russian Federation in the context of the found indicators for assessing the environment of the smart city and reindustrialization.

The study used methods of quantitative and qualitative bibliographic analysis, as well as content analysis.

4 Results

In the first phase of the study, the Scopus database was searched for (smart AND city AND indicators AND reindustrialization). Unfortunately, with this query, the search result was zero, which confirms the assumption of insufficient research that integrates analytics of the development of smart cities and processes of deindustrialization.

A word query (smart AND city AND indicators) revealed 1,609 research papers from 2001 to 2022. If in the period from 2001 to 2011, not more than 5 articles per year were noted, then since 2012, there was a sharp increase in publications by 2021 reaching 304. The lower value for 2022 is explained by the fact that the study covers publications up to and including October 15, 2022, respectively, one can expect an increase in publications during 2022 (Fig. 1).

Authors from China (279) accounted for the largest number of publications in the given field of study, followed by Italy (143), the Russian Federation (107), the United States (104), Spain (96), and many publications from India (90), Great Britain (81), and Brazil (62).

The analysis of the selected sources showed significant differences among the authors in determining the significant parameters that characterize "smart cities" [16]. For example, Mahizhnan's study [22] identifies four areas of analysis: IT education, IT infrastructure, IT economy, and quality of life. Giffinger et al. [23] use such characteristics as economy, mobility, environment, residents, and management. Eger [24] in his analysis of smart cities is limited to the following main areas – technology, economic development, employment growth, and improving the quality of life. In Nam and Pardo [25], the list of characteristics is extended, compared to the previous authors: economic socio-political problems of the city, environmental issues, interconnection, tools, integration, programs, and innovation. Similar areas of analysis are highlighted in the work by Barrionuevo et al. [26]: economy, residents, society, environment, and institutions. Kourtit and Nijkamp [27] consider smart cities through the prism of different types of capital–human, infrastructural, social, and entrepreneurial. Chourabi [28] and co-authors propose to limit the analysis of smart cities to the areas of governance and organization, technology, public administration, politics, residents and their communities, the economy, and the environment. Summarizing the

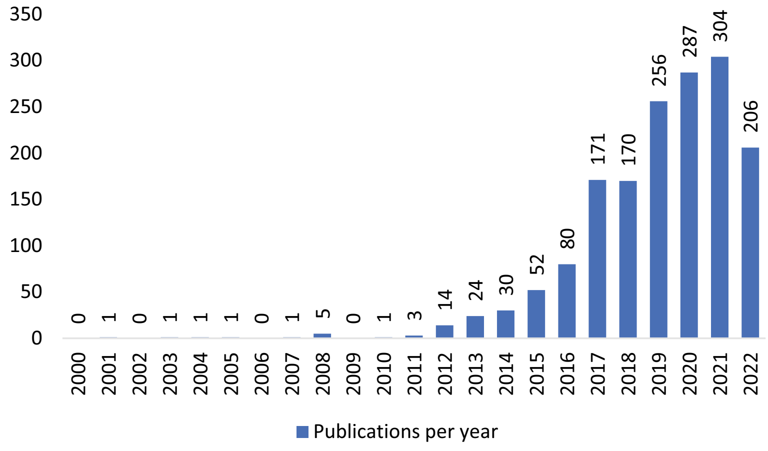

Fig. 1 Dynamics of publications in the subject area of "smart city indicators"

Table 1 Key elements highlighted in the analysis of smart cities

Key elements	Additional elements
Economy	Economic growth, economic development, entrepreneurial capital, labor market
Society Environment	Residents, communities, mobility, human capital
Facilities	Management, education, politics,
Technologies Infrastructure	Programs, innovations

approaches of various authors, one can integrate the main characteristics of smart cities as follows (see Table 1).

The list of characteristics of a smart city predetermines the composition of indicators recommended by the authors for the analysis of the urban environment. For example, the analytical model presented in the study by Liu et al. [29] is based on three areas of analysis—economy, society, and natural environment, each of which is allocated groups of indicators (see Fig. 2), and in each area, development goals vary, depending on the current level of maturity of the smart city. The first level defines strategic development objectives following the concept of a smart city. The second level is the development of information and communication infrastructure according to the objectives. At the third level, smart city services are already provided based on the established digital infrastructure through local service centers, mobile applications, and web portals. At the fourth level, systems and data are integrated to provide urban services, and technologies such as the Internet of Things, cloud computing, and artificial intelligence are used to improve service quality. At the fifth level, cooperation between systems, data, innovative services, and applications will continuously improve the well-being and satisfaction of citizens and the value of the urban environment.

A detailed methodology developed by the International Telecommunications Institute (ITU) [30] is an international standard for systematizing indicators of smart city development (hereinafter referred to as the ITU Indicators System). According to this methodology, the indicators of smart city development are distributed in three areas: economy, environment, society, and culture. In general, the methodology includes 100 indicators coordinated with the UN Sustainable Development Goals.

If the problem of indicators of digitalization and the development of smart cities is sufficiently developed, the issues of indicators of reindustrialization are characterized by a significant lack of research papers. A query of the Scopus database with the keywords (indicators AND industrialization AND city) revealed only three publications, the query (indicators AND reindustrialization AND town) did not reveal any publications, and the query (indicators AND reindustrialization) revealed only 17 publications.

The process of structural changes in the economy caused by the transition of the post-industrial stage of development, from the industrial sector to the service sector is accompanied by a reorientation from an energy-intensive economy to a technological

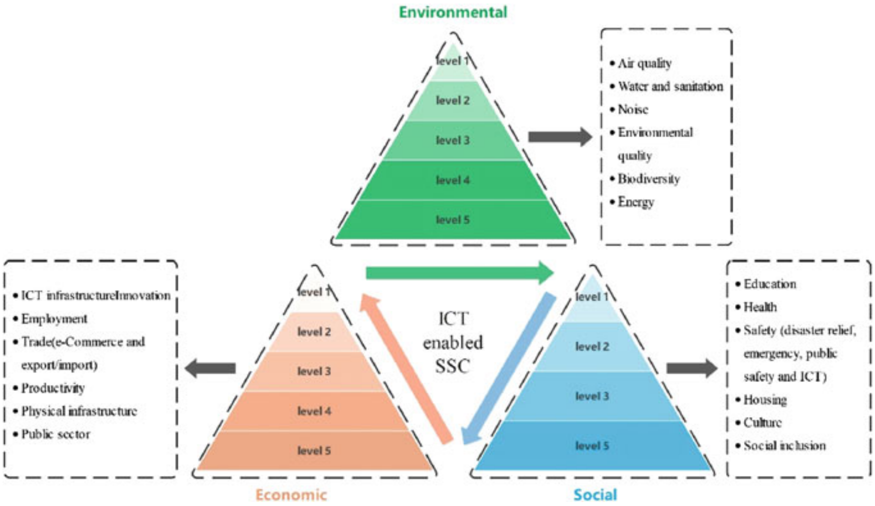

Fig. 2 Smart city analysis model [29]

one [31]. It is generally accepted that, as a result of the processes of industrial transformation and digitalization noted above, environmental degradation will gradually decrease due to increased environmental awareness, stricter environmental regulations, the introduction of clean technologies, and investment in these technologies [32]. However, several researchers believe that the service sector can also contribute to environmental degradation, due to the large-scale growth of consumption. Some leisure activities, including those associated with mass tourism, cause serious damage to the environment. The development of tourist services requires large investments in infrastructure: roads, airports, catering and accommodation facilities, which can lead to soil erosion, air, and water pollution, reduction of fauna habitats, etc. [33]. Tourism and outdoor activities can increase energy and water consumption and waste generation. As a consequence of the above, energy consumption in the service sector can be almost the same as in manufacturing [34]. Consequently, an obligatory element in the analysis of deindustrialization and reindustrialization should be a block of indicators related to the impact on the environment, the presence of such indicators in the analysis of smart cities noted earlier.

Damiani and Uvalic [35] examine structural changes in the industry in OECD countries, using the following indicators:

1. the share of those employed in the manufacturing industry (overall and by subsectors)
2. the share of value added in the manufacturing industry (overall and by subsectors).

Destek's study [36] analyzes the processes of deindustrialization and reindustrialization using the following indicators:

1. the volume of carbon monoxide emissions from economic activity;

2. GDP dynamics (as an indicator of economic growth);
3. share of industry in GDP (indicator of industrialization—deindustrialization);
4. indicator of environmental degradation, a composite indicator calculated according to the methodology of the author using the indicators listed above.

Accordingly, the assessment of the reindustrialization of cities requires the addition of indicators of smart city development with indicators characterizing the structure of the economy, including the share of industrial production, taking into account both the value of production and the number of people employed in the industrial sector.

5 Discussion

The use of the system of ITU indicators to assess the development of smart cities in Russia, with all the advantages of this methodology, is very difficult due to the significant differences in the system of statistical accounting of the Russian Federation and Western countries. Many of the indicators offered by the ITU are either not calculated at all in the RF or are published in very limited numbers. The problem is exacerbated by the fact that small and medium-sized cities belong to the municipal level of territorial division (included in municipal districts, urban districts, and urban settlements), and the peculiarity of the system of statistical indicators in the Russian Federation is a sharp decrease in the amount of available statistical information when moving to a lower level of territorial division.

The main source of open and publicly available statistical information is the information materials of the Federal State Statistics Service (Rosstat). Let us consider what indicators applicable to the assessment of smart cities can be found in the public domain on the official website of Rosstat (https://rosstat.gov.ru/). The “Municipal Statistics” section includes four information blocks: the statistical bulletin “Formation of Local Self-Governance in the Russian Federation”, the statistical bulletin “Population Size in the Russian Federation by Municipal Entities”, the volume of social payments to population and taxable cash income of population by municipal entities, and the “Municipal Entities Indicators” database (MEI DB).

The Bulletin “Formation of Local Self-Government in the Russian Federation” contains the following indicators summarized for the Russian Federation as a whole or by subjects of the Russian Federation and federal districts:

1. Availability of municipalities;
2. The number of municipalities voluntarily participating in associations of municipalities and inter-municipal non-profit organizations;
3. The number of municipalities participating in inter-municipal commercial organizations;
4. Municipal unitary enterprises;
5. Municipal banks and other financial organizations.

Unfortunately, these indicators can characterize the development of smart cities very indirectly; in addition, they cannot be traced to a particular municipality.

In the bulletin "Population of the Russian Federation by Municipalities," one can find the population of a municipality and identify the presence of certain problems of urban development. For example, there is a list of municipalities (including single-industry towns), where there are risks of a deteriorating socio-economic situation, as well as a list of municipalities with a stable socio-economic situation. In addition, there is a list of single-industry towns with the most difficult socio-economic situation. This information can be used in the formation of additional indicators in assessing the cities' economy, but unfortunately, the bulletin does not provide the original data for municipalities and single-industry towns to be grouped according to these criteria.

The table "Volume of social payments to the population and taxable money income of the population in the context of municipalities" contains information on payments to citizens and receipts into the budget system. This data can be used in such directions of assessment of smart cities as the economy and population (society).

The most complete information on socio-economic development is contained in the "Municipal Entities Indicators". The volume of information allows getting a certain idea of the development of the economy of the municipality, contains information on its population, the availability of certain types of services, the development of certain types of infrastructure (postal and telephone communications), etc. Unfortunately, data describing the degree of development of information and communication technologies, the digital environment, and the inclusion of its inhabitants are practically not presented.

Despite these difficulties, there are attempts by researchers to assess the potential for the development of smart cities, supplementing the indicators available in the public domain on the Rosstat website, the indicators published by the territorial divisions of Rosstat, as well as departmental statistics and reporting on the implementation of program and project documents.

Antonova [37] analyzes the existing methods for assessing single-industry towns and concludes that they are poorly implemented in the Russian Federation due to the lack of necessary indicators. The author collects from available data in Russia a list of indicators of smart city development, distributing them according to the criteria: smart economy, smart people, smart management, smart mobility, smart environment, and smart living, which is consistent with the approaches of foreign authors discussed above (see Table 2).

Unfortunately, this list of criteria allows evaluating smart cities only at the first level of maturity; however, even this assessment allows for forming a holistic picture of the development of the modern urban environment.

There is a lack of indicators from the sphere of innovation and communication development of the territory to expand the above list of indicators of smart cities. In the Russian Federation, one can find examples of the calculation of such indicators, for example, the compilations "Innovation Activity Indicators" [38] and "Digital Economy Indicators" [39] prepared by the Higher School of Economics. In particular, in the second of these compilations, one can find such indicators as expenses on

Table 2 The list of indicators for assessing smart city development (according to Antonova's methodology)

Evaluation criteria	Indicators
Smart economy	Grant support for small and medium-sized businesses, the financial performance of enterprises, average monthly wage per employee, unemployment rate, the number of individual entrepreneurs, the number of organizations, retail trade turnover, turnover of medium and large organizations, and investment in fixed capital
Smart people	The number of preschool educational and general educational organizations, satisfaction with the quality of preschool education, the overall performance of students, the number of students, the number of children with disabilities enrolled in a full educational program, the number of families receiving social support to pay for utilities, the number of applications of citizens to the Administration, and the number of foreign nationals
Smart management	Satisfaction with authorities, satisfaction with the activities of authorities to ensure the safety of citizens, the number of children attending kindergartens, kindergarten waiting lists, the share of replaced water supply networks, installed production capacity of water pipes, leakage, and unaccounted water consumption, the number of accidents in the water supply system, the share of replaced sewage networks, the share of replaced heating and steam networks, heat losses, supply of heat to the population, the number of accidents in the heat supply system
Smart mobility	Migration loss, passenger turnover of public transport, cargo turnover of motor transport, the number of public busses per 100,000 people, the use of the Internet in organizations, the number of PCs per 100 employees, and the number of cameras recording offenses
Smart environment	Environmental protection costs, the number of water pipelines, the number of heat supply sources with a capacity of up to 3 Gcal/hour, average capacity of one heat supply source, air pollutant emissions, the number of stationary sources of hazardous substances at enterprises not equipped with treatment facilities, the number of households and industrial waste utilization and processing enterprises, the number of specialized vehicles used for cleaning territories and household waste disposal, electricity consumption per 1 resident, hot water consumption per 1 resident, and cold water consumption per 1 resident
Smart life activity	The number of cinemas and movie theaters, the number of libraries, the number of museums, the number of detected HIV-infected patients, the number of registered persons with detected malignancies, the number of doctors of all specialties, the number of hospital beds in independent hospital institutions, the number of registered crimes, population assessment of crime rate, the number of sports institutions, commissioning of apartments, the number of resettled from old and emergency houses, and the volume of accomplished landscaping works

research and development in the priority area “Information and Telecommunication Systems”, patent applications for ICT inventions, development and use of advanced production technologies related to ICT, the share of the ICT sector in gross value added, the dynamics of communication services by type, Internet access subscribers, broadband Internet subscribers, Internet traffic, employed in professions related to the intensive use of ICT, the number of IT specialists, the level of digital skills of residents, the use of ERP and CRM systems in organizations, and several other indicators.

6 Conclusion

The study allows drawing the following conclusions. With the tightening of the inter-regional and international competitive environment, the high demand for highly skilled labor significantly increases the requirements for urban development, improving the standard of living and the quality of life of citizens. Modern information technology provides potential opportunities to solve these issues through qualitative changes in the parameters of the urban environment with the involvement of high-tech solutions, including the Internet of Things, digital twins, artificial intelligence, etc. A prerequisite for digital transformation should be the development of the territory’s digital infrastructure and the improvement of accessibility of this infrastructure to the population, as well as the acquisition by residents of additional competencies in the use of the digital environment. In the Russian Federation, there is an increase in state stimulation of the processes of digitalization and digital transformation, including through the expansion of program and project documents in this area.

For small and medium-sized cities, most of which are characterized by a mono-industrial structure of the economy, inclusion in the above trends is critical. Digital transformation in old industrial cities is becoming bi-directional. First, industrial production is changing based on the use of modern ICT and the transition (in the future) to Industry 4.0, which significantly affects both the industry structure and the labor market, increasing the requirements for employee qualifications while increasing production capacity, production efficiency, and wages, i.e., the territory is undergoing another stage of reindustrialization using modern technological capabilities. Second, the urban environment is developing, providing more opportunities and satisfying more needs of the population together with the growth of the consumer market based on the use of modern ICT solutions, i.e., the implementation of processes of transformation of the urban environment based on digitalization with the development of smart technologies in all areas of the city life.

Modern Russian statistics do not yet allow for a full quantitative assessment of the processes of digital transformation at the municipal level, but attempts at such analysis are underway, and there are prerequisites for the development of the statistical base, including the expansion of the calculation base of socio-economic indicators for the municipal level of territorial structure in Russia.

Acknowledgements The research was funded by the Russian Science Foundation (grant No. 22-18-00679, https://rscf.ru/project/22-18-00679/).

References

1. Pedersen, J. S., & Wilkinson, A. (2018). The digital society and provision of welfare services. *International Journal of Sociology and Social Policy, 38*(3/4), 194–209. https://doi.org/10.1108/IJSSP-05-2017-0062
2. Popkova, E., Bogoviz, A.V., & Sergi, B.S. (2021). Towards digital society management and 'capitalism 4.0' in contemporary Russia. *Humanities & Social Sciences Communications, 8*(77). https://doi.org/10.1057/s41599-021-00743-8
3. Vertakova, Yu.V., Polozhentseva, Yu.S., & Maslennikova, V.V. (2021). Industrial transformation in the context of the digitalization of the economy: implementation features and trends. *Economics and Management, 27*(7), 491–503. https://doi.org/10.35854/1998-1627-2021-7-491-503
4. Glezman, L.V., Butorin, S.N., & Glavatskiy, V.B. (2020). Digitalization of industry as a factor of technological development of the regional spatial and industrial structure. *Voprosy innovatsionnoy ekonomiki, 10*(3), 1555–1570. https://doi.org/10.18334/vinec.10.3.110762
5. Zvereva, A.A., Belyaeva, Zh.S., & Sohag, K. (2019). Impact of the economy digitalization on welfare in the developed and developing countries. *Economy of Regions, 15*(4), 1050–1062. https://doi.org/10.17059/2019-4-7
6. Goisauf, M., Akyüz, K., & Martin, G. (2020). Moving back to the future of big data-driven research: reflecting on the social in genomics. *Humanities & Social Sciences Communications, 7*(55). https://doi.org/10.1057/s41599-020-00544-5
7. Ma, X., Li, G., Zhou, J., Gao, X., Nie, Q., Xue, Sh., Liu, L., Wang, J., Xu, T., & Jin, A. (2020). Family-to-family child migration network of informal adoption in China. *Humanities & Social Sciences Communications, 7*(48). https://doi.org/10.1057/s41599-020-00542-7
8. Malin, J.R., Brown, C., Ion, G., van Ackeren, I., Bremm, N., Luzmore, R., Flood, J., & Rind, G.M. (2020). Worldwide barriers and enablers to achieving evidence-informed practice in education: what can be learned from Spain, England, the United States, and Germany? *Humanities & Social Sciences Communications, 7*(99). https://doi.org/10.1057/s41599-020-00587-8
9. MiCiC, L. (2017). Digital transformation and its influence on GDP. *Economics, 5*(2), 135–147.
10. Myovella, G. (2020). Digitalization and economic growth: a comparative analysis of Sub-Saharan Africa and OECD economies. *Telecommunications Policy, 44*(2). https://doi.org/10.1016/j.telpol.2019.101856
11. Niebel, T. (2014). ICT and economic growth: comparing developing, emerging and developed countries. *ZEW Discussion Papers* No. 14–117. https://ub-madoc.bib.uni-mannheim.de/37488
12. Posu, S. M. A. (2006). Information and communication technologies in the Nigerian economy. In *Proceedings of the Conference on Human and Economic Resources* (pp. 327–337). https://ideas.repec.org/h/izm/prcdng/200626.html
13. Shahbaz, M., Rehman, I. U., Sbia, R., & Hamdi, H. (2016). The role of information communication technology and economic growth in recent electricity demand: Fresh evidence from combine cointegration approach in UAE. *Journal of the Knowledge Economy, 7*, 797–818. https://doi.org/10.1007/s13132-015-0250-y
14. Caragliu, A., del Bo, C., & Nijkamp, P. (2011). Smart cities in Europe. *Journal of Urban Technology, 18*(2), 65–82. https://doi.org/10.1080/10630732.2011.601117
15. Hollands, R. G. (2008). Will the real smart city please stand up? Intelligent, progressive or entrepreneurial. *City, 12*(3), 303–320. https://doi.org/10.1080/13604810802479126

16. Albino, V., Berardi, U., & Dangelico, R. M. (2015). Smart cities: Definitions, dimensions, performance, and initiatives. *Journal of Urban Technology, 22*(1), 3–21. https://doi.org/10.1080/10630732.2014.942092
17. Wang, K., Guo, B., Yang, H., Li, M., Zhang, F., & Wang, P. (2022). A semi-supervised co-training model for predicting passenger flow change in expanding subways. *Expert Systems with Applications, 209*, 118310. https://doi.org/10.1016/j.eswa.2022.118310
18. Aziz Butt, S., Khalid, A., & Ali, A. (2022). Software development for medical with a multiple decision taking functionalities. *Advances in Engineering Software, 174*, 103294. https://doi.org/10.1016/j.advengsoft.2022.103294
19. Nassif, A., Bresser-Pereira, L. C., & Feijo, C. (2018). The case for reindustrialization in developing countries: Towards the connection between the macroeconomic regime and the industrial policy in Brazil. *Cambridge Journal of Economics, 42*(2), 355–381. https://doi.org/10.1093/cje/bex028
20. Reznikova, K., Koptseva, N., Seredkina, N., & Zamaraeva, J. (2016). Regional specifics of social values and their impact on Central Siberian territories' modernization (based on research of Krasnoyarsk region). *Economic Annals-XXI, 160*(7–8), 92–95. https://doi.org/10.21003/ea.V160-18
21. Singh, D. (2022). Cluster space among labor productivity, urbanization, and agglomeration of industries in Hungary. *Journal of the Knowledge Economy, 13*(2), 1008–1027. https://doi.org/10.1007/s13132-021-00726-9
22. Mahizhnan, A. (1999). Smart cities: The Singapore case. *Cities, 16*(1), 13–18. https://doi.org/10.1016/S0264-2751(98)00050-X
23. Giffinger, R., Fertner, C., Kramar, H., & Meijers, E. (2007). *Smart Cities Ranking of European Medium-Sized Cities.* Vienna, UT: Centre of Regional Science. Retrieved November 26, 2022, from http://www.smart-cities.eu/download/city_ranking_final.pdf
24. Eger, J. M. (2009). Smart growth, smart cities, and the crisis at the pump a worldwide phenomenon. *I-Ways, 32*(1), 47–53. https://doi.org/10.3233/IWA-2009-0164
25. Nam, T., & Pardo, T. (2011). Conceptualizing smart city with dimensions of technology, people, and institutions. In *Proceedings of the 12th Annual International Digital Government Research Conference: Digital Government Innovation in Challenging Times (dg.o '11)* (pp. 282–291). New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/2037556.2037602
26. Barrionuevo, J. M., Berrone, P., & Ricart, J. E. (2012). Smart cities, sustainable progress. *IESE Insight, 14*, 50–57.
27. Kourtit, K., & Nijkamp, P. (2012). Smart cities in the innovation age. *Innovation: The European Journal of Social Science Research, 25*(2), 93–95. https://doi.org/10.1080/13511610.2012.660331
28. Chourabi, H., Taewoo, N., Walker, S., Gil-Garcia, J.R., Mellouli, S., Nahon, K., Pardo, T.A., & Scholl, H.J. (2012). Understanding smart cities: an integrative framework. In *Proc. 45th Hawaii International Conference on System Sciences* (pp. 2289–2297). IEEE. https://doi.org/10.1109/HICSS.2012.615
29. Liu, J., Chen, N., Chen, Z., Xu, L., Du, W., Zhang, Y., & Wang, C. (2022). Towards sustainable smart cities: Maturity assessment and development pattern recognition in China. *Journal of Cleaner Production, 370*, 133248. https://doi.org/10.1016/j.jclepro.2022.133248
30. International Telecommunications Institute (ITU). Collection Methodology for Key Performance Indicators for Smart Sustainable Cities. https://u4ssc.itu.int/u4ssc-methodology/
31. Tsurumi, T., & Managi, S. (2010). Decomposition of the environmental Kuznets curve: Scale, technique, and composition effects. *Environmental Economics and Policy Studies, 11*, 19–36. https://doi.org/10.1007/s10018-009-0159-4
32. Panayotou, T. (1993). Empirical tests and policy analysis of environmental degradation at different stages of economic development. *ILO Working Papers 992927783402676*. International Labour Organization. http://www.ilo.org/public/libdoc/ilo/1993/93B09_31_engl.pdf

33. Ozturk, I., Al-Mulali, U., & Saboori, B. (2016). Investigating the environmental Kuznets curve hypothesis: The role of tourism and ecological footprint. *Environmental Science and Pollution Research, 23*(2), 1916–1928. https://doi.org/10.1007/s11356-015-5447-x
34. Rosenblum, J., Horvath, A., & Hendrickson, C. (2000). Environmental implications of service industries. *Environmental Science & Technology, 34*(22), 4669–4676. https://doi.org/10.1021/es9914083
35. Damiani, M., & Uvalic, M. (2014). Industrial development in the EU: Lessons for the future member states? *Croatian Economic Survey, 16*(1), 5–48. https://doi.org/10.15179/ces.16.1.1
36. Destek, M. A. (2021). Deindustrialization, reindustrialization and environmental degradation: Evidence from ecological footprint of Turkey. *Journal of Cleaner Production, 296*, 126612. https://doi.org/10.1016/j.jclepro.2021.126612
37. Antonova, A.V. (2020). Development of a methodology for assessing the city according to the criteria of "smart city. *Management Issues, 6,* 122–141. https://doi.org/10.22394/2304-3369-2020-6-122-141
38. Gokhberg, L.M., Gracheva, G.A., Ditkovsky, K.A. et al. (2021). *Indicators of Innovation Activity: 2021: Statistical Collection.* Moscow: National Research University "Higher School of Economics".
39. Abdrakhmanova, G.I., Vasilkovsky, S.A., Vishnevsky, K.O., Gokhberg, L.M. et al. (2023). *Indicators of the Digital Economy: 2022: Statistical Collection.* Moscow: National Research University "Higher School of Economics".

Impact of Digital Technologies on the Industrial Complex Development: The Russian Experience

Olga Smirnova and Lyudmila Chesnyukova

Abstract The rapid development of communications has led to the transformation of digital technologies and the introduction of advanced innovations in the production activities of the industrial complex. The digital transformation of the industrial complex contributes to the efficiency of the entire production chain, virtual simulation of the production process, increased production flexibility, and, as a consequence, a change in operating costs. The positive impact of digitalization allows for increasing productivity, optimizing existing business models and processes, and changing the traditional ways of doing business. The study conducted a comparative analysis of the implementation of digital technologies in the industrial complex of the subjects of the Ural Federal District of Russia. The key elements of the digitalization of the industrial complex of Russia are identified. The study results made it possible to group the industrial complex of the Ural Federal District subjects by maturity and identify the limiting factors for the introduction of digital technology in the Russian industrial complex. The maturity assessment allows for determining the readiness of the Ural Federal District industrial enterprises for digital solution implementation. More digitally mature subjects have been shown to act more flexibly and dynamically. Directions for implementing digital technologies in the industrial complex, based on a set of solutions for companies with low, medium, and high levels of digital maturity are presented.

Keywords Industrial complex · Digital technologies · Digital transformation of industry

O. Smirnova (✉)
Institute of Economics of the Ural Branch of the Russian Academy of Sciences, 29 Moskovskaya St., Ekaterinburg 620014, Russian Federation
e-mail: smirnova.op@uiec.ru

Ural Federal University, 19 Mira St., Ekaterinburg 620002, Russian Federation

L. Chesnyukova
Ural State University of Economics, 62 8-Marta St., Ekaterinburg 620144, Russian Federation
e-mail: uvl70@yandex.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_4

1 Introduction

One of the key factors of competitiveness is the introduction of digital technology in the production activities of the industrial complex. The industry is currently adopting a variety of available digital technologies that offer significant economic advantages, unlock additional revenue potential, and develop new business models. However, the changes caused by digitalization in the economy are not predetermined in advance but depend on the innovation strategy and investment activity of the subjects involved.

The Ural Federal District (UFD) is one of the engines of the economic and technological development of the Russian industrial complex. Based on a comparative analysis of the UFD subjects, the study describes the different impacts of digitalization processes on industrial activity and identifies regional differences in the growth rate of transformation of the industrial complex.

The study aims to assess the level of balanced development of the UFD industrial complex in the conditions of digitalization.

The methodological basis of the study includes the results of scientific economists on the problems of stable and balanced functioning of the industrial complex.

2 Literature Review

The works by Akberdina [1], Abdrakhmanova et al. [2], and Romanova [3, 4], in which it is noted that engineering developments related to the introduction of digital technologies optimize a wide range of industrial processes and increase their competitiveness, are devoted to the issues of industrial digitalization.

The following digital technologies are highlighted: individual human–machine interaction; energy efficiency and renewable energy; artificial intelligence; biotechnology; digital twins and simulations; transmission technology; data storage and analysis. Based on the above, digital technology can contribute to the sustainable development of industrial production [5–7].

A number of economists study the approaches to assessing the effect of digitalization on labor productivity in the industrial complex. They argue that the introduction of technological innovations and digital technologies into business processes is not enough to ensure economic growth and enhance the efficiency of production processes. The opposite approach is premised on the idea that an increase in the efficiency and productivity of labor is due to advances in the digital economy, which is at the stage of highly efficient technologies being formed [8].

The works by Bauer et al. [9], Herter and Ovtcharova [10], Meissner et al. [11], and Schlaepfer et al. [12] are devoted to the assessment of the impact of digital technology on the development of enterprises.

Key digital technologies used in industry, such as blockchain and supply chain traceability, the Internet of Things, and artificial intelligence, are enabling more efficient use of available economic resources [13, 14].

The works by Ahmad and Schreyer [15], Arens [8], Brynjolfsson and McAfee [16], Gerbert et al. [17], Kelchevskaya and Shirinkina [18], and Schwab [19] substantiate the tools of digitalization, which allow the economic effect of reducing the cost and increasing productivity.

Smirnova and Chesnyukova [7] and Abdrakhmanova et al. [2] distinguish regions by the degree of digital maturity: regions with high, medium, and low levels.

The results of the studies presented by Akberdina [1], Nabatova and Plotnikov [20], Akberdina and Romanova [3], Stepanov [21], Tarasov [22], and Tolkachev and Morkovkin [23] made it possible to develop applied tools for assessing the level of digital transformation of the Russian industrial complex.

The widespread introduction of digital technologies into business processes and the development of technological innovations can have a positive impact on the development of the UFD industrial complex.

3 Materials and Methods

The pairing of digitalization tools and the ranking of regions according to the level of digital maturity (high, medium, and low) made it possible to develop a theoretical model of digitalization of the industrial complex. The model includes digital tools and additional technological capabilities at various stages of the production chain (Fig. 1).

The methodology for assessing the processing development of the UFD industrial complex is conducted on the primary Rosstat indicators for 2017–2021. Linear regression equations were built, and linear correlation and determination coefficients (R^2) were determined. The estimated regression equation determines the analytical relationship of changes in the resultant indicator by the influence of one or more factor variables and shows that in the aggregate, the relative economic well-being of the area is proportional to the development of digital technology.

The analysis contains the following stages: (1) distribution of digital technologies in the organizations of the industrial complex that used digital technologies; (2) dynamics evaluation of developed advanced production technologies of the UFD subjects; (3) structural analysis of research and development costs by high-tech, medium-tech, and science-intensive types of economic activity; and (4) structure evaluation of the industrial complex by indicators: the share of shipped goods of own production; analysis of the growth rate of labor productivity [1, 4, 28].

The share of regions using digital technology is calculated as an indicator that includes several sub-indices [4].

$$\mathrm{Dreg}_{de} = \sqrt[4]{\mathrm{Ddat} \cdot \mathrm{Duat} \cdot \mathrm{Dudt} \cdot \mathrm{Duct}} \quad (1)$$

where $\mathrm{Dreg}_{\mathrm{de}}$ is the share of regions using digital end-to-end technologies; Ddat is the share of regions that have developed advanced production technologies; Duat is the share of regions using advanced production technologies; Dudt is the share of

Production chain and industry digitalization tools

Analysis of data produced by equipment, sensors, and business processes themselves	Automation of assembly lines and delivery process	Machine learning to detect and predict failures in the early stages of production chains

Technology solutions and trends	Cost reduction	Performance improvement	Increase in sales volumes
applicable to companies with a high level of digital maturity with general information and some advantages offered, given that their implementation, in any case, requires the support of staff or specialized companies	Accounting management; Remote solutions	Cloud technologies; Gathering opinions; Digital payments;	Antivirus software; Cloud solutions; Internal communication channels; Electronic invoices;
designed for companies with medium maturity, from which information is offered on the main elements to be considered when launching, as well as resources of interest to the company	RFID; Solutions for industrial platforms; Storage management; Supervision and control	Security plan; ERP solutions	Virtual assistants; Digital marketing; Payment platforms; Marketplaces
designed for companies with a low digital maturity; a guide to their offline implementation is offered	Self-driving cars; Augmented reality; Robotics; Artificial intelligence; Big data	IoT; Blockchain	Digital twins; Reconnaissance business; 3D printing

Regulatory framework and digitalization strategy for the industrial complex

Fig. 1 The model of industrial complex development in the implementation of digital end-to-end technology. *Source* compiled by the authors based on [7, 15, 17, 18, 24–27]

regions using digital technology; Duct is an index reflecting the share of enterprises using communications technology.

The advantage of this method is that it allows different scenarios to be analyzed and evaluated, and the evaluation results are more comparable.

4 Results and Discussion

The introduction of digital technology has led to various changes due to new developments that have taken place in areas such as microelectronics or intelligent

Table 1 Dynamics of labor productivity in the UFD industry, rub thousand/person

Labor productivity, rub thousand/person	2017	2018	2019	2020	2021
Ural federal district	1699.0	2052.2	2097.4	1856.2	2745.5
Kurgan region	364.4	411.0	496.2	483.1	617.6
Sverdlovsk region	1014.1	1157.8	1225.5	1272.4	1543.8
Tyumen region	3143.6	3943.6	3988.4	3238.2	5119.7
Khanty-Mansi autonomous area	3484.5	4325.2	4452.8	3251.5	5223.0
Yamal-Nenets autonomous area	5535.6	7110.6	7348.9	6549.6	10,249.3
Tyumen region without autonomous districts	1259.1	1562.2	1341.5	1280.1	1971.2
Chelyabinsk region	920.7	989.9	984.6	1000.9	1465.7

Source [29]

systems. However, their inclusion in production processes shows different intensities depending on the specifics of the region and sectors of the economy (Table 1).

In general, the highest labor productivity indicators are observed in highly profitable extractive regions, with labor productivity growth rates in the Yamal-Nenets Autonomous Area increasing by 85.2% over 5 years, due to the discovery of new fields. The lowest indicators of labor productivity are in the subsidized Kurgan Region, despite the growth of the indicator by 61.6% over the 5 years analyzed. The Tyumen, Sverdlovsk, and Chelyabinsk Regions also show relatively high growth in labor productivity in the Tyumen (+56.6%), Sverdlovsk (+52.2%), and Chelyabinsk (+59.2%) Regions.

The use of digital end-to-end technologies affects sustainable and stable development in the global market and is one of the key competitive advantages of industrial enterprises in Russia (Table 2).

The introduction of digital end-to-end technology is noted in the Sverdlovsk, Chelyabinsk, and Tyumen Regions. The digitalization of industry is proceeding at a slower pace.

Table 2 Dynamics of the share of UFD subjects using digital end-to-end technology, %

Share of subjects using digital end-to-end technologies	2017	2018	2019	2020	2021
Ural federal district	95.03	96.09	96.35	90.15	90.25
Kurgan region	6.42	6.42	6.13	5.44	5.33
Sverdlovsk region	58.68	57.29	55.12	67.18	62.65
Tyumen region	41.86	44.13	51.13	42.88	44.72
Khanty-Mansi autonomous area	7.35	17.55	29.11	23.52	23.08
Yamal-Nenets autonomous area	27.85	26.55	28.80	26.95	25.77
Tyumen region without autonomous districts	25.24	27.00	27.48	23.19	26.58
Chelyabinsk region	57.77	58.23	56.22	41.70	45.96

Source [30]

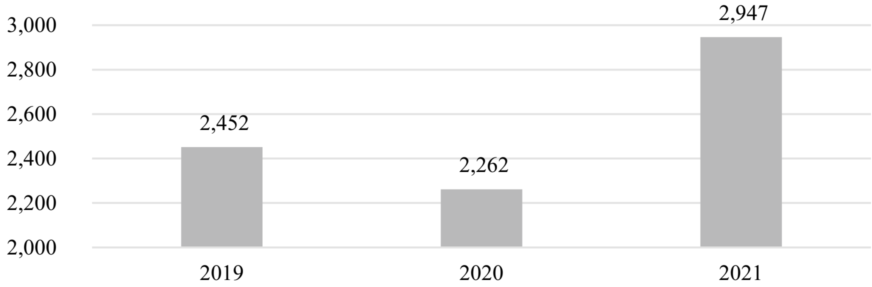

Fig. 2 Dynamics of internal costs for the development of the digital economy, RUB mln. *Source* [30]

In the Khanty-Mansi Autonomous Area and Yamal-Nenets Autonomous Area, the digital gap is typical not only for federal districts and regions but also between the largest cities.

The dynamics of domestic costs for the development of the digital economy are shown in Fig. 2.

Data analysis shows an increase in internal costs by 30.3% in 2021; the largest share of costs was associated with the development of information and communication technologies (Fig. 2).

According to Fig. 3, the most important (37.1%) item of expenditure on the development of the digital economy is the purchase of computers and office equipment. Its volume in 2021 amounted to 1093.3 RUB bln. About 1/5 of the total expenditure accounts for the purchase of software (18.1%, 533.4 RUB bln), and one-tenth of the total expenditure is payment for telecommunications services (12.1%, 356.6 RUB bln). According to the National Research University Higher School of Economics, "domestic spending on the development of the digital economy will continue to grow and will reach 5.1% of GDP in 2024" [21].

Modeling of the factors influencing the dynamics of productivity was carried out using paired regression. The forecast results are presented in Table 3.

The simulation showed that labor productivity depended to a greater extent on the dynamics of digital activity, and the use of digital technology in the Sverdlovsk and Tyumen Regions, as well as the Khanty-Mansi Autonomous Area. An inversely proportional relationship is observed in the Yamal-Nenets Federal Area and the Kurgan Region. Thus, the challenge of improving industrial productivity is focused on solutions based on robotics, IoT, data analytics, operational technologies, artificial intelligence, intelligent logistics, and blockchain.

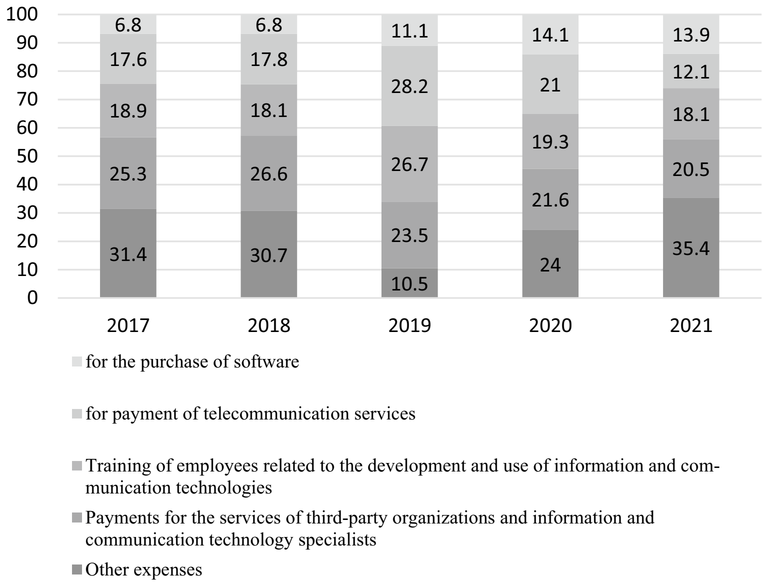

Fig. 3 Structure of internal costs for the development of the digital economy, %. *Source* [30]

Table 3 Assessment of the regression analysis of the development of the UFD subjects

Subject	Regression equation	Determination factor R^2	Linear correlation ratio
Ural federal district	$y = -0.0032x + 1002$	0.16	−0.41
Kurgan region	$y = -0.0046x + 8.1272$	0.70	−0.84
Sverdlovsk region	$y = 0.0108x + 46.809$	0.19	0.44
Tyumen region	$y = 0.0016x + 38.842$	0.12	0.34
Khanty-Mansi autonomous area	$y = 0.0043x + 2.2236$	0.17	0.42
Yamal-Nenets autonomous area	$y = -0.0004x + 30.132$	0.36	−0.60
Tyumen region without autonomous districts	$y = 0.0025x + 22.187$	0.19	0.43
Chelyabinsk region	$y = -0.0172x + 70.457$	0.25	−0.50

Source [29, 30]

5 Conclusion

The introduction of digital technology is a competitive advantage for the production activities of enterprises of the industrial complex. There is a directly proportional relationship between the digital maturity of industrial enterprises and the ability to compete in an increasingly global, specialized, technological, and constantly evolving marketplace. This study made it possible to consider the current state of the industrial complex of the Ural Federal District, its main needs, and its problems. Depending on the implementation of digital technology and the rate of productivity, regions with a high level of digital maturity (Sverdlovsk, Chelyabinsk, and Tyumen Regions), regions with a medium level of digital maturity (Khanty-Mansi and Yamal-Nenets Autonomous Areas), and a region with a low level of digital maturity (Kurgan Region) were defined. Conclusions are drawn on the possibility of reducing costs, increasing productivity, and increasing production and sales volume through the use of different digital technologies at each level of digital maturity.

Acknowledgements The article was prepared under the research plan for the Institute of Economics of the Ural Branch of the Russian Academy of Sciences.

References

1. Akberdina, V. V. (2018). Transformation of the industrial complex of Russia in the context of digitalization of the economy. *Proceedings of the Ural State University of Economics, 19*(3), 82–99. https://doi.org/10.29141/2073-1019-2018-19-3-8
2. Abdrakhmanova, G. I., Vishnevsky, K. O., Gokhberg, L. M., et al. (2021). *Digital economy: 2021: Brief statistical digest*. National Research University Higher School of Economics.
3. Akberdina, V. V., & Romanova, O. A. (2021). Regional aspects of industrial development: Review of approaches to the formation of priorities and regulatory mechanisms. *Regional Economy, 17*(3), 714–736. https://doi.org/10.17059/ekon.reg.2021-3-1
4. Romanova, O. A., & Ponomareva, A. O. (2020). Industrial policy: New realities, problems of formation and implementation. *Economic and Social Changes: Facts, Trends, Forecast, 13*(2), 25–40. https://doi.org/10.15838/esc.2020.2.68.2
5. de Reuver, M., Sørensen, C., & Basole, R. C. (2018). The digital platform: A research agenda. *Journal of Information Technology, 33*(2), 124–135.
6. Russell, S. J., & Norvig, P. (2016). *Artificial intelligence: A modern approach* (3rd ed.). Pearson Education Limited.
7. Smirnova, O. P., & Chesnyukova, L. K. (2022). Influence of digital technologies on the sustainable development of the industrial complex of the Ural Federal District. *Regional Economics and Management, 2*(70). https://doi.org/10.24412/1999-2645-2022-270-6
8. Arens, Yu. A., Katkova, N. A., Halimon, E. A., & Brikoshina, I. S. (2021). The fifth industrial revolution—Innovations in the field of biotechnologies and neural networks. *E-Management, 4*(3), 11–19.
9. Bauer, H., Patel, M., & Veira, J. (2016). *The internet of things: Sizing up the opportunity*. McKinsey & Company.
10. Herter, J., & Ovtcharova, J. (2016). A model-based visualization framework for cross discipline collaboration in Industry 4.0 scenarios. *Procedia CIRP, 57*, 398–403.
11. Meissner, H., Ilsena, R., & Aurich, J. C. (2017). Analysis of control architectures in the context of Industry 4.0. *Procedia CIRP, 62*, 165–169.
12. Schlaepfer, R. C., Koch, M., & Merkhofer, P. (2015). *Challenges and solutions for the digital transformation and use of exponential technologies*. Deloitte.
13. Cherepanov, N. V. (2019). Principles and approaches of Industry 5.0 at the enterprise. *Innovations and Investments, 9*, 144–147.

14. Fedorov, A. A., Liberman, I. V., Koryagin, S. I., & Klachek, P. M. (2021). Design technology of neuro-digital ecosystems to implement the concept of Industry 5.0. *Scientific and Technical Bulletin of St. Petersburg State Polytechnic University. Economic Sciences, 14*(3), 19–39. https://doi.org/10.18721/JE.14302
15. Ahmad, N., & Schreyer, P. (2016). Measuring GDP in a digitalized economy. *OECD Statistics Working Papers, 2016/07*.
16. Brynjolfsson, E., & McAfee, A. (2014). *The second machine age: Work, progress, and prosperity in a time of brilliant technologies*. WW Norton & Company.
17. Gerbert, P., Lorenz, M., Rüßmann, M., Waldner, M., Engel, P., Harnisch, M., & Justus, J. (2015, April 9). Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries. *BCG*. https://www.bcg.com/publications/2015/engineered_products_project_business_industry_4_future_productivity_growth_manufacturing_industries.aspx
18. Kelchevskaya, N. R., & Shirinkina, E. V. (2019). The impact of digital technology industries on the potential economic effect. *The World of Economics and Management, 19*(2), 19–30. https://doi.org/10.25205/2542-0429-2019-19-2-19-30
19. Schwab, K. (2016). *La cuarta revolución industrial*. Foro Económico Mundial.
20. Nabatova, N. Yu., & Plotnikov, V. A. (2021). Innovations, informatization, industry: Structural analysis of macroeconomic dynamics in the Russian Federation. *BENEFICIUM, 1*(38), 90–99. https://doi.org/10.34680/BENEFICIUM.2021.1(38).90-99
21. Stepanov, E. V. (2022). Digital transformation of industrial enterprises based on intelligent solutions of the concept of "Industry 4.0". *Bulletin of Samara University. Economics and Management, 13*(1), 49–55. https://doi.org/10.18287/2542-0461-2022-13-1-49-55
22. Tarasov, I. V. (2018). Technologies of Industry 4.0: Impact on increasing the productivity of industrial companies. *CPRM, 2*(107), 62–69. https://doi.org/10.17747/2078-8886-2018-2-62-69
23. Tolkachev, S. A., & Morkovkin, D. E. (2019). Trends in digitalization of manufacturing industries in Germany and Russia. *Scientific Works of the Free Economic Society of Russia, 218*(4), 260–272.
24. European Commission Directorate-General for Research and Innovation. (2020). *Enabling Technologies for Industry 5.0*. https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/enabling-technologies-industry-50_en
25. Hajjaji, Y., Boulila, W., Farah, I. R., Romdhani, I., & Hussain, A. (2021). Big data and IoT-based applications in smart environments: A systematic review. *Computer Science Review, 39*, 100318. https://doi.org/10.1016/j.cosrev.2020.100318
26. Za, S., Consorti, A., & Virili, F. (2022). Looking at the digitized world from different perspectives. *Lecture Notes in Information Systems and Organisation, 54*, 1–7. https://doi.org/10.1007/978-3-030-86858-1_18
27. Zhou, Z., Chen, X., Li, E., Zhang, L., Luo, K., & Zhang, J. (2019). Edge intelligence: Paving the last mile of artificial intelligence with edge computing. *Proceedings of the IEEE, 107*(8), 1738–1762. https://doi.org/10.1109/JPROC.2019.2918951
28. Avdeeva, E. A., Averina, T. A., & Balashova, N. A. (2022). Technological breakthroughs as a fundamental factor of global competitiveness. *Bulletin of SUSU. Computer Technology, Control, and Radioelectronics Series, 22*(2), 141–147. https://doi.org/10.14529/ctcr220213
29. Rosstat. (2022). *Industrial production*. Federal State Statistics Service (Rosstat). https://rosstat.gov.ru/enterprise_industrial
30. Rosstat. (2022). *Science, innovation, and technology*. Federal State Statistics Service (Rosstat). https://rosstat.gov.ru/statistics/science

A Comparision of Digital Transformation of Industry in the Russian Federation with the European Union

Vikas Kumar and Grigoriy Korovin

Abstract The concept of Industry 4.0 is based on a set of digital technologies, forms a new paradigm in the economic and social sphere, and significantly changes production models. The study aims to find out the status and pace of digitalisation of the economy of the Russian Federation, highlighting the industrial sector. The author explores the most relevant digital technologies that enable machine connectedness, adaptability, predictability, and autonomous production. The study hypothesises that the digital transformation of the industry should manifest itself in an increase in the use of digital technology by companies. The author used selected indicators from Russian and European statistical databases, showing enterprises' use of certain types of digital technology. We found that in the Russian Federation, in the last five years, there has been no growth in the use of special software tools for design and production management. The same is observed in enterprise resource management systems (enterprise resource planning and customer relationship management). In the Russian Federation and the European Union, there is an established level of use, which has not changed over the past 5 years. On the other hand, the use of cloud computing technology is growing, including in the manufacturing industry of the Russian Federation. The author identified Russia is lagging behind the European Union in using big data technologies, artificial intelligence, the Internet of Things, radio-frequency identification, and cloud technologies. Russia's share of companies using these technologies is usually 2–5 points lower than the average European level. The results obtained can be used in forming the Russian Federation's industrial policy

V. Kumar
Faculty of Business, Law and Social Sciences, Birmingham City University, City Centre Campus, Curzon Building, 4 Cardigan Str., Birmingham B4 7BD, UK

Department of Management Studies, Graphic Era Deemed to be University, Bell Road, Clement Town Dehradun, Uttarakhand, India

University of Economics Ho Chi Minh City (UEH), A.016—59C Nguyen Đinh Chieu Dist. 3, Ho Chi Minh City, Vietnam

G. Korovin (✉)
Institute of Economics of The Ural Branch of The Russian Academy of Sciences, 29 Moskovskaya St., Ekaterinburg 620014, Russian Federation
e-mail: korovin.gb@uiec.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_5

in the digitalisation field. In the future, lengthening the observation history will allow a more detailed evaluation of the dynamics of the digitalisation process. A limitation in the use of the results can be considered differences in the methods for collecting and processing statistical information in the Russian Federation and the European Union.

Keywords Digital transformation · Industry 4.0 · Industrial policy

1 Introduction

The focus on Industry 4.0 and the digitalisation processes is related to the scale of the impact of new technologies on the economic, social, and production spheres. Since 2011, initiatives have been actively developing worldwide to combine industrial production, digital technology, and the Internet, creating a new technological paradigm. Furthermore, digital technology makes it possible in the face of increased competition in the markets and a changing environment to more quickly develop effective solutions in the management of production [1–3], personnel [4], and interaction with customers [5], partners, and government agencies [6, 7].

Modern digital technology supports the entire life cycle of production, including the development of the product concept, the formation of a system of technical and marketing requirements, detailed specifications, the development of design and technological documentation and digital models, collecting data on customer satisfaction, maintenance, etc. In addition, digital technologies support decision-making in the management of resources, employees, and information links [8].

Traditional business models and production management methods do not always cope with modern challenges, generating risks of reduced efficiency, loss of markets, and loss of enterprises from value chains [9]. Such manifestations can arise in the economy, causing socio-economic problems [10–13], lack of sustainability [14], long-term lagging [15], and the territory's falling out of the common space [16–18].

In general, digitalisation, being a new technological paradigm, offers fundamentally new opportunities for the economy and social area [19, 20], especially in the field of industrial production, ensuring its sustainability [21–23], organising interaction within and between enterprises [24, 25].

A review of the literature shows a lack of publications comparing the level of development and dynamics of digital technologies' penetration into the economy at the company level. Here we wanted to see country comparisons.

The study aims to determine the state and pace of digitalisation of the Russian economy, highlighting the industrial sector and comparing them with similar indicators of the European Union. The article focuses on the most promising and relevant digital technologies applicable to industrial production.

As a hypothesis, it is assumed that the available data will show a digital transformation of the economy, particularly its industrial sector, expressed in an increase in the use of digital technology. Perhaps in an international comparison, the characteristic profile of digitalisation, associated with the priority implementation of certain technologies, will be noticeable.

The study will use selected indicators of Russian (gks.ru) and European (ec.europa.eu/eurostat/en/) statistical databases, taking into account the use of certain types of digital technology by companies as a basis for evaluation.

2 Methods

2.1 Evaluation of Digitalisation

When assessing the level of digitalisation, the question of search, selection, and quality of the data used naturally arises. Often considered indicators of the development of the digital economy are the ICT Development Index, Networked Readiness Index, Inclusive Internet Index, World Digital Competitiveness Index, Global Connectivity Index, International Digital Economy and Society Index, e-Government Development Index, UNCTAD B2C e-Commerce Index, Global Cybersecurity Index, Local Online Service Index, Digital Intelligence Index (Digital Evolution and Digital Trust), and others. The task of these indices is usually to calculate and present a comprehensive indicator consisting of modules to assess the digitalisation of society, public administration, the creation of digital infrastructure, etc. These indicators are not suitable for the objectives of this study, as they include several elements not related to Industry 4.0 and the industrial sector. Therefore, this study focuses on selecting individual indicators that characterise the degree of digitalisation in certain areas and technologies [26]. The level of readiness of the economy for digital technology has already been estimated for European countries [27] but did not include data from the Russian Federation.

In the industrial sphere, it is quite difficult to adequately assess digitalisation processes because digitalisation covers a huge number of technologies and ways of their application [28, 29]. The information technologies used for interaction via global networks, electronic document management, and enterprise resource management are no longer considered digital. As the most advanced, providing new opportunities within Industry 4.0 are called big data, Internet of Things, artificial intelligence (machine learning, deep learning), blockchain, VR and AR, wireless communication technologies (in particular, 5G), cloud computing, additive manufacturing, robotics, and simulation [30]. The more complex the technology, the more important it is to Industry 4.0.

Akberdina proposed [31] a five-level "pyramid of digitalisation", including the stages: computerisation, the use of computer networks; electronic exchange of economic data with partners; means of providing computer support for production; own production of ICT and equipment; production and use of robots, sensors, and other means of industrial digitalisation.

A report from Acatech (https://www.acatech.de) published in 2017 proposed six stages of digitalisation, with only the last four stages attributed to Industry 4.0 technologies. At these stages, information systems and sensors allow recording the performance of production processes, forming a digital model of the company, allows analysing and using the information collected, justifying the decisions made, making reasonable forecasts, reducing the number of unforeseen downtimes, providing a more stable operation of the company.

There are other approaches to the classification of digital technologies, such as four technological layers—Sensor, Integration, Intelligent, and Response [32]. More complex technology development roadmaps and initiatives [33], with allocating the most important technologies for individual areas [25].

When assessing the domestic economy's digitalisation level, the focus should be on the highest stages of digitalisation development and their corresponding technologies [32, 34]. This study will use the Rosstat data for the Russian economy, highlighting the industrial sector. In addition, the averaged data of the Eurostat for the EU countries will be used as a comparative basis. Data for European countries do not include financial sector companies—this is the approach used by Eurostat.

Data to assess the extent of use of the most relevant digital technologies have begun to appear in domestic statistics in recent years. Furthermore, in 2020, Rosstat began adapting statistics collected on digitalisation issues to international standards. The present study considers the widest range of indicators provided by Rosstat, focusing on technologies that can be attributed to Industry 4.0 and which will determine the prospects for industrial development.

Rosstat, like Eurostat, offers indicators of the share of companies using certain types of digital technology for consideration. It should be noted that in 2020, Rosstat changed the data collection and structuring methodology, which manifested itself in a sharp change in values, created a gap in observations, and did not make it possible to assess the changes that occurred in 2019–2020 adequately. The selection of studied technologies allowed for limiting the range of technologies covered by the statistics:

- the use of special software (for design, for automated production control);
- cloud technologies;
- artificial intelligence;
- big data technologies;
- radio-frequency identification (RFID) technologies.

3 Results

3.1 Special Software Tools

In the first stage, let us consider the dynamics of using special software tools in the economy and, separately, in industry. These technologies include a wide range of information tools: for design, automated production management, warehouse, enterprise resource management, information security, procurement management, sales, and financial calculations, as well as for scientific research, electronic document management, etc. The study of the proportion of companies that use any special software tools is declining in the industry with a slight increase in such companies in the economy as a whole. The overall level is 86–87%, with a downward trend (Fig. 1).

Some special tools can be attributed to the digitalisation characteristic of Industry 4.0. Among these technologies, one can name tools for computer support of design and technological preparation of production and technical analysis. However, statistics show no growth in the share of companies using this type of funds (Fig. 2). For industry, the established level is 30%, and for the economy as a whole—10–13%.

One can see roughly the same thing in using software to control individual equipment, technological processes, and industries. The share of companies in Russia that use these funds is about 15%. For industry, it is higher—more than 35% (Fig. 3). In the considered five-year period, this indicator remained virtually unchanged. This demonstrates the modest pace of digitalisation processes, or rather the frozen structure of technologies used in this area.

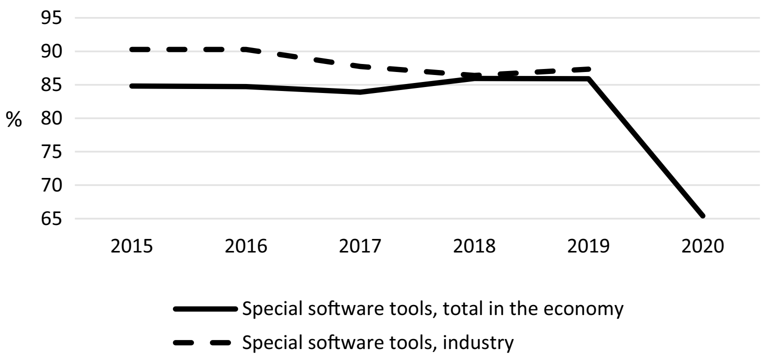

Fig. 1 Share of companies in the Russian Federation that use special software tools, %

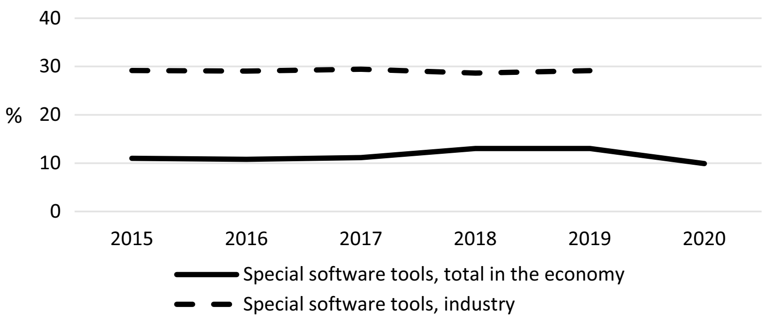

Fig. 2 The share of Russian companies using special software for design (CAD/CAE/CAM/CAO)

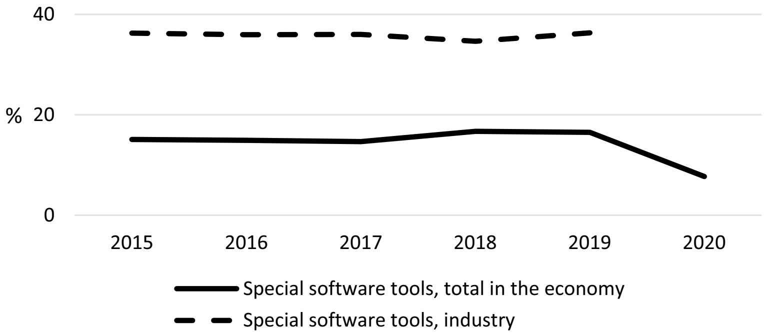

Fig. 3 Share of Russian companies using special software for automated production and process control

However, the special software tools considered in this section of the statistics, likley to be intended for scientific research, warehouse management, human resources, electronic document management, human resources, procurement, and financial calculations, refer to the initial stages of informatisation of production and cannot be the basis for tracing the processes of industry transformation within Industry 4.0. The dynamics of the indicators of this section of statistics, in general, show that in the Russian Federation economy, and the industry in particular, in the observed five-year period, there were no significant processes of expanding the use of digital technology.

3.2 Cloud Technologies

Since 2020, detailed information on the use of big data, artificial intelligence, the Internet of Things, RFID, and remote data centres by companies has become available in Russian statistics. Unfortunately, not all indicators in this section have a history of observation, and one can only assess the level of digital development achieved using them. The growth in the use of cloud technology in the economy is noticeable and, according to available data, has reached a level of 26–27% in the Russian economy as a whole and the manufacturing industry (Fig. 4).

In the Eurostat database, there is an indicator of the proportion of companies that have purchased cloud services. The average for the 27 EU countries rose from 19% in 2016 to 36% in 2020 and 41% in 2021. Despite the noticeable growth, one can talk about the lag of domestic companies from the average European level.

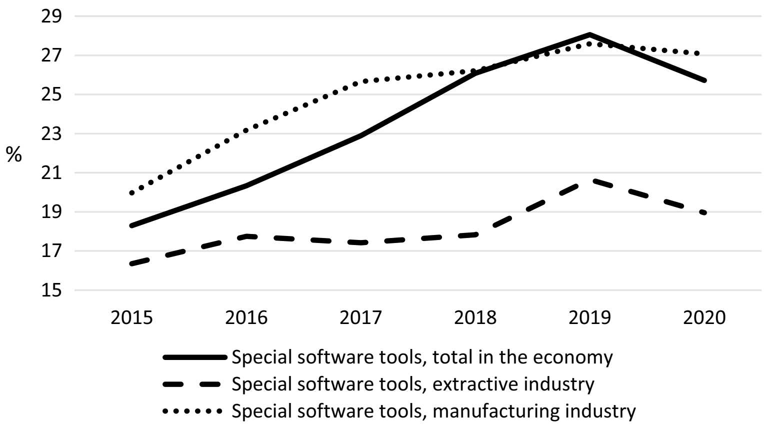

Fig. 4 Share of Russian companies using cloud technologies, %

3.3 Big Data

Enterprises most actively use big data generated from their own websites, social networks, mobile operators, and enterprise accounting systems (Fig. 5). In the economy as a whole, 22.4% of companies use any technology to collect and process big data, whereas in manufacturing—26.5%, and in extractive industries—21.8% (Fig. 5).

As of 2020, in the EU, 13% of companies used big data analytics technology from at least one source. That said, big data on geolocation and big data from social

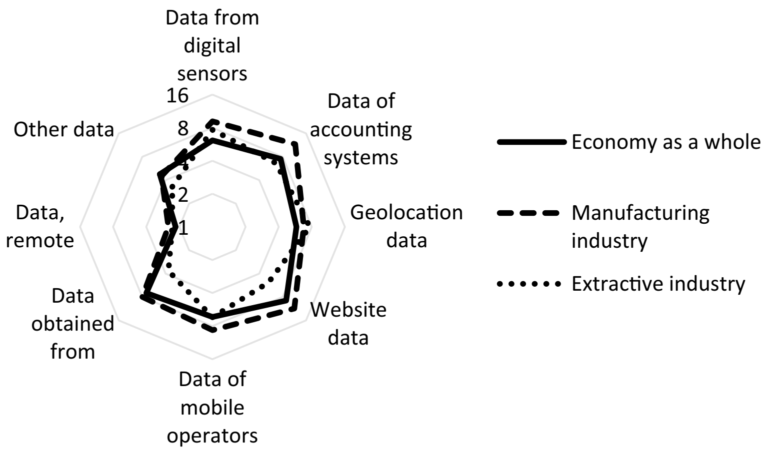

Fig. 5 Share of Russian enterprises using big data by type of data, 2020, %

media is handled by about 7% of companies, and data from smart sensors and devices within companies by about 4%.

Domestic companies are already at the average European level in this technological area, especially manufacturing ones. If one considers big data use, the main two reasons are for sales (marketing) and the production process and, to a lesser extent, for security.

3.4 Artificial Intelligence

Artificial intelligence as a set of technologies belongs to the most important areas of Industry 4.0. The share of companies using individual artificial intelligence technologies does not exceed 5.4% (3.65% in manufacturing, 2.5% in mining), with machine learning, computer vision, and language processing being the most important technology areas (Fig. 6). It should be noted that in the financial and insurance services and trade, the share of companies using these technologies for certain types of services reaches 20%. Trade and financial services in the Russian Federation, as the easiest areas for digitalisation, are much more developed in this direction.

Artificial intelligence is used primarily for production and marketing and less so for security. About 8% of companies in the EU use artificial intelligence for certain functions. At the same time, the share of companies using artificial intelligence for the implementation in individual areas: speech recognition, machine learning, computer vision, decision support systems, automation, robotics, and written language processing is in the range of 2–3%. One can observe that domestic companies have reached the average European level.

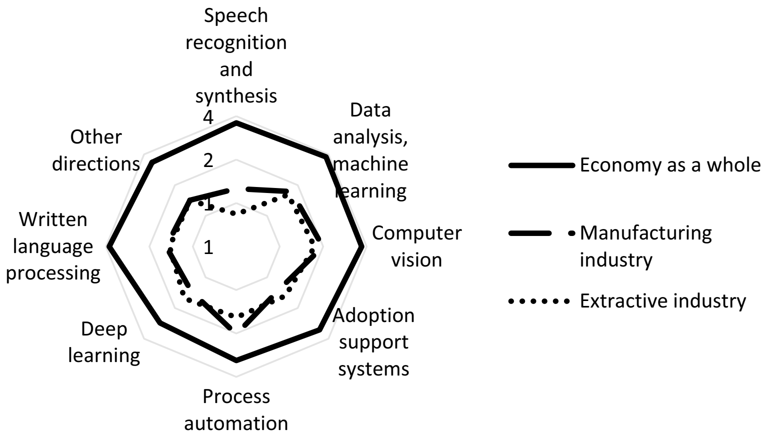

Fig. 6 Share of Russian organisations that used artificial intelligence technology in the areas

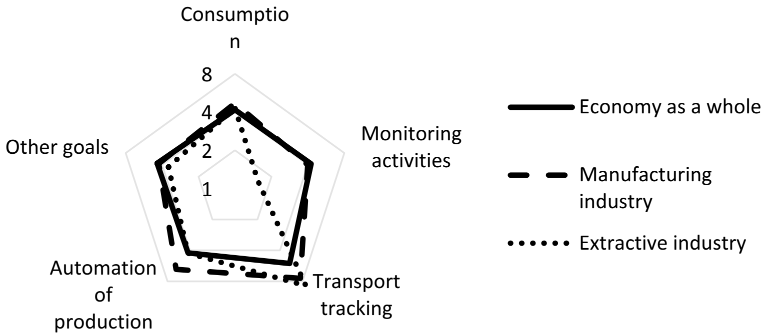

Fig. 7 The share of Russian enterprises that use IoT technologies by directions in 2020

3.5 Internet of Things

Only 4% of Russian companies use the Internet of Things technologies. Among the main uses are optimising electricity and heat consumption, monitoring customer activity, tracking the movement of vehicles and products, automating the production process, and managing logistics and product movement (Fig. 7). In some areas, manufacturing enterprises are more actively using this technology. In the wholesale and retail trade, the use of Internet of Things technology reaches 25%.

At the same time, about 30% of companies in the EU use the Internet of Things, including 9%—to control energy consumption, 5%—to control sensors and cameras, 7%—to control the movement of objects, 5%—to control production processes and 6%—for logistics. In addition, this type of technology provides the connectivity of equipment, collecting the data needed for predictive analytics, a key element of Industry 4.0. However, a significant observation is that the domestic industry lags far behind the European average in using this technology.

3.6 Radio Frequency Identification (RFID) Technology

Companies in the Russian Federation use RFID technology to identify individuals, control access to hotel rooms, and monitor and control production and logistics processes. At the same time, the share of companies using these technologies does not exceed 8% (Fig. 8). In retail and wholesale trade, the use of Internet of Things technology reaches 22.3% in the direction of personal identification and access control to hotel facilities. Limited Eurostat data shows that the percentage of EU companies using RFID tags rose from 11% in 2014 to 13% in 2017. On the other hand, the share of domestic companies using RFID in the most important area—directly in the production process does not exceed 3% for the industry.

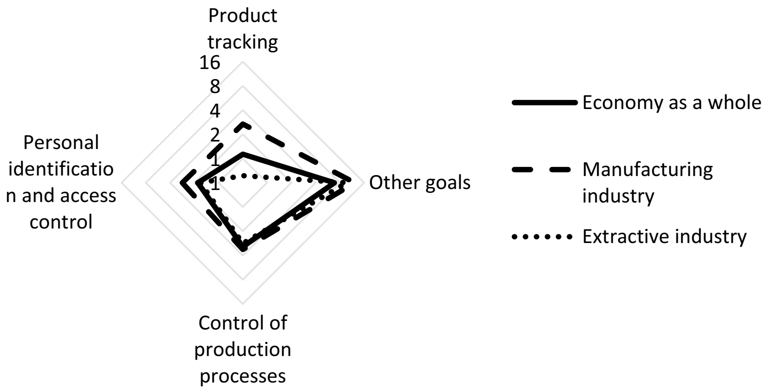

Fig. 8 Share of enterprises using radio-frequency identification (RFID) technology, by areas, 2020

One can consider the level of companies' use of integrated resource utilisation systems as an additional element for comparison. The use of enterprise resource planning (ERP) systems in European countries is at 36–38% and has not grown in the past five years. In Russia, ERP systems are used by 13% of companies in the economy, 12.3%—in extractive industries, and 18.6%—in manufacturing. There is also a noticeable lag in the system's interaction with customers and partners. In European countries, the established level of use of customer relationship management (CRM) systems is 35–37%, and in Russia—12.1% (5.2%—in the extractive industries and 10.5%—in manufacturing).

4 Conclusions

This study assesses the status and pace of digitalisation of the Russian economy and, separately, the extractive and manufacturing sectors of the Russian Federation. The study focused on current and promising digital technologies applicable to industrial production. These technologies ensure the accumulation and processing of big data and provide connectivity, predictability, and autonomy of production management within Industry 4.0. In addition, based on data from the statistical authorities of the Russian Federation and the European Union, a comparative analysis of the level of use of digital technology by organisations was conducted.

The study showed that there had been no growth in the use of special software tools in the Russian Federation over the past five years. This applies to software tools for design and production management. Furthermore, the study shows that companies have already provided the necessary level of use of special software tools in this area, demonstrating a saturation effect. On the other hand, cloud computing technology is growing, including in the manufacturing industry. This is probably due to the development of cloud technology capabilities applicable to the industry.

A comparison of the level of digital technology use by Russian companies with EU data reveals a lag in cloud technology, big data processing, artificial intelligence, the Internet of Things, and radio-frequency identification technologies. At the same time, the lag, as a rule, does not exceed 2–5 points. In addition, a lower level of use is noticeable in traditional enterprise resource management systems—ERP and CRM. In this area, both in the European Union and in the Russian Federation, there is an established level of use, which has not changed over the past five years.

The results expand the understanding of the state and dynamics of digitalisation processes in the Russian Federation and can be used in managing the digital transformation of industry in the Russian Federation. Furthermore, results underscore the need for government measures to increase digital technologies used by Russian companies to improve their performance of industries and reduce the gap with European companies.

Short observation periods and international differences in static techniques can be considered limitations in using the results obtained. We see prospects for further research of the problem in the application of econometrics and other methods to assess the processes of industry digitalization. This will become possible after expanding the number of monitored indicators and increasing the time period of statistical observation. We consider it promising to build agent-oriented models describing the process of digital technologies adoption by industrial enterprises.

Acknowledgements The research was carried out following the task for the Institute of Economics of the Ural Branch of the Russian Academy of Sciences.

References

1. Gaglio, C., Kraemer-Mbula, E., & Lorenz, E. (2022). The effects of digital transformation on innovation and productivity: Firm-level evidence of South African manufacturing micro and small enterprises. *Technological Forecasting and Social Change, 182*,. https://doi.org/10.1016/j.techfore.2022.121785
2. Rahnama, H., Johansen, K., Larsson, L., & Öhrwall Rönnbäck, A. (2021). Exploring digital innovation in the production process: A suggested framework for automation technology solution providers. *Procedia CIRP., 104*, 803–808. https://doi.org/10.1016/j.procir.2021.11.135
3. Shaheer, N., Kim, K., & Li, S. (2022). sInternationalisation of digital innovations: A rapidly evolving research stream. *Journal of International Management, 28*, 4. https://doi.org/10.1016/j.intman.2022.100970
4. Liu, N., Gu, X., & Lei, C. K. (2022). The equilibrium effects of digital technology on banking, production, and employment. *Finance Research Letters, 49*,. https://doi.org/10.1016/j.frl.2022.103196
5. Nambisan, S. (2002). Designing virtual customer environments for new product development: Toward a theory. *Academy of Management Review, 27*(3), 392–413.
6. Chanias, S., Myers, M. D., & Hess, T. (2019). Digital transformation strategy making in pre-digital organisations: The case of a financial services provider. *The Journal of Strategic Information Systems, 28*(1), 17–33. https://doi.org/10.1016/j.jsis.2018.11.003
7. Tsou, H.-T., Sh., & Hsu, H.-Y. (2015). Performance effects of technology–organisation–environment openness, service co-production, and digital-resource readiness: The case of the IT

industry. *International Journal of Information Management, 35*(1), 1–14. https://doi.org/10.1016/j.ijinfomgt.2014.09.001
8. Matarazzo, M., Penco, L., Profumo, G., & Quaglia, R. (2021). Digital transformation and customer value creation in Made in Italy SMEs: A dynamic capabilities perspective. *Journal of Business Research, 123*, 642–656. https://doi.org/10.1016/j.jbusres.2020.10.033
9. Marcon, E., Le Dain, M.-A., & Frank, A. G. (2022). Designing business models for Industry 4.0 technologies provision: Changes in business dimensions through digital transformation. *Technological Forecasting and Social Change, 185*. https://doi.org/10.1016/j.techfore.2022.122078
10. Arntz, M., Gregory, T., & Zierahn, U. (2016). The risk of automation for jobs in OECD countries. *OECD Social Employment and Migration Working Papers, 189*,. https://doi.org/10.1787/5jlz9h56dvq7-en
11. Chipeva, P., Cruz-Jesus, F., Oliveira, T., & Irani, Z. (2018). Digital divide at individual level: Evidence for Eastern and Western European countries. *Government Information Quarterly, 35*(3), 460–479. https://doi.org/10.1016/j.giq.2018.06.003
12. Lucendo-Monedero, A. L., Ruiz-Rodríguez, F., & González-Relaño, R. (2019). Measuring the digital divide at regional level. A spatial analysis of the inequalities in digital development of households and individuals in Europe. *Telematics and Informatics, 41*, 197–217. https://doi.org/10.1016/j.tele.2019.05.002
13. Novakova, L. (2020). The impact of technology development on the future of the labour market in the Slovak Republic. *Technology in Society, 62*,. https://doi.org/10.1016/j.techsoc.2020.101256
14. Th., Lammers, Rashid, L., Kratzer, J., & Voinov, A. (2022). An analysis of the sustainability goals of digital technology start-ups in Berlin. *Technological Forecasting and Social Change, 185*,. https://doi.org/10.1016/j.techfore.2022.122096
15. Lv, C., Song, J., & Lee, C.-C. (2022). Can digital finance narrow the regional disparities in the quality of economic growth? Evidence from China. *Economic Analysis and Policy, 76*, 502–521. https://doi.org/10.1016/j.eap.2022.08.022
16. Cardona, M., Kretschmer, T., & Strobel, T. (2013). ICT and productivity: Conclusions from the empirical literature. *Information Economics and Policy, 25*(3), 109–125. https://doi.org/10.1016/j.infoecopol.2012.12.002
17. Wang, D., Zhou, T., Lan, F., & Wang, M. (2021). ICT and socio-economic development: Evidence from a spatial panel data analysis in China. *Telecommunications Policy, 45*, 7. https://doi.org/10.1016/j.telpol.2021.102173
18. Zhang L., & Chen, S. (2019). China's Digital Economy: Opportunities and Risks. *IMF Working Paper, 19/16*. International Monetary Fund. https://www.imf.org/en/Publications/WP/Issues/2019/01/17/Chinas-Digital-EconomyOpportunities-and-Risks-46459. Retrieved 29 Nov 2022.
19. Beier, G., Matthess, M., Shuttleworth, L., Guan, T., Iubel, D., Xue, B., Pinheiro de Lima, E., & Chen, L. (2022). Implications of industry 4.0 on industrial employment: A comparative survey from Brazilian, Chinese, and German practitioners. *Technology in Society, 70*. https://doi.org/10.1016/j.techsoc.2022.102028
20. Grybauskas, A. Stefanini, A., & Ghobakhloo, M. (2022). Social sustainability in the age of digitalisation: A systematic literature review on the social implications of Industry 4.0. *Technology in Society, 70*. https://doi.org/10.1016/j.techsoc.2022.101997
21. Ching, N. T., Ghobakhloo, M., Iranmanesh, M., Maroufkhani, P., & Asadi, Sh. (2022). Industry 4.0 applications for sustainable manufacturing: A systematic literature review and a roadmap to sustainable development. *Journal of Cleaner Production, 334*. https://doi.org/10.1016/j.jclepro.2021.130133
22. Satyro, W. C., Villas Bôas, C. M., Pinto, M. J. A., Contador, J. C., Giannetti, B. F., Ferreira, A., & Fragomeni, M. A. (2022). Industry 4.0 implementation: The relevance of sustainability and the potential social impact in a developing country. *Journal of Cleaner Production, 337*. https://doi.org/10.1016/j.jclepro.2022.130456
23. Verma, P., Kumar, V., Daim T., Sharma, N. K., & Mittal, A. (2022). Identifying and sprioritising impediments of industry 4.0 to sustainable digital manufacturing: A mixed method approach. *Journal of Cleaner Production, 356*. https://doi.org/10.1016/j.jclepro.2022.131639

24. Glezman, L. V., Butorin, S. N., & Glavatskiy, V. B. (2020). sDigitalisation of industry as a factor of technological development of the regional spatial and industrial structure. *Voprosy innovatsionnoy ekonomiki, 10*(3), 1555–1570. https://doi.org/10.18334/vinec.10.3.110762
25. Rad, F. F., Oghazi, P., Palmié, M., Chirumalla, K., Pashkevich, N., Patel, P. C., & Sattari, S. (2022). Industry 4.0 and supply chain performance: A systematic literature review of the benefits, challenges, and critical success factors of 11 core technologies. *Industrial Marketing Management, 105*, 268–293. https://doi.org/10.1016/j.indmarman.2022.06.009
26. Braglia, M., Gabbrielli, R., Marrazzini, L., & Padellini, L. (2022). Key performance Indicators and Industry 4.0—A structured approach for monitoring the implementation of digital technologies. *Procedia Computer Science, 200*, 1626–1635. https://doi.org/10.1016/j.procs.2022.01.363
27. Castelo-Branco, I., Cruz-Jesus, F., & Oliveira, T. (2019). Assessing industry 4.0 readiness in manufacturing: Evidence for the European Union. *Computers in Industry, 107*, 22–32. https://doi.org/10.1016/j.compind.2019.01.007
28. Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of Production Economics, 204*, 383–394. https://doi.org/10.1016/j.ijpe.2018.08.019
29. De Giovanni, P., & Cariola, A. (2020). Process innovation through Industry 4.0 technologies, lean practices, and green supply chains. *Research in Transportation Economics*, 100869. https://doi.org/10.1016/j.retrec.2020.100869
30. Lu, Y. (2017). Industry 4.0: A survey on technologies, applications, and open research issues. *Journal of Industrial Information Integration, 6*, 1–10. https://doi.org/10.1016/j.jii.2017.04.005
31. Akberdina, V. V. (2018). The transformation of the Russian industrial complex under digitalisation. *Journal of the Ural State University of Economics, 19*(3), 82–99. https://doi.org/10.29141/2073-1019-2018-19-3-8
32. Battistoni, B., Gitto, S., Murgia, G., & Campisi, D. (2022). Adoption paths of digital transformation in manufacturing SME. *International Journal of Production Economics, 255*,. https://doi.org/10.1016/j.ijpe.2022.108675
33. Lu, H.-P., & Weng, C.-I. (2018). Smart manufacturing technology, market maturity analysis, and technology roadmap in the computer and electronic product manufacturing industry. *Technological Forecasting and Social Change, 133*, 85–94. https://doi.org/10.1016/j.techfore.2018.03.005
34. Niu, Y., Wen, W., Wang, S., & Li, S. (2022). Breaking barriers to innovation: The power of digital transformation. *Finance Research Letters, 51*,. https://doi.org/10.1016/j.frl.2022.103457

Multicollinearity Analysis of DESI Dimensions for Russian Federation and EU28 with Variance Inflation Factor (VIF)

Zoltán Bánhidi, Madina Tokmergenova, and Imre Dobos

Abstract This article is aimed to analyze the statistical features of digital dimensions for Russia and the European Union countries (EU28), investigating the relationships and interdependency between the principal dimensions in our dataset, which is based on the principal dimensions of the I-DESI report, commissioned and published biennially by the European Commission. In order to understand the tenets of digital transformation and to develop a sound strategy to improve digital competitiveness, a robust measurement system is vitally important. An essential requirement for the DESI indicators, specified by the European Commission, is that they should not be statistically redundant. Our hypothesis is that the five DESI dimensions are collinear. In this article, the VIF (Variance Inflation Factor) indicator and multidimensional scaling (MDS) models are used for determining the multicollinearity of DESI dimensions. We also investigate linear regression models to find out whether each of the dimensions could be explained in terms of the others, and whether the estimation of filtered dimensions depends on using the enter or stepwise estimation procedure. We find that two of the five dimensions can be expressed as a linear combination of the remaining three with little loss of information. Our results suggest that the "no redundancy" requirement could not seem to be fulfilled by the five principal dimensions.

Keywords DESI index · Multicollinearity · Variance inflation factor · Multidimensional scaling · Multivariate statistics · European union · Russia

Z. Bánhidi · M. Tokmergenova (✉) · I. Dobos
Budapest University of Technology and Economics, Műegyetem Rkp. 3, 1111 Budapest, Hungary
e-mail: tokmergenova.madina@gtk.bme.hu

Z. Bánhidi
e-mail: banhidi.zoltan@gtk.bme.hu

I. Dobos
e-mail: dobos.imre@gtk.bme.hu

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_6

1 Introduction

Based on a review of 282 scholarly articles and synthesizing the extant definitions he found in them, Gregory Vial defined "digital transformation" as a "process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies" [1]. This definition is sufficiently general to be applicable to firms, industries or even to countries (i.e., to the macro level), which is the level of analysis chosen by our article. Whenever policy makers intend to improve the competitiveness of the national economy effectively and cost-efficiently [2], they need to develop a sound digital transformation strategy that builds on the country's existing strengths and advantages and adequately addresses its weaknesses in terms of the digital "dimensions" or "pillars", for which a robust measurement system is vitally important.

The Digital Economy and Society Index (DESI), which was designed to fulfill this crucial role, comprises a set of indicators and an accompanying set of reports, which are published annually since 2015 by the European Commission to benchmark the digital performance of the European Union and its member states against each other and the targets set by its digital strategies [3]. It is a multidimensional framework that is aimed to track the advancement of digital transformation in the main dimensions of the digital economy and society, which are Connectivity, Human Capital, Use of Internet, and Integration of Digital Technology. The reports also include a number of sub-dimensions and individual indicators [4]. The closely related International Digital Economy and Society Index (I-DESI) is a separate but related report (and set of indicators), which is commissioned and published biennially by the European Commission with the aim of mirroring and extending the results of the DESI for EU countries and selected non-EU countries, including the Russian Federation. The 2018 report on I-DESI was prepared by the independent consulting firm Tech4i2 [5] and is based on 24 individual indicators, which are aggregated into the five main dimensions, which have the same name as the DESI dimensions. For the sake of simplicity, we will henceforth refer to both measurement frameworks simply as "DESI".

The main features, advantages, and disadvantages of DESI were analyzed inter alia by BellResearch and eNet and Bánhidi et al. [6, 7]. In this study, we focus on a particular characteristic that these papers have already touched upon, a high degree of collinearity among the main DESI dimensions. An important requirement posed by the "Methodological note" of DESI is that "the index should not contain indicators that are redundant, either statistically or in terms of interpretation". Our investigation is closely related to the statistical aspects of this requirement, applied to the five main dimensions of DESI, and examined through multivariate statistical methods.

The problem of collinearity often occurs during linear regression. As the textbooks note, this leads to a bad estimation of the parameters, because the inverse of our data matrix, which is needed to estimate the parameters by the least squares method, does not necessarily exist. If this matrix is linearly connected but not singular, the inverse can still lead to high values. For all this, the problem of collinearity needs to be addressed.

In our study, we examine this phenomenon on the example of DESI's five principal dimensions. We approach this problem with two research questions. In the first research question, we examine the interrelatedness and redundancy between the variables through Pearson correlation and then through the VIF values of the five variables. This study reveals collinearity. The other research question focuses on how collinearity can be estimated by entering and stepwise linear regressions. This study may call attention to the fact that collinear, dependent variables can be well estimated with the help of independent variables with a smaller loss of *R*-square. In our case, we can also find out the relationship between the three independent and two dependent variables. This can also shed new light on the partial correlation.

2 Short Literature Review

The paper is focused on analyzing the DESI indices for 28 EU countries and Russia and we first present a short literature review to characterize the digital development in the Russian Federation and some European countries, and then a short overview of some recent papers concerning multicollinearity and VIF.

2.1 Digital Transformation in Russia and Europe

Revinova and Lazanyuk analyzed the development of digital technologies in regions of the Russian Federation [8]. They found that the level of digitalization varies highly in regions; the Northwestern district is the most developed among the federal districts and Moscow and St. Petersburg are the leaders among the subjects. Akberdina argues that the industrial sector plays a crucial role in industrial digitalization, and the degree of digitalization and automation characterizes the level of industrial digitalization development [9]. According to her study, historical factors and high-tech industries are also major factors in digital development and can explain the lack of development in a number of regions within the Russian Federation. Mironova et al. determined that digital education and digital literacy are some of the important factors contributing to the economic and social development of Russia [10]. Tokmergenova et al. state that Russia is closest to a group of "moderately developed" European countries regarding its overall level of digital competitiveness, although its strengths and weaknesses are slightly different [11]. Notably, Russia is strongest in the dimensions of Human Capital and Digital Public Services, but it lags behind its European peers in terms of Connectivity and the Integration of Digital Technology [12]. As for Connectivity, the Russian Federation's unique geography (vast territory with low population density) poses a challenge regarding universal broadband coverage, since rolling out a fast broadband network in the remote, sparsely populated Asian regions is almost certainly financially unviable on a for-profit basis. However, the government has set ambitious aims to overcome the connectivity gap of the country, namely, that 80% of the population should have ultrafast broadband coverage (bandwidths in excess of 100 Mbps) by 2018. However, since the 2018 I-DESI dataset covers a four-year period preceding the announcement of these targets (2013–2016), it cannot reflect the progress made in this area in the subsequent years. As for European countries, Karnitis et al. analyzed the relationship between economic growth and digital performance (as measured by the DESI dimensions) in the Baltic states, concluding that the Digital Public Services and Use of Internet dimensions have a significant influence on the economic development [13]. The correlation is very strong in the given model of digital variables with GDP. Bilozubenko et al. based their research on the cluster method to evaluate the digital development of EU countries [14]. This method of analysis divides countries into different levels and determines specific problems to solve for the countries. Euclidean distance metric and the k-means algorithm were used for cluster analysis.

2.2 Multicollinearity and VIF

Tamura et al. focuses their research on eliminating multicollinearity based on VIF, for this purpose a mixed integer optimization (MIO) method was used, demonstrating its ability to eliminate multicollinearity using a carefully selected subset of explanatory variables [15]. Thompson et al. suggest that the calculation of VIFs is the only way to avoid multicollinearity [16]. The authors indicate that the testing of multicollinearity is a weak side of primary studies, which could be solved and detected by the VIF method. Akinwande et al. identified positive results of the suppression effect that can be applied to multiple regression analysis [17]. The three main advantages of using suppressor variables are the more accurate regression coefficients, more predictive interpretation of the model, and improvement of theory building. Katrutsa and Strijov proposed quadratic programming for feature selection to solve the problem of multicollinearity [18]. The methodology used in the study allows redundancy reduction and provides a stable model. The comparison of this method with other feature selection methods is also presented in this research to access the quality of quadratic programming to avoid multicollinearity. The topic of multicollinearity is addressed in several textbooks [19, 20]. However, research is also very intensive in this area. The former textbooks generally list at least eight methods for detecting multicollinearity. However, scientific articles also list newer methods. Imdadullah et al. presents fourteen methods for recognizing multicollinearity in their article [21]. Other articles also list countless methods and suggestions for treating collinearity [22–25]. The VIF method is very easy to use, so it is often used. However, it has the disadvantage that it cannot be used to identify the specific variables that are linearly related to those with the highest VIF values. Therefore, in our paper, we supplemented the VIF method with a stepwise linear regression procedure.

3 Research Questions and Methodology—Statistical Analysis of DESI Indicators

The original I-DESI dataset, which was compiled from the European Commission's official website, comprises indicators for 45 countries: all EU Member States and 17 non-EU countries, including the Russian Federation [5]. From this dataset, we only used the data for the five principal dimensions in the 28 EU countries plus Russia, obtaining a dataset with 29 countries. The same dataset was used in an earlier paper [11].

We have formulated two research questions (RQ) to analyze the problem of multicollinearity, which we had introduced; one of them related to the problem of linear independence of dimensions (RQ1), and another assigned to the problem of estimation of dimensions with other ones. (RQ2).

RQ1: To what extent are the dimensions of DESI linearly related (correlated)? Based on their relationships, can the number of dimensions be reduced without any information loss?

RQ2: How can the digital dimensions filtered with multicollinearity be estimated? To what extent does the estimation of filtered dimensions depend on whether we use the enter or stepwise estimation procedure in SPSS?

Answering the two research questions will clarify the relationship between the digital dimensions. The first question aims to reduce the number of variables, in our case dimensions. The filtered variables have some linear relationship with the remaining dimensions, but the VIF procedure does not explain which variables and what linear relationship there is. In the second research question, we research the estimation of the filtered variables as outcome variables as a function of the independent, i.e., explanatory variables. It is also an interesting question—which of the two linear regression estimation methods, i.e., enter and stepwise, gives more acceptable information?

4 Results

4.1 RQ1: Investigation of Multicollinearity with VIF

The correlation coefficients between the five digital dimensions are all positive and significant at the 1% level, except the correlation between Connectivity and Digital Public Services, which is significant at the 5% level. Nevertheless, the moderate to strong correlations suggest that our dataset comprising the five principal dimensions could be determined by a high level of multicollinearity, and hence indicate that some of these dimensions could be redundant in the DESI model. Table 1 presents the correlation matrix along with the abbreviations that are hereinafter used to denote them.

Table 1 Correlation matrix between the DESI dimensions

Pearson correlation (sig. 2-tailed)	Human Capital (*HC*)	Use of Internet (*UI*)	Integration of Digital Technology (*IT*)	Digital Public Services (*PS*)
Connectivity (*CN*)	0.492** (0.007)	0.773** (0.000)	0.699** (0.000)	0.454* (0.013)
Human Capital (*HC*)		0.753** (0.000)	0.665** (0.000)	0.501** (0.006)
Use of Internet (*UI*)			0.826** (0.000)	0.594** (0.001)
Integration of Digital Technology (*IT*)				0.681** (0.000)

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)
Source Own compilation based on data compiled from the I-DESI report [5]

There is no general rule in the literature regarding the right VIF threshold for collinearity. Even though some possible thresholds ranging from 2.5 to 10 have been tested empirically in earlier studies, there is not any set of theoretical or logical rules for redundancy filtering that can be reliably determined. Therefore, we made a decision in this regard, based on the recommendations in the literature [26, 27], choosing five as our threshold value.

Table 2 shows the sequential filtering of the variables.

We would note that although there is no deterministic algorithm for filtering out collinear variables, which could have meant that there is some ambiguity regarding the first variable to be omitted from the model (as any variable above the threshold is appropriate to take the first step), only one VIF value was above the selected threshold (Use of Internet with a value of 5.728).

All VIF values of the remaining variables were less than 5, that is, below the threshold value so no variable could be included in the collinear variables to be eliminated due to the stepwise decrease of the VIF value.

Table 2 VIF values during algorithm execution

Variables	Step 0	Step 1
CN	2.730	1.966
HC	2.488	1.813
UI	5.728	
IT	4.041	3.478
PS	1.896	1.885

Source Own compilation based on the database compiled from I-DESI [5]

Another method was applied to test the model of collinear variables obtained by omitting the dimension with the greatest VIF value (Use of the Internet). This was done using multidimensional scaling. The method assumes that our variables are vectors in the space of countries. We form the distances between the variables in this space and try to map the variables in a lower dimensional space. In short, the scaling model also maps vectors to a lower dimensional space. For visualization, two-dimensional space, i.e., the plane, usually is the appropriate one. The goodness of mapping to a lower space is measured by a stress function and the linear relationship between the distances between the two spaces is measured by the R-squared. Thus, in our studies, we want to map the five digital dimensions from a 29-dimensional space into a two-dimensional space. The distance measure, or metric in our case, is the Euclidean distance. However, the variables were normalized with a function before which the distances were calculated, with the expected value of the new variables being zero and the standard deviation being one. This normalization is also called the z score. Our result is shown in Fig. 1.

This map perfectly depicts the 29-dimensional space on the plane, as the stress value is 0.000, and the R-squared is just one (that shows a perfect fit). The map shows that the Human Capital, Connectivity, and Digital Public Services digital dimensions are located at the edges of the map, away from the other two dimensions. At the center of the map is the Integration of Digital Technology (Business Technology) and Use of Internet dimensions, very close to each other. This visual result also confirms that these two digital dimensions are highly correlated with each other. Since the Use of Internet digital dimension shows a lower correlation with the three digital dimensions, omitting it now gives an image whose dimensions are far apart. Thus, this also supports our result with VIFs. This means that the dimension Use of Internet

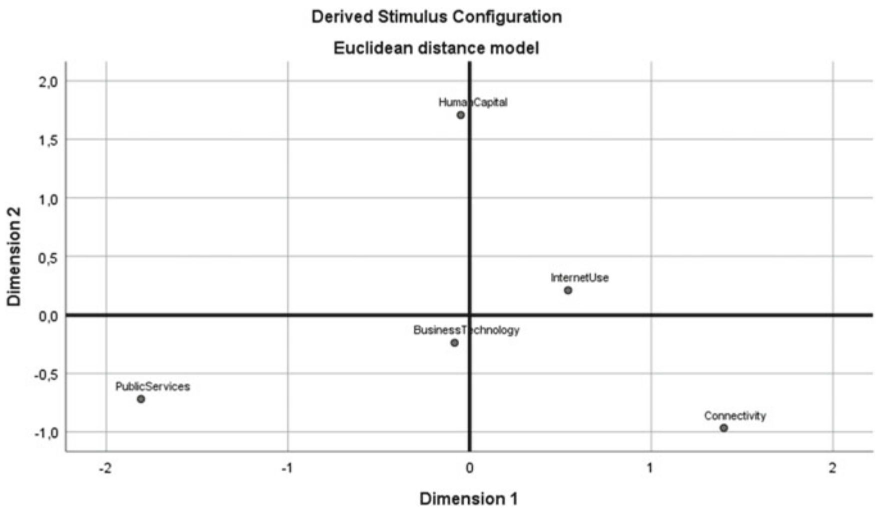

Fig. 1 Location of variables on the plane of digital dimensions. *Source* Own compilation based on the database compiled from I-DESI [5]

(UI) has a linear dependence on the other variables. The result obtained shows that one of the five digital dimensions can be defined as some linear combination of the remaining four. The following research question explores this linear combination using linear regression.

4.2 RQ2: Linear Regressions of Collinear Dimensions

First, the two filtered collinear digital dimensions are estimated using the two algorithms of SPSS 26, i.e., enter and stepwise. The enter algorithm largely gives an R^2, but the error of the parameters is larger, which can also lead to some variables being filtered out by the stepwise algorithm.

The filtered collinear variable *UI* (Use of Internet) is now estimated with the remaining four variables compiled from the I-DESI database [5], using enter and stepwise algorithms. The linear equation of the estimate is with enter algorithm as follows:

$$\begin{aligned} UI = &- 0.071 + 0.491 \cdot CN + 0.361 \cdot HC + 0.255 \cdot IT + 0.034 \cdot PS + \varepsilon_{UI} \\ &(0.415) \quad (0.005) \quad (0.006) \quad (0.060) \quad (0.718) \end{aligned} \tag{1}$$

After estimating the Use of Internet with the remaining four variables, R^2 became 0.825, which is a very high value. However, this is a natural consequence of the high VIF value. The residual value of linear regression is $\varepsilon_{UI.}$

The equation shows how an increase in Connectivity, Human Capital, Integration of Digital Technology, and Digital Public Services is reflected in the Use of Internet. Equation (1) draws attention to the point that the explanatory variables are logically positive. The estimation of parameters *CN*, *HC*, and *IT* are significant at the level of 6.0%, which supports the explanatory power of the model.

The stepwise regression of this model is given below

$$\begin{aligned} UI = &- 0.062 + 0.448 \cdot CN + 0.365 \cdot HC + 0.365 \cdot IT + \varepsilon_{UI} \\ &(0.449) \quad (0.005) \quad (0.005) \quad (0.020) \end{aligned} \tag{2}$$

The R^2 became 0.824 which is less than with the enter algorithm. The Public Services digital dimension was filtered out by this procedure because the parameter was not significant enough.

The stepwise estimations of all other dimensions with the variables resulted in the next models. We first show the relationship of the four non-collinear variables to the other four dimensions shown in Eqs. (3)–(6). We present this because the three dimensions depend only on collinear variables. This means that two groups of dimensions can be clearly separated. The *R*-squares are shown in Table 3.

$$CN = 0.279 + 0.575 \cdot UI + \varepsilon_{CN}$$

Table 3 Comparison of enter and stepwise linear regressions with R-squares

Variables	*Enter* R^2	*Stepwise* R^2
CN	*0.634*	*0.597*
HC	*0.598*	*0.567*
UI	*0.825*	*0.824*
IT	*0.753*	*0.739*
PS	*0.473*	*0.464*

Source Own compilation based on the database compiled from I-DESI [5]

$$(0.000)\,(0.000) \tag{3}$$

$$\begin{aligned} HC =& 0.156 + 0.717 \cdot UI + \varepsilon_{HC} \\ & (0.041) \quad (0.000) \end{aligned} \tag{4}$$

$$\begin{aligned} IT =& -0.148 + 0.800 \cdot UI + 0.284 \cdot PS + \varepsilon_{IT} \\ & (0.066) \quad (0.000) \quad (0.026) \end{aligned} \tag{5}$$

$$\begin{aligned} PS =& 0.273 + 0.706 \cdot IT + \varepsilon_{PS} \\ & (0.001) \quad (0.000) \end{aligned} \tag{6}$$

Each of the parameters is significant. The stepwise linear regression of the collinear variable is illustrated in Eq. (2).

However, the estimates of Eqs. (3)–(6) calculated by the enter algorithm are not presented, but their *R*-squares are compared with those obtained by stepwise linear regression. As can be seen, the *R*-squared values of the stepwise regression are lower because variables with non-significant parameters were filtered out. However, the new *R*-squares do not show a drastic decrease in our case. Table 3 presents the estimated *R*-squares of the variables.

Stepwise linear regression can be a good complement to the VIF method if the collinear variables are estimated with this regression. This sheds light on the linear interdependence between the variables, in our case, the dimensions.

5 Discussion

Our first research question on the presence of multicollinearity could be answered in the affirmative, as there was a strong linear relationship between some variables. However, the exploration of multicollinearity also provides an opportunity to eliminate variables that are highly correlated with individual variables or groups of variables.

Multicollinearity analysis was performed using three different methods, which are the traditional correlation analysis, followed by variance inflation factor, and finally multivariate scaling.

All three analyses showed that the digital dimension of Use of Internet is some stochastic function of the other four dimensions, and therefore, can be eliminated from the analyses. This result was corroborated by some of our earlier findings on the (EU-only) DESI [28], and also supported by the recent DESI publications of the European Commission, as the 2022 study only used the remaining four dimensions.

The filtered collinear variable was estimated using two regression estimation methods. In the SPSS 26 software package, the two estimation methods are named enter and stepwise. These two methods were used for estimation. Both procedures yielded strong R-square values for the Use of Internet dimension, which in addition were close to each other, so we obtained a valuable estimate. This gave the linear function that can be used to recover the omitted dimension.

The digital dimensions retained in the study were then estimated with the others, first using the stepwise and then the enter regression estimation method. This procedure resulted in dimensions that depended on the omitted collinear variable. Finally, we also performed an analysis using the enter method, and the two procedures to compare the R-squares of the two results. Again, the results were similar.

The latter analysis pointed out that the dependent variable excluded by the former method can be well expressed by linear regression.

6 Conclusions

Our results suggest that the requirement posed by the European Commission that variables included in DESI "should not be redundant … statistically" might be violated by the five principal dimensions of the dataset. Some of these dimensions are strongly correlated with the others, and the VIF values indicate that the Use of Internet and the Integration of Digital Technology may be expressed as a linear combination of the remaining three dimensions with little loss of information. In fact, the stepwise linear regression method reveals that the combination of just two of these dimensions (Connectivity and Human Capital) already reflects a large proportion of the information contained within the Use of Internet dimension. This finding is in accordance with the European Commission's observation that the five dimensions are "not isolated areas that contribute separately to digital development but are in fact interconnected" and their line of argument for DESI's weighting system. The Commission attributes a higher weight to Human Capital and Connectivity, which they consider the most important dimensions, representing "the infrastructure of the digital economy and society", and the Use of Internet is given a lower weight, since it is "enabled by the infrastructure and [its] contribution is strengthened by the quality of such infrastructure". However, we are of the opinion that if the "no statistical redundancy" requirement is taken seriously by the European Commission, the structure of the DESI and/or the number of principal dimensions might also need to be reconsidered.

References

1. Vial, G. (2021). Understanding digital transformation: A review and a research agenda. *Managing Digital Transformation*, 13–66.
2. 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. https://doi.org/10.1371/journal.pone.0257365.
3. European Commission. (2020). *Digital Economy and Society Index (DESI).* European Commission. Retrieved from https://ec.europa.eu/digital-single-market/en/desi.
4. European Commission. (2020). *Digital Economy and Society Index (DESI) 2020 Methodological note*. European Commission. Retrieved from http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=67082.
5. European Commission. (2018). *International Digital Economy and Society Index 2018*. Publications Office of the European Union, Luxembourg, Rep. SMART 2017/0052. Retrieved from https://ec.europa.eu/digital-single-market/en/news/international-digital-economy-and-society-index-2018.
6. Bánhidi, Z., Dobos, I., & Nemeslaki, A. (2019). Comparative analysis of the development of the digital economy in Russia and EU measured with DEA and using dimensions of DESI. *Vestnik Saint-Petersburg University. Economics, 35*(4). 588–604. https://doi.org/10.21638/spbu05.2019.405.
7. BellResearch & eNet. (2018). *A digitális ökoszisztéma mérőszámainak pontosítására – kutatási összefoglaló* (Improving the Measurement of the Digital Ecosystem – research summary). Kormányzati Informatikai Fejlesztési Ügynökség. Budapest, Hungary (in Hungarian).
8. Revinova, S., & Lazanyuk, I. (2018). Prerequisites for development of the digital economy in Russia: Differentiation of regions. *International Journal of Business and Management Studies (IJBMS), 7*(2), 607–618.
9. Akberdina, V. V. (2018). Digitalization of industrial markets: Regional characteristics. *Upravlenets – The Manager, 9*(6), 78–87.
10. Mironova, O. A., Bogdanova, R. M., & Kolesnikov, Y. A. (2019). Aspects of the generational theory application in terms of digital education development in Russia. *Medioobrazovanie, 1*, 93–104.
11. Tokmergenova, M., Bánhidi, Z., & Dobos, I. (2021). Analysis of I-DESI dimensions of the digital economy development of Russian federation and EU-28 using multivariate statistics. *Vestnik Saint-Petersburg University. Economics, 37*(2), 189–204. https://doi.org/10.21638/spbu05.2021.201.
12. Bánhidi, Z., Dobos, I., & Tokmergenova, M. (2021). Russia's place Vis-à-Vis the EU28 countries in digital development: A ranking using DEA-type composite indicators and the TOPSIS method. In *Digitalization, Digital Transformation and Sustainability in the Global Economy* (pp. 135–146). Springer, Cham. https://doi.org/10.1007/978-3-030-77340-3_11.
13. Karnitis, G., Virtmanis, A., & Karnitis, E. (2019). Key drivers of digitalization; EU context and Baltic case. *Baltic Journal Modern Computing, 7*(1), 70–85. https://doi.org/10.22364/bjmc.2019.7.1.06.
14. Bilozubenko, V., Yatchuk, O., Wolanin, E., & Korneyev, M. (2020). Comparison of the digital economy development parameters in the EU countries in the context of bridging the digital divide. *Problems and Perspectives in Management, 18*(2), 206–218. https://doi.org/10.21511/ppm.18(2).2020.18.

15. Tamura, R., Kobayashi, K., Takano, Y., et al. (2019). Mixed integer quadratic optimization formulations for eliminating multicollinearity based on variance inflation factor. *Journal of Global Optimization, 73*, 431–446. https://doi.org/10.1007/s10898-018-0713-3.
16. Thompson, C. G., Kim, R. S., Aloe, A. M., & Becker, B. J. (2017). Extracting the variance inflation factor and other multicollinearity diagnostics from typical regression results. *Basic and Applied Social Psychology, 39*(2), 81–90. https://doi.org/10.1080/01973533.2016.1277529.
17. Akinwande, M. O., Dikko, H. G., & Samson, A. (2015). Variance inflation factor: As a condition for the inclusion of suppressor variable (s) in regression analysis. *Open Journal of Statistics, 5*(7), 754–767. https://doi.org/10.4236/ojs.2015.57075.
18. Katrutsa, A., & Strijov, V. (2017). Comprehensive study of feature selection methods to solve multicollinearity problem according to evaluation criteria. *Expert Systems with Applications, 76*, 1–11. https://doi.org/10.1016/j.eswa.2017.01.048.
19. Gujarati, D. (2004). *Basic econometrics fourth* (4th ed.). MacGraw Hill Inc.
20. Rao, C. R., Toutenburg, H., Shalabh, H. C., & Schomaker, M. (2008). *Linear models and generalizations: Least squares and alternatives* (3rd ed.). Springer.
21. Imdadullah, M., Aslam, M., & Altaf, S. (2016). An R package for detection of collinearity among regressors. *R Journal, 8*(2), 495–505. https://doi.org/10.32614/rj-2016-062.
22. Dormann, C. F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., ... Münkemüller, T. (2013). Collinearity: A review of methods to deal with it and a simulation study evaluating their performance. *Ecography, 36*(1), 27–46.https://doi.org/10.1111/j.1600-0587.2012.07348.x.
23. Kim, J. H. (2019). Multicollinearity and misleading statistical results. *Korean Journal of Anesthesiology, 72*(6), 558–569. https://doi.org/10.4097/kja.19087.
24. Lafi, S., & Kaneene, J. (1992). An explanation of the use of principal-components analysis to detect and correct for multicollinearity. *Preventive Veterinary Medicine, 13*(4), 261–275. https://doi.org/10.1016/0167-5877(92)90041-D.
25. Liao, D., & Valliant, R. (2012). Variance inflation factors in the analysis of complex survey data. *Survey Methodology, 38*(1), 53–62.
26. Shrestha, N. (2020). Detecting multicollinearity in regression analysis. *American Journal of Applied Mathematics and Statistics*, *8*(2), 39–42. https://doi.org/10.12691/ajams-8-2-1.
27. Vörösmarty, G., & Dobos, I. (2020). Green purchasing frameworks considering firm size: A multicollinearity analysis using variance inflation factor. *Supply Chain Forum: An International Journal, 21*(4), 290–301. https://doi.org/10.1080/16258312.2020.1776090.
28. Bánhidi, Z., Dobos, I., & Nemeslaki, A. (2020). What the overall digital economy and society index reveals: A statistical analysis of the DESI EU28 dimensions. *Regional Statistics, 10*(2), 42–62. https://doi.org/10.15196/RS100209.

Potential for Using Methodological Tools Digitalization of the Economy of Russian Regions in the Practice of China

Gao Jixiang, Anna Urasova, and Evgeniy Shcheglov

Abstract In modern science, a high profile is given to the processes of digitalization and approaches to digital transformation aimed at identifying homogeneous groups of territories according to sectoral specifics, making it possible to take into account the nature and patterns of socio-economic changes in similar regions to further make appropriate practical decisions. The paper discusses the issue of the potential use of Russian methodological tools in the practice of Chinese academic analysis based on the logic of building a digital transformation in Russia, during which the sphere of interaction with friendly countries is formed from the position of progressiveness of some or other direction of economic development. Based on logical and structural analysis, the paper identifies priority areas for academic and technological interaction between Russia and China in the context of the scientific and methodological understanding of digital transformation processes. As a result of this task, the specifics of the methodological tools for assessing digitalization processes that are available in Russian and Chinese studies are identified; an analysis of the general methodological guidelines in assessing the digitalization of economic processes that prevail in Russian and Chinese scientific practice is carried out. Thus, the methodological possibilities of assessing the level of digitalization of territories are disclosed, which can be used in the academic practice of Chinese researchers, thereby expanding the areas of Russian-Chinese interaction in digitalization.

Keywords Digital transformation · Information space · Technological development · Regional economy · International cooperation · Digital economy

G. Jixiang
Institute of Russia, Eastern Europe and Central Asia, Chinese Academy of Social Sciences, 3 Dong Cheng District, Zhang Ji Zhong Lu St., Peking 100007, China
e-mail: gao010@163.com

A. Urasova (✉) · E. Shcheglov
Institute of Economics of The Ural Branch of The Russian Academy of Sciences, 50, Lenina Street, 620014 Perm, Russian Federation
e-mail: urasova.aa@uiec.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_7

1 Introduction

The formation of a digital economy is a matter of national security and independence of Russia, the competitiveness of domestic companies, and the country's position on the world stage in the long term, in fact, for decades to come [2]. The key setting in the implementation of digital policy in Russia is the formation of a certain way of life, a new basis for the development of the public administration system, economy, business, social sphere, and the entire society.

In the context of the program documents "Digital Economy of the Russian Federation" and "National Strategy for the Development of Artificial Intelligence of the Russian Federation until 2030," one can talk about a systematic and continuous process of digitalization in the Russian Federation. Based on this, the issue of setting priorities via interaction with participants and leaders of digitalization around the world is on the agenda.

One of these priorities may be bilateral interaction with China in the direction of scientific and theoretical understanding of ongoing processes and the development of new tools for assessing digital processes in the economy and methods for increasing cross-country cooperation. In recent years, China has been considered in scientific discourse as one of the digital leaders.

Taking into account the development of the theoretical and methodological foundations of the theory of the world economy, within the framework of this study, the goal is set: to reveal the methodological potential for assessing the level of digitalization of territories that can be used in the academic practice of researchers in the PRC. As tasks, the following are formulated: to identify the specifics of the methodological tools for evaluating digitalization processes that are available in Russian and Chinese research; to compare general methodological guidelines in assessing the digitalization of economic processes prevailing in Russian and Chinese academic practice; to propose a methodology for assessing the digitalization of Russian regions, which can and should be adapted to the practice of the PRC by implementing it in connection with Chinese provinces.

2 Literature Review

The solution to the issue of choosing tools for analyzing modern economic processes in the context of digital changes is based on a set of methods for quantifying indicators and criteria for technological conditions.

The authors consider it expedient, studying the context of the stated topic, to analyze the key studies in this area, which stand out within the framework of Russian and Chinese academic discourse. Thus, in separate studies by Russian scholars, the problems of assessing the technological potential of a region are analyzed in detail from the position of searching for options for using production assets and applying technological initiatives for particular industries [1, 18]. At the same time, attention is focused on the level of technological development of enterprises [14]. In particular, the sectoral clustering of enterprises and a typology of Russian regions are also carried out according to sectoral characteristics. A number of studies are devoted to assessing the development of individual clusters in terms of the level of interconnectedness of enterprises and organizations participating in the cluster.

The issues of interaction within the framework of the technological development of industries and complexes from the standpoint of their quantitative assessment were considered in the works of a number of researchers. So, Sukharev, Voronchikhina, Samonova, Shevchenko [13, 16], and others focused on the resulting indicators that depend on the goals of the assessment. In addition, a significant place in their study was given to calculations of social and environmental effects. Methods of this kind have a high level of universality from the point of view of the levels of the economy, that is, they can be applied at the micro-level (the level of individual enterprises) and at the meso level (for example, individual regions).

In Belyakov and Shpak [3], an assessment is made of the development of individual sectors of the economy of Russian regions. Such assessments can also be found in the publication by Shelegeda et al. [15], who focus on the technological side of the issue. What makes their study special is the evaluation technique, which combines, along with economic and mathematical methods, the methods of fuzzy set theory and interpolation methods. However, the selected toolkit does not go beyond the boundaries of a single enterprise. The authors would like to emphasize that this kind of methodology has an advantage associated with taking into account the uncertainty factors in technological development, which allows calculations to be made without being limited to the transient nature of the analyzed processes [5]. Thus, the obvious disadvantage of this approach can be called the complexity of delimiting uncertain processes from other realities and the rationale for such a separation. In addition, borderline trends appear, which have a number of mixed features, which increases the number of errors in the built models [6, 7].

An increasing number of papers propose to use the graph theory. In this context, any optimization processes entail the process of data linearization, that is, the application of systems of linear equations that clearly simplify the entire complexity of socio-economic processes. So, Goykher et al. [5] analyzed the innovativeness of sectors in this way through the prism of their interconnectedness.

Separately, the methods used by researchers in China should be noted, namely the papers that assess the level of China's digital economy using the entropy approach and calculate the growth of the overall productivity of green factors in China's manufacturing using the Luenberger-Hicks-Moorsteen indicator and taking into account side production [11]. The results show that China's digital economy is growing steadily [4, 8, 10].

In addition, of interest is the study in which, based on panel data from the provinces of China from 2014 to 2020, the impact of the development of the digital economy on employment in China is empirically analyzed [22]. The results show that the digital economy has significantly affected the employment structure in China. With the development of digital technologies, the workforce has become more production-oriented, high-tech, and highly skilled. The paper states that further testing of the mechanism shows that the modernization of the sectoral structure and human capital reserve has a somewhat positive impact on the employment structure in the development of the digital economy [22].

In addition, let us designate a study that used a pooled regression to examine the impact of an innovative digital economy on total factor productivity in China based on data that includes the provincial index calculated using a dual approach and the digital economy index proposed by principal component analysis [12].

Thus, the existing methods include several groups using data blocks: (1) classical econometric methods based on regularly observed statistical data [10, 13]. However, in most cases, the studies present data at the national level, without detailing by regions and individual territories, complexes, and enterprises; (2) modified methods that combine several methods of analysis, which are based, in addition to official statistics, on freely distributed data (expert and sociological surveys, the results of a semantic analysis of Internet content, etc.) [6, 7]. Their advantages include the possibility of studying phenomena and processes that have not yet developed in the scientific and practical sense, having a sufficient number of manifestations and trends.

Summarizing the review, it is necessary to note the virtual absence of studies which would offer ready-made tools for analyzing and diagnosing relevant technological factors and conditions, searching and analyzing digital data, and visualizing them in the context of the digital transformation of individual countries and regions [11, 20, 21, 23]. Most of the methodological developments are based on the micro-level and use the data of individual enterprises as a basis, a priori having a number of industry-specific features [24, 26]. Thus, it is advisable to adapt only a limited range of methods to a wide range of technological areas and levels of system development (national, regional, and territorial) [25]. This requires a search for such tools and potential developers, etc., [17] not only within a country but also in the foreign cooperation format.

Accordingly, in the context of such cooperation, the issue of how to identify the conditions for digital transformation at the present stage, including its elements, and to find common ground for cross-country cooperation comes to the fore.

3 Materials and Methods

In order to expand Russian-Chinese interaction in the academic and methodological field, the paper proposes the results of testing a methodology for assessing the level of digitalization of the regions of the Russian Federation, considered appropriate to adapt to the practice of the PRC. The data used in the study were compiled by regional sources, the sample of which was obtained using a multilevel rubricator of indicators. Based on the hierarchical structure of the rubricator, several options for data sampling were chosen: (1) a tabular method with a manual layout; (2) a passport method with an automated collecting data layout. Such a combination of data compilation methods made it possible to account for sectoral and territorial data, on the one hand, and meso and micro-level data (regional indicators and data on enterprises), on the other hand, which are presented here.

As a result, data were selected for the largest innovative enterprises by regions of the Russian Federation for 2018–2021. For data processing, methods of coefficient and statistical analysis were chosen, making it possible to assess the homogeneity of the processes of digitalization in the regions of the Russian Federation.

The following formula was used to calculate the transformation coefficient of sectors of the industry of a constituent entity of the Russian Federation [19]:

$$k_{\mathrm{tr}m(S)} = \frac{\left|\int_{j}^{i} \mu(x)dx\right|}{k_{(\mathrm{order})}}, \tag{1}$$

where $k_{\mathrm{tr}m\,(S)}$—coefficient of digital transformation of the industry m of a constituent entity of the Russian Federation (S); $\mu(x)$—a function that describes the current dynamics of changes in industry m for the period under study; i, j—limits of the integrable function as the boundaries of the dynamics of change in the industry m of the region S for the period under study; $k_{(\mathrm{order})}$—the coefficient of high productivity of the industry m; m—the number of analyzed sectors of the region's industry; S—a particular Russian region.

The data obtained as a result of the study can be used by municipal and regional authorities in the course of creating an industrial policy.

4 Results

While assessing the level of digitalization of the Russian regions, this study managed to diagnose a number of areas that are difficult to parameterize and include in some or other stage of the assessment. Accordingly, these are some limitations that cannot be taken into account in relation to both Russian and Chinese practice.

First, information security and sovereign information space come to the fore. It is not possible to quantify security processes in the present conditions of digitalization.

Second, this is the priority promotion of digitalization in state institutions and state enterprises. On the one hand, the national governance system stimulates the development and implementation of end-to-end digital technologies by signing bilateral agreements with enterprises. On the other hand, digitalization is promoted by regional and municipal executive authorities and state enterprises. Both trends are not regularly observed by the statistics. Thus, one can talk about an imbalance in the process of digitalization of the economy in the regions of the Russian Federation in favor of entities interconnected with state authorities.

Third, it is necessary to say about the obstacles in the way of the deployment of 5G and other infrastructure of the digital economy. According to the Ministry of Digital Development, Communications and Mass Media of the Russian Federation, the transmission of frequencies for 5G began only in 2021, and it is still difficult to talk about the results.

Fourth, it is the active implementation of import substitution in the development of Russian-made technological solutions, which lies beyond regular statistical monitoring.

Fifth, enhancing the system of education and training in the field of digital technologies. In particular, training in digital competencies has been added to the higher education system, and the number of IT-related specialties has been expanded to more than 20. It is also very difficult to assess these qualitative changes at this stage of the study.

Sixth, support for the IT industry. In the first half of 2022, IT companies' revenue grew by 60%. The Russian government provided the IT industry with unprecedented support: grants for 750 million rubles were provided to IT startups, Russian software manufacturers were exempted from VAT, and social insurance rates for IT specialists were reduced from 14% to 7.6%. The effectiveness of the introduced measures can be assessed after the next period of strategic planning.

Thus, a number of areas of development of the Russian economy that have arisen in the context of digitalization turn out to be, due to the initial stage of their life cycle, devoid of any regularly observed metrics, and, accordingly, cannot be included in the analysis.

Let us move on to the results of the assessment of digitalization in the regions of the Russian Federation by industries.

The digitalization of the Russian industry was quantified using the digital transformation coefficient [18] (formula 1). The results are shown in Fig. 1.

In general, as a result of regional comparisons of results, one can conclude the following:

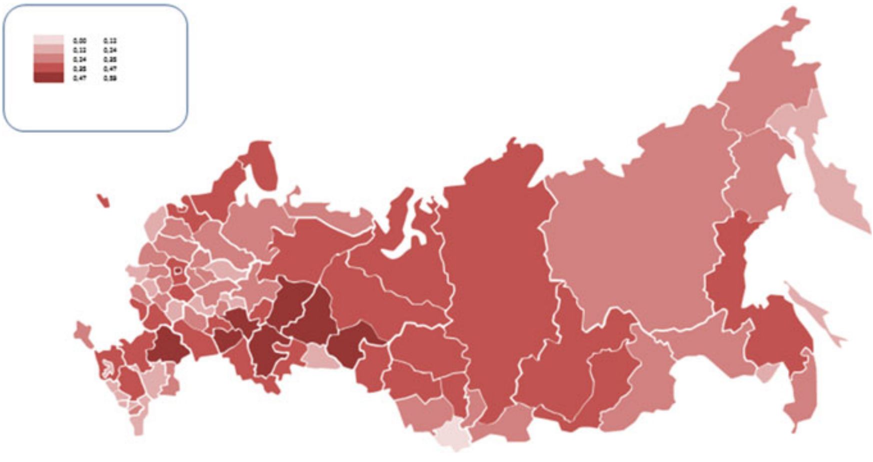

Fig. 1 The level of digitalization of the regions of the Russian Federation in 2021 (calculated according to Rosstat). *Source* Compiled according to Rosstat, https://rosstat.gov.ru/

– the value of the digital transformation coefficient in the regions of the Russian Federation ranges from 0.11 to 0.61, which indicates a high heterogeneity of digitalization processes;
– the absence of high digitalization indicators indicates the high potential of technology in the regions of the Russian Federation.

The principles of administrative-territorial organization in China are very similar to those in Russia. The Chinese provinces are also extremely heterogeneous in terms of the level of development; they have different resource opportunities, geographic and socio-economic parameters. As a result, in terms of territorial management and evaluation of digitalization, Chinese management structures are faced with the problem of finding the most adaptive methods and techniques for analysis and diagnostics. From this point of view, taking into account the bilateral desire for scientific and technological development, outlining the advantages of the proposed methodological tools: the methodology is based on regularly observed statistical data (a similar database has been created and is functioning in China); a combination of quantitative and qualitative data (binary assessment of individual digitalization trends); the underlying indicators of the level of digitalization in a region reflect the overall picture of changing technological conditions. As a result, the proposed assessment methodology can be used as an independent analytical tool; given the large number of differences in the development of regions, a flexible approach is used in calculating the coefficients of digital transformation, which determines the limits of integrable functions based on the quantitative metrics of a particular region; the technique makes it possible to use a different number of indicators, increasing or reducing the total number of metrics, thereby not limiting the researcher to constant indicators.

Actively developing around the world, the factors and conditions for the digital transformation of the economy in modern technological realities form a number of expectations for a positive forecasted future for each country, and for enterprises to acquire significant competitive advantages in the long term, despite the ongoing processes of reducing jobs, strengthening inter-territorial differentiation, etc. In Russia, a number of regions, within the framework of strategic planning documents, have provided for a set of measures aimed at adapting to new digital realities. In particular, these events are aimed at enterprises and organizations that are capable of implementing end-to-end: digital twin technologies, artificial intelligence systems, big data collection, and analysis, etc. [16, 18]. Meantime, a number of regions can be called lagging behind, requiring additional investments, and building up digital competencies. In turn, in China, a similar trend is observed, the provinces have different approaches to the issue of adapting to digitalization trends, and the more relevant the issue of finding and implementing analytical tools becomes. Thus, as an option for applying methodological developments for assessing the level of digitalization of the economy of Russian regions in the practice of the PRC, this proposed methodology for assessing the level of digitalization of the regions of the Russian Federation is used.

5 Conclusion

The methodological cooperation opportunities between the Russian Federation and China in digitalization outlined in this paper allow for continuing the dialogue seeking to adapt a methodology for assessing the digitalization of Russian regions to the practice of the PRC, shifting it to the Chinese provinces.

Thus, from the standpoint of expanding Chinese-Russian cooperation in the direction of scientific and technological interaction in digital transformation, several provisions can be identified.

First, in the scientific discourse of both Russia and China, there is no unambiguous correct universal methodology for assessing the economic processes of digitalization.

Second, the total nature and high speed of digital transformations require from the management system of each country adaptive tools for diagnosing and evaluating digital phenomena, taking into account the diversity of administrative and territorial features. It should be taken into account that China's digital economy is actively developing, but the problem of lagging behind in building management systems and national standardization systems has become noticeable. Russia's experience in building management rules and methodological standards in advance, instead of looking for solutions when problems arise, is very important for China. China has its own uniqueness in stimulating the viability of enterprises and local governments to develop the digital economy.

Third, the similarity of the principles of the administrative-territorial organization of Russia and China increases the possibility of adapting Russian methodological developments to assess digital phenomena and processes, forming a system of interaction and a common digital space.

Acknowledgements The work was performed in accordance with the Research Plan of the Institute of Economics of the Ural Branch of the Russian Academy of Sciences.

References

1. Afanasyev, M. V. (2020). Process development of the industry as part of industrial policy in a competitive environment: Mechanisms and assessment tools. *Vestnik Tehnomac, 3*(12), 47–56.
2. Arkhipova, L. I. (2021). IT in digital business development. *Big Data and Advanced Analytics, 7*(2), 125–133.
3. Belyakov, S. A., & Shpak, A. S. (2014). Assessment of researches and technological development of the regions of the Siberian federal district. *Fundamental Research, 6*(2), 293–297.
4. Deng, H., Bai, G., Shen, Z., & Xia, L. (2022). Digital economy and its spatial effect on green productivity gains in manufacturing: Evidence from China. *Journal of Cleaner Production, 378*, 134539. https://doi.org/10.1016/j.jclepro.2022.134539.
5. Goykher, O. L., Skuba, R. V., Bugrova, O. S., Strelkov, V. E., & Kudryakov, R. I. (2019). Analysis methodology of innovative development in regional industrial segment by graph theory. In E. G. Popkova (Ed.), *The future of the global financial system: Downfall or harmony* (pp. 1145–1154). Springer. https://doi.org/10.1007/978-3-030-00102-5_121.

6. Karminsky, A., & Voytov, N. (2022). Platform ecosystems and its modelling: Russian evidence. *Procedia Computer Science, 199*, 572–579. https://doi.org/10.1016/j.procs.2022.01.070.
7. Likhacheva, T. P., Ryzhkova, O. V., & Ulas, Yu. V. (2017). Methodology for evaluating the potential of region technological development for "stretching" production chains of advanced technologies and designing their protection in the region. *Azimuth of Scientific Research: Economics and Administration, 6* 4(21), 230–236.
8. Lyandau, Yu. V., & Nikulin, L. F. (2016). *Sixth technological wave: Paradigm development of management. Monograph.*. Paleotip. (102 p.).
9. Ma, S., Ding, W., Liu, Y., Ren, S., & Yang, H. (2022). Digital twin and big data-driven sustainable smart manufacturing based on information management systems for energy-intensive industries. *Applied Energy, 326*, 119986. https://doi.org/10.1016/j.apenergy.2022.119986.
10. Nevzorova, T. (2022). Functional analysis of technological innovation system with inclusion of sectoral and spatial perspectives: The case of the biogas industry in Russia. *Environmental Innovation and Societal Transitions, 42*, 232–250. https://doi.org/10.1016/j.eist.2022.01.005.
11. Nosova, S., Norkina, A., Makar, S., & Fadeicheva, G. (2021). Digital transformation as a new paradigm of economic policy. *Procedia Computer Science, 190*, 657–665. https://doi.org/10.1016/j.procs.2021.06.077.
12. Pan, W., Xie, T., Wang, Z., & Ma, L. (2021). Digital economy: An innovation driver for total factor productivity. *Journal of Business Research, 139*, 303–311. https://doi.org/10.1016/j.jbusres.2021.09.061.
13. Samonova, Ch. V., & Shevchenko, I. K. (2015). Analysis of existing indicators systems and methodologies for assessing the technological position in territory and industrial complexes. *Engineering Journal of Don*, 2–2(36).
14. Schu, G., Anderl, R., Gauzemeier, J., Hompel, M., Walster, W., et al. (2017). *Maturity index industries 4.0—Digital management company transformation*. Herbert Utz Verlag.
15. Shelegeda, B. G., Sharnopolskaya, O. N., Russijan, S. A., Pogorzhelskaya, N. V., & Logacheva, O. M. (2007). The features of the calculation methods of the integral assessment technological way at the enterprises of coal industry. *Vestnik NSUEM, 2*, 221–234.
16. Sukharev, O. S., & Voronchikhina, E. N. (2020). Structural growth policy in Russia: resources, technology intensity, risk, and industrialization. *Journal of New Economy, 21*(1), 29–52. https://doi.org/10.29141/2658-5081-2020-21-1-2.
17. Tuncel, C. O., & Polat, A. (2016). Sectoral system of innovation and sources of technological change in machinery industry: An investigation on turkish machinery industry. *Procedia—Social and Behavioral Sciences, 229*, 214–225. https://doi.org/10.1016/j.sbspro.2016.07.131.
18. Turovets, J., Proskuryakova, L., Starodubtseva, A., & Bianco, V. (2021). Green digitalization in the electric power industry. *Foresight and STI Governance, 15*(3), 35–51. https://doi.org/10.17323/2500-2597.2021.3.35.51.
19. Urasova, A. A. (2021). *Methodology of Modeling the Processes of Digitalization of the Economy of the Regions of the Russian Federation: Technological Dominants and Industry Transformation. Monograph.* Yekaterinburg. (354 p.).
20. Vasilyeva, Z. A., Ryzhkova, O. V., & Ulas, J. V. (2017). Estimation methodology of integrated effects of technological development in the region for the short-term and long-term periods. *Azimuth of Scientific Research: Economics and Administration, 6* 4(21), 208–211.
21. Wang, P., & Li, F. (2021). Science, technology and innovation policy in Russia and China—Mapping and comparisons in objectives, instruments and implementation. *Technological Forecasting and Social Change, 162*, 120386. https://doi.org/10.1016/j.techfore.2020.120386.
22. Wu, B., & Yang, W. (2022). Empirical test of the impact of the digital economy on China's employment structure. *Finance Research Letters, 49*, 103047. https://doi.org/10.1016/j.frl.2022.103047.
23. Yang, Q., Ma, H., Wang, Y., & Lin, L. (2022). Research on the influence mechanism of the digital economy on regional sustainable development. *Procedia Computer Science, 202*, 178–183. https://doi.org/10.1016/j.procs.2022.04.025.
24. Yüksel, H. (2020). An empirical evaluation of Industry 4.0 applications of companies in Turkey: The case of a developing country. *Technology in Society, 63*, 101364. https://doi.org/10.1016/j.techsoc.2020.101364.

25. Zabelina, I. A. (2022). Assessment of the socio-ecological and economic welfare of the Russian eastern regions using Sen's extended function. *Economy of Regions, 18*(2), 398–412. https://doi.org/10.17059/ekon.reg.2022-2-7.
26. Zhou, X., Cai, Z., Tan, K.-H., Zhang, L., Due, J., & Song, M. (2021). Technological innovation and structural change for economic development in China as an emerging market. *Technological Forecasting and Social Change, 167*, 120671. https://doi.org/10.1016/j.techfore.2021.120671.

Digital Transition of Industries: Challenges and Barriers in an Uncertain Environment

Digital Transformation and Sustainability. A Systematic Literature Review

Giada Pierli, Federica Murmura, and Laura Bravi

Abstract The study contributes to enriching the current literature on the connection between digital transformation and sustainability at the industry level, by developing a Systemic Literature Review (SLR). The database used to identify the documents was Web of Science; the selected time period was from 2010 to 2022 in order to perform an as comprehensive as possible analysis of the published articles on this topic. Three research categories were selected: Business, Management, and Economics. The results underlined that digital transformation can significantly support the achievement of sustainable goals, representing a key opportunity for both institutions and businesses to change their management models to meet the community's increasingly pressing expectations in terms of environmental protection and social welfare. In this sense, the results show the need for more comprehensive studies on the relationship between digital transformation and the pillars of sustainability, especially the social one. The study has some limitations deriving from only using articles, a single database, and a specific query to identify relevant documents.

Keywords Digital transformation · Sustainability · Systemic literature review

1 Introduction and Theoretical Background

Over the past decade, the topic of sustainability has become the focus of a major academic, industry, and policy debate. As environmental, social, and economic pressures have become increasingly severe and unrelenting, international organizations

G. Pierli · F. Murmura · L. Bravi (✉)
Department of Economics, Society, Politics, Carlo Bo University of Urbino, 61029 Urbino, Italy
e-mail: laura.bravi@uniurb.it

G. Pierli
e-mail: g.pierli@campus.uniurb.it

F. Murmura
e-mail: federica.murmura@uniurb.it

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_8

and countries worldwide have begun to promote the adoption of new action plans [1] that are able to combine economic growth with environmental protection and societal well-being.

In this context, the concept of sustainable development—closely intertwined with that of sustainability—has become the guiding principle of development policies globally. Although this theme has undergone a profound evolution depending on the different contexts of application [2–4], the widely shared definition of sustainable development is the one formulated in the Brundtland Report carried out in 1987 by the World Commission on Environment and Development (WCED). According to this report, sustainable development can be defined as "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" [5, p. 43]. This concept is the result of the increased awareness of the planet's resource exhaustibility and the consequent need to preserve the natural heritage [6], through the definition of more balanced economic-social development models than those adopted in the past. On this basis, sustainability can be declined into three main pillars: environmental, social, and economic [7, 8].

The environmental dimension is concerned with the need to preserve the reproducibility and availability of natural resources, the social dimension is aimed at tackling inequalities and ensuring the inclusion and accessibility of services, and the economic component is related to the ability to ensure economic efficiency and income for businesses and jobs for people's livelihoods [9, 10]. Over the last few years, the idea of sustainability has been increasingly intertwined with that of digital transformation [11], emphasizing the important role of technology in improving global well-being. Since 2016, the United Nations have been committed to an international agenda to achieve the 17 Sustainable Development Goals (SDGs) by 2030, underlining the relevance of technology to their achievement [12]. Similarly, the European Commission has recently highlighted the fundamental function of digital technology for the implementation of the Green Deal, which is Europe's new growth strategy to promote the green transition with the ultimate goal of reaching climate neutrality by 2050 [13]. Most recently, the Next Generation EU fund, set up by the European Union in response to the significant economic and social impacts generated by the Covid-19 pandemic, further stressed the need to combine sustainability and digitalization, laying the foundations for a significant transformation in this direction [14].

Despite being apparently distant, the themes of sustainability and digital transformation are closely related and mutually complementary. In order to understand this interconnection, it might also be useful to introduce the definition of digital transformation. Among the many existing notions, it could be generically described as "the most profound and accelerating transformation for business activities, processes, competencies, and models to leverage the changes of digital technology and their impact in a strategic and prioritized way" [15, p. 723]. Digital transformation thus represents an evolutionary process in which digital technologies and capabilities generate new opportunities for value creation, requiring fundamental changes in organizations that can also have a strong impact in terms of sustainability [16, 17]. According to the United Nations and the Organization for Economic Co-operation and Development (OECD), digital technologies are not only essential tools for business operations, but they can also significantly facilitate the achievement of sustainable goals [12, 18]. Similarly, Seele and Lock [19, p. 183] state that "digital technologies in the form of e-health services, robotics, or emission reduction solutions could help individuals, organizations, and nations achieve a more sustainable planet in light of the sustainable development goals."

Digital transformation is not an exclusively organization-focused process, but rather a phenomenon that triggers changes in industry and society [20]. Indeed, digital technologies are able to produce widespread effects that simultaneously involve all dimensions of sustainable development [11], including global productivity, social equality and inclusion, and environmental protection. The main technological innovations to drive the transition to sustainability include the Internet of Things (IoT), big data analytics, blockchain, artificial intelligence and machine learning, cloud, 5G Internet, and virtual reality systems [21–23]. Specifically, the environmental pillar can benefit significantly from the use of such digital tools, which can effectively protect the ecosystem by contributing to emissions reduction, waste management, resilience to natural hazards, and minimization of climate change effects in any economic sector [11, 16, 24]. Regarding the social dimension, digital transformation offers effective methods and solutions for ensuring access to basic services—such as food, health, water, and energy—thus reducing inequalities and improving the health and food conditions of populations [11]. Finally, the economic component can take advantage of digital technologies in terms of innovation in production processes, which allows an increase in efficiency and a reduction in emissions [11].

It is therefore evident that sustainability and digital transformation are closely interconnected. According to Weippl et al. [25], information and communication technologies (ICTs) are a key determinant in achieving sustainable development goals through their potential for more efficient use of resources, education, and business operations. As stated by Vinuesa et al. [26], artificial intelligence can contribute to the fulfillment of the most sustainable goals by acting on all dimensions of sustainability. Kostoska and Kocarev [27] developed a new Information and Communications Technology (ICT) framework to address sustainability, arguing that digital technologies can enable its effective achievement.

Despite the consistent discussion on the different possible ways to meet sustainability goals, there are still few studies on the relationship between digital transformation and sustainability [11, 16, 17, 28], especially at the corporate level. In this context, a useful recent tool for identifying a company's sustainable performance is the Environmental, Social, and Governance (ESG) score. As outlined by the European Banking Authority (EBA) [29], ESG factors are "environmental, social or governance matters that may have a positive or negative impact on the financial performance or solvency of an entity, sovereign or individual." Precisely, ESG is a standard used by investors to evaluate corporate behavior and future performance based on three key elements, namely Environment (E), Social (S), and Governance (G) [1]. In this sense, companies are required to adopt innovative business models capable of fostering the joint pursuit of environmental, social, and economic performance.

Given the need for more knowledge to understand the connection between digital transformation and sustainability, this study aims to fill this gap by developing a Systemic Literature Review (SLR) on the topic. Specifically, it aims to address the following research question:

What is the current state of the art on the relationship between digital transformation and sustainability at the industry level?

In this perspective, the study contributes to enrich the current literature and identify potential future research directions and developments. Furthermore, it could offer useful insights for institutions and companies on what are the main benefits and controversial aspects encountered in the combination of digital and sustainability, encouraging their application and possible support measures.

The paper is organized as follows: Sect. 2 describes the methodology used to develop the systematic literature review, Sect. 3 illustrates the results, and Sect. 4 provides the main conclusions and future research.

2 Methodology

In order to present current and future research trends with respect to the relationship between digital transformation and sustainability in industrial settings, a Systematic Literature Review (SLR) was developed. Indeed, it provides an effective method for identifying the current state of research and defining future research opportunities [30, 31]. Based on guidelines from the previous studies on doing a Systematic Literature Review [32, 33], the following steps were implemented:

(a) Selection of sources. The database used to identify the documents of interest was Web of Science, which is considered as one of the most relevant academic search systems [34].
(b) Setting search criteria. The keywords used in the search were ("sustainability" OR "sustainable development" OR "ESG") AND "digital transformation." In this way, it is possible to find all articles that have the words sustainability and digital transformation, sustainable development and digital transformation or ESG and digital transformation in the title, keywords, or abstract.
(c) Selection criteria. The selected time period was from 2010 to 2022 in order to perform an as comprehensive as possible analysis of the published articles related to this last topic. It is clarified that the information included for 2022 corresponds to the first six months of the year since the search process was carried out on July 1, 2022. The analysis includes all articles published in English. Publications such as books, conference proceedings reports, working papers, etc., were excluded from this study. Based on the objective of the study, three research categories were selected, namely, Business, Management, and Economics. Finally, the abstract of each article was read to confirm or not its relevance to the investigated topic.

(d) Content analysis and synthesis. After selecting a sample of articles, a content analysis was conducted. To this end, each article has been analyzed in terms of authors, year of publication, paper title, type of research category, journal, and citations. This provided a framework for understanding the current state of the art on the topic. Subsequently, the articles were analyzed and grouped by research area, with the aim of identifying the main themes addressed.

Initially, 501 different manuscripts were identified in the search. After applying the selection criteria defined above (iii), 60 articles were considered within the scope of this analysis.

3 Results

This section presents the main results of the analysis conducted. It has been divided into three parts, consistent with the perspectives considered: (1) time, (2) journal, (3) subject areas, topic, and citations.

3.1 Paper by Time

As shown in Fig. 1, the topic investigated has increased in recent years. In particular, 2021 has the highest number of publications on the relationship between digital transformation and sustainability, while 2010 is the year when the first article on the topic was published. The research was carried out in June 2022, so it is interesting to note that in just 6 months, 19 articles have already been published, which is a very close number to those of the previous year.

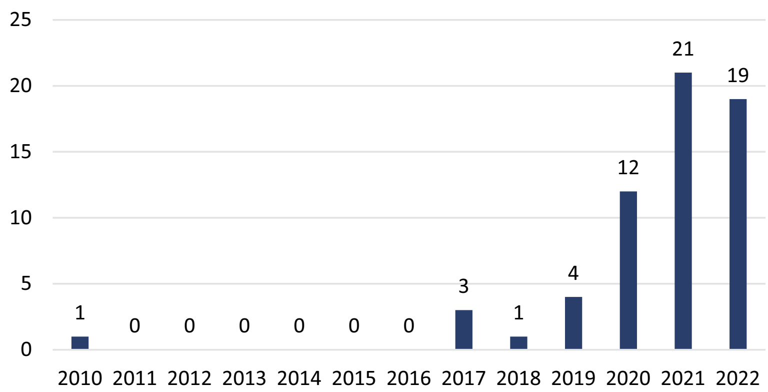

Fig. 1 Article's distribution over time

3.2 Papers by Journal

The articles analyzed are distributed in 48 different journals. The journal with the highest number of publications on the subject is Business Strategy and the Environment, in which there are 4 articles published during the period considered. Technological Forecasting and Social Change follows with 3 published articles. Other relevant journals where at least 2 papers on this issue have been published are Journal of Asian Finance Economics and Business, Ecological Economics, Total Quality Management & Business Excellence, Journal Of the Knowledge Economy, Journal of Business Research, Industrial Marketing Management, Economic Annals-XXI.

3.3 Papers by Subject Area, Topic, and Citations

Figure 2 shows the distribution of the documents analyzed with respect to the selected subject areas. It should be noted that some papers do not belong exclusively to one category, but were included in at least two subject areas. Thus, the category with the highest number of manuscripts is Business (16), followed by Management (15), Business & Management (12), and Economics (9). The remaining areas are Business & Economics and Management & Economics, with 6 and 2 papers each.

Table 1 summarizes the main topics of the articles analyzed with a subdivision by category. In the *Business* area, the main topics are the impact of digital transformation in terms of corporate financial, production and environmental performance and the use of digital technologies to effectively communicate Corporate Social Responsibility (CSR). On the other hand, the main topics in the *Management* category are the impact of digital transformation in achieving the Sustainable Development Goals (SDGs), the importance of developing innovative business models for sustainable business transformation, the positive relationship between digital transformation and the company's environmental and financial performance, the role of digital technologies in improving production and managerial processes, the link between digital

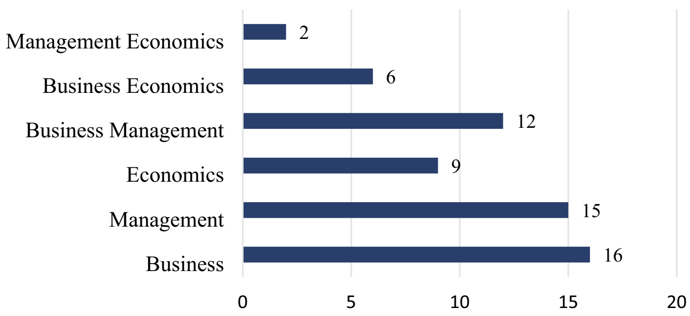

Fig. 2 Distribution of papers by subject area

technologies and the circular economy, and the importance of digitization in making the supply chain sustainable. For the *Economics* area, the main topics include the role of digital transformation as a key factor for governments in promoting inclusive economic growth, social development, and environmental protection; the efficiency of governance in implementing sustainable goals using digital technologies; challenges and opportunities of the digital and sustainable transition; and the use of digital tools to implement sustainable practices within public institutions. Finally, the categories Business & Economics, Business & Management, and Management & Economics mostly present an overlap of issues compared to those illustrated individually for the three previous areas. Nevertheless, new issues can be identified in terms of Green Digitization, complexity of digital and sustainable transformation at the organizational level, and the importance of adopting automated methods and processes to reduce energy waste and CO_2 emissions.

Consistent with the years in which publications began to increase, the highest number of citations is recorded from 2019 (Fig. 3). The year 2021 represents the one with the highest number of citations (305), showing a significant increase from the previous year's 84 citations. The date for 2022 is also quite positive, with 211 citations achieved just in the first six months of the year.

4 Discussion and Conclusion

The aim of this study was to analyze and identify the state of knowledge related to the relationship between digital transformation and sustainability, with a focus on the industry level. In order to achieve this goal, a Systematic Literature Review (SLR) was developed through which selected papers could be examined in terms of year of publication, journal, subject area, main topic, and citations. In particular, the analysis performed indicates that interest in the topic has grown in recent years, especially since 2021. The fact that the first six months of 2022 reached a number of publications rather close to that of 2021 is an indicative of increasing attention to the topic. Articles have been published in several important journals, among which Business Strategy and the Environment ranks first in terms of publications on the issue. Consistent with the period of greatest publications, the highest number of citations is in 2021. The main topics of the selected papers include (i) the impact of digital transformation in achieving sustainable goals, especially with respect to the environmental and economic dimensions; (ii) the importance of adopting innovative business models in order to facilitate digital and sustainable transformation; (iii) the role of digital transformation as a key factor for governments in promoting inclusive economic growth, social development, and environmental protection. These results confirm the need for more comprehensive studies on the relationship between digital transformation and the different pillars of sustainability, especially with respect to the social one [20, 35]. They also support that most scholars have focused on the

Table 1 Topic by subject area

Business	Management	Economics	Business and Economics	Business and Management	Management and Economics
Digital transformation impact on logistics sustainability	Link between digitalization and the achievement of the Sustainable Development Goals (SDGs) in the Italian agri-food sector	Efficiency of governance and sustainability of public finance based on digital transformations	Impact of Digital Transformation's (DT) readiness on SMEs' sustainability	Collaboration and coordination in a digital supply chain to achieve sustainability	Role of digital technology adoption, digital dynamic capabilities, and digital transformation performance in the textile sector in facing the opportunities and challenges of sustainable development
Digital transformation impact on production process	Significant impact of digital transformation in corporate environmental performance	Impact of digital transformation in the localization and achievement of sustainable development goals, at the government level	CRM as Green IT, oriented toward digital transformation and sustainable business model innovation	Digitization of business as a tool to enable a better dialogue between business economic theory, sustainability studies, and business ethics	Application of green digitization in the electric power sector, its prerequisites and potential economic and social impacts
Effect of digital transformation on sustainability, considering the important role of customers, data and innovation	Positive impact of digital transformation in achieving Sustainable Goals 4 and 9	Resources, capabilities, and management choices necessary to implement digital transformation and achieve sustainable goals	Impact of corporate digitalization on the corporate sustainability performance and barriers and supportive institutional frameworks for corporate digital technology adaptation	Influence of sustainable development, organizational drivers, cultural context, and digital transformation at a strategic level	

(continued)

Table 1 (continued)

Business	Management	Economics	Business and Economics	Business and Management	Management and Economics
Communication of corporate transformation Industry (CTTI4.0) and role of ESG disclosure	Innovative business models facilitate the company's transition to sustainable development	Digital transformation within universities as a means of setting the stage for sustainability priorities and considerations	Need for policies and strategies that foster smart tourism destinations and the development of a more digitized and sustainability-oriented economy	Complexity of a digital transformation of the business organization and how to make this transition sustainable	
Importance of adopting a stakeholder orientation in the context of digital transformation. In this way, companies have better financial and customer service performance	Opportunities related to digital transformation in terms of its impact on society and industries	Digital transformation as a key driver for governments to promote sustainable and inclusive economic growth, social development and environmental protection	Role of digital transformation in the public sector and how it affects society	Combination of corporate sustainability and digitalization facilitates in transforming the organizational nature of banks by simultaneously narrowing their boundaries and expanding their scope	
Significant effects of digital accounting on financial reporting quality, accounting information usefulness, and strategic decision effectiveness	Positive interrelationship between digital maturity and corporate financial indicators	Digital transformation in seaports as a tool to implement operational efficiency while coping with new economic issues	Importance of automated production methods and business processes in reducing energy waste	CO_2 reduction through digital transformation in long-haul transportation	

(continued)

Table 1 (continued)

Business	Management	Economics	Business and Economics	Business and Management	Management and Economics
How multinational companies are coping with the environmental and pandemic crisis in combination with digitalization	Positive link between digital transformation, digital business model maturity, and sustainable business excellence in the tourism sector	Challenges and opportunities related to the dual transition—digital and sustainable—within European countries		Synergies between digital technologies and the circular economy paradigm through the lens of digital functions	
The relationship between three growth paths for firms: internationalization, digitalization, and sustainability	Importance of creating equal opportunities for the current workforce to improve their digital fluency and skillset by providing information about the benefits of digital twins throughout the infrastructure sector and organizations to improve adoption and the realization of benefits	Country's institutional framework on the relationship between digital transformation and environmental performance		Role of big data and social media analytics for business to achieve business sustainability	

(continued)

Table 1 (continued)

Business	Management	Economics	Business and Economics	Business and Management	Management and Economics
How global communities can address the investment collapse caused by COVID-19 through digital transformation as a driver to facilitate the achievement of sustainable development goals	Innovative business models as key elements in achieving sustainable goals	The predominant role played by information and communication technologies in boosting the economic growth		Distinct and combined effects of digital business transformation (DBT), organizational ambidexterity (OA), and circular business models (CBMs) on the relationship between I4.0 capabilities and sustainable supply chain performance	
Corporate Social Responsibility (CSR) and digital technologies as key elements for the success of food sharing platforms	Digital transformation process of family businesses from the perspective of the firm's human capital			Building responsible innovation in international organizations	
Digital transformation as a tool for creating effective and innovative business networks, making production processes more flexible and efficient	Relevance of digital transformation to the achievement of management efficiency			Purpose Product lifecycle management (PLM) as a tool to address the challenges of sustainability, traceability, and transparency in industry and inter-industry collaborations	

(continued)

Table 1 (continued)

Business	Management	Economics	Business and Economics	Business and Management	Management and Economics
A new paradigm of sustainable development for healthcare and welfare systems at the global level, through technological progress	Importance of adopting innovative and sustainable business models			Students' digital learning orientation. The indirect effect of digital learning orientation on innovative work behavior through readiness for change	
Data analytics and Artificial Intelligence (AI) toward social and economic sustainability	Big-data-driven supply chain action as a moderator of the relationship between circular economy human resource management and business performance for a circular economy supply chain				
The role of SME owners is a key factor in initiating technology readiness for organizational sustainability	Challenges to make manufacturing supply chain 4.0 sustainable				

(continued)

Table 1 (continued)

Business	Management	Economics	Business and Economics	Business and Management	Management and Economics
The role of the Internet and digital technologies in communicating corporate social responsibility (CSR)	Organizational integration of modern IT-based technologies and digitization of value chains to make production processes more effective and efficient				
Digital transformation and the improvement of manufacturing processes					

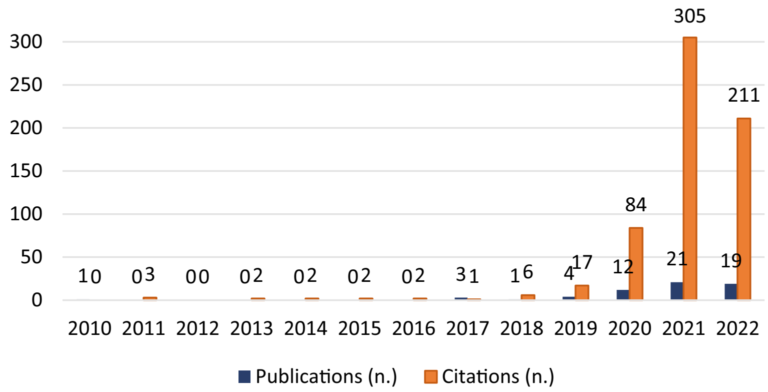

Fig. 3 Number of citations

opportunities provided by digital transformation to make a given business sustainable [11], while there are still few studies on the relationship between these two dimensions.

Nevertheless, it is possible to argue that digital transformation is an effective tool for achieving sustainability [19, 36], through a range of tools that enable organizations to significantly improve their environmental, economic, and social performance. As pointed out by Camodeca and Almici [11], artificial intelligence, blockchain, data analytics, robotics, Internet of Things, social media, cloud technology, and digital reality are tools through which businesses can contribute to the protection of the ecosystem by circular economy models, the development of sustainable production and consumption patterns, and the reduction of inequality and discrimination by ensuring equity, parity of opportunity, and broad accessibility to primary services.

It is therefore evident that digital transformation can significantly support the achievement of sustainable goals, representing a key opportunity for both institutions and businesses to change their management models in order to meet the community's increasingly pressing expectations in terms of environmental protection and social welfare.

The paper presents both academic and practical contributions. Indeed, it contributes to the existing literature by providing a framework on the current state of the art in the field and identifying emerging and potential avenues for future research. The study provides practical implications. In particular, it emphasizes the need for action by policymakers both to introduce measures to promote sustainability-friendly technology investments and to foster international cooperation in the digital and sustainable transition. In addition, it highlights the importance of adopting key performance indicators within the enterprise—such as ESG—to monitor and assess its environmental, social, and economic impacts concurrently with the implementation of organizational and operational digital changes.

The study has some limitations. Firstly, the research focused only on articles, excluding books, conferences, and other sources. Therefore, additional sources might lead to different conclusions. Furthermore, a specific query was used to identify relevant articles and only one database was used. The use of different terms and the consideration of multiple databases could lead to alternative results.

Future research could focus exclusively on the mutual relationship between digital transformation and sustainability. To date, most studies investigated the impact of digital technologies in achieving sustainable goals, analyzing their linkage unidirectionally. Furthermore, it might be interesting to further investigate the correlation between digitalization and the social dimension of sustainability within the business context, which is still poorly investigated. Finally, it might be important to analyze what digital transformation capabilities and organizational and operational changes are required to successfully combine digitalization and sustainability.

References

1. Li, T. T., Wang, K., Sueyoshi, T., & Wang, D. D. (2021). ESG: Research progress and future prospects. *Sustainability, 13*(21), 11663.
2. Du Pisani, J. A. (2006). Sustainable development–historical roots of the concept. *Environmental Sciences, 3*(2), 83–96.
3. Bilan, Y. (2013). Sustainable development of a company: Building of new level relationship with the consumers of XXI century. *Amfiteatru Economic Journal*, 15(Special No. 7), 687–701.
4. Shi, L., Han, L., Yang, F., & Gao, L. (2019). The evolution of sustainable development theory: Types, goals, and research prospects. *Sustainability, 11*(24), 7158.
5. World Commission on Environment and Development. (1987). *Our common future*. Oxford University Press.
6. Fernández, M. B., García-Centeno, M. C., & Calderón Patier, C. (2021). Women sustainable entrepreneurship: Review and research agenda. *Sustainability, 13*, 12047.
7. Mensah, J. (2019). Sustainable development: Meaning, history, principles, pillars, and implications for human action: Literature review. *Cogent Social Sciences, 5*(1), 1653531.
8. Milenković, M., Vaseashta, A., & Vasović, D. (2021). Strategic planning of regional sustainable development using factor analysis method. *Polish Journal of Environmental Studies, 30*(2), 1317–1323.
9. D'Amico, E., Coluccia, D., Fontana, S., & Solimene, S. (2014). Environmental sustainability: An empirical survey on Italian listed companies. In *Knowledge and Management Models for Sustainable Growth. Proceedings of the 9th International Forum on Knowledge Asset Dynamics*, Matera, Italy, 11–13 June 2014, Emerald: Bingley, UK.
10. Salvioni, D. M., & Almici, A. (2020). Transitioning toward a circular economy: The impact of stakeholder engagement on sustainability culture. *Sustainability, 12*(20), 8641.
11. Camodeca, R., & Almici, A. (2021). Digital transformation and convergence toward the 2030 agenda's sustainability development goals: Evidence from italian listed firms. *Sustainability, 13*(21), 11831.
12. United Nations. (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development*. Resolution Adopted by the General Assembly on 25 September, Department of Economic and Social Affairs: San Francisco, CA, USA.
13. European Commission. (2019). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. The European Green Deal; European Commission: Brussels, Belgium.
14. European Commission. (2021). Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the

region. The next generation of own resources for the EU Budget; European Commission: Brussels, Belgium.
15. Hamidi, S. R., Aziz, A. A., Shuhidan, S. M., Aziz, A. A., & Mokhsin, M. (2018). SMEs maturity model assessment of IR4. 0 digital transformation. In *International Conference on Kansei Engineering & Emotion Research* (pp. 721–732). Springer.
16. Feroz, A. K., Zo, H., & Chiravuri, A. (2021). Digital transformation and environmental sustainability: A review and research agenda. *Sustainability, 13*(3), 1530.
17. Gomez-Trujillo, A. M., & Gonzalez-Perez, M. A. (2021). Digital transformation as a strategy to reach sustainability. *Smart and Sustainable Built Environment*.
18. OECD. (2020). *The digitalization of science, technology and innovation.* OECD Library.
19. Seele, P., & Lock, I. (2017). The game-changing potential of digitalization for sustainability: Possibilities, perils, and pathways. *Sustainability Science, 12*(2), 183–185.
20. Vial, G. (2019). Understanding digital transformation: A review and a research agenda. *The Journal of Strategic Information Systems, 28*, 118–144.
21. Du, W. Y., Pan, S. L., & Huang, J. S. (2016). How a latecomer company used IT to Redeploy slack resources. *MIS Quarterly Executive, 15*, 195–213.
22. Lee, H. J. (2012). A review of value creating motive and business model in smart technology. In Park, Y. H., Jin, Q., Yeo, M. S., Hu, B. (Eds.), *Human centric technology and service in smart space*. Springer.
23. Esmaeilian, B., Sarkis, J., Lewis, K., & Behdad, S. (2020). Blockchain for the future of sustainable supply chain management in industry 4.0. *Resource Conservation & Recycling, 163*, 1–15.
24. Demartini, M., Evans, S., & Tonelli, F. (2019). Digitalization technologies for industrial sustainability. *Procedia Manufacturing, 33*, 264–271.
25. Weippl, E., Tjoa, A. M., & Kieseberg, P. (2021). Digital transformation for sustainable development goals (SDGs)—A security, safety and privacy perspective on AI. In *International Cross-Domain Conference for Machine Learning and Knowledge Extraction.* Cham, Switzerland: Springer.
26. Vinuesa, R., Azizpour, H., Leite, I., Balaam, M., Dignum, V., Domisch, S., Felländer, A., Langhans, S. D., Tegmark, M., & Nerini, F. F. (2020). The role of artificial intelligence in achieving the sustainable development goals. *Nature Communications, 11*(1), 1–10.
27. Kostoska, O., & Kocarev, L. (2019). A novel ICT framework for sustainable development goals. *Sustainability, 11*(7), 1961.
28. Esses, D., Csete, M. S., & Németh, B. (2021). Sustainability and digital transformation in the visegrad group of central european countries. *Sustainability, 13*(11), 5833.
29. EBA. (2022). EBA Report on Management and Supervision of ESG Risks for Credit Institutions and Investment Firms. Retrieved June 28, 2022, from https://www.eba.europa.eu/sites/default/documents/files/document_library/Publications/Reports/2021/1015656/EBA%20Report%20on%20ESG%20risks%20management%20and%20supervision.pdf?retry=1.
30. Jones, M. L. (2004). Application of systematic review methods to qualitative research: Practical issues. *Journal of Advanced Nursing, 48*, 271–278.
31. Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review* Introduction: The need for an evidence- informed approach. *British Journal of Management, 14*, 207–222.
32. Bandara, W., Miskon, S., Fielt, E. (2011). A systematic, tool-supported method for conducting literature reviews in information systems. In *Proceedings of the 19th European Conference on Information Systems (ECIS 2011)*, Helsinki, Finland, 9–11 June 2011, p. 221.
33. Vom Brocke, J., Simons, A., Niehaves, B., Niehaves, B., Riemer, K., Plattfaut, R., & Cleven, A (2009). Reconstructing the giant: On the importance of rigour in documenting the literature search process. In *Proceedings of the 17th European Conference on Information Systems (ECIS 2009)*, Verona, Italy, 8–10 June 2009, p. 161.
34. Gusenbauer, M., & Haddaway, N. R. (2020). Which academic search systems are suitable for systematic reviews or meta_analyses? Evaluating retrieval qualities of Google Scholar. *Research Synthesis Methods, 11*, 181–217.

35. Majchrzak, A., Markus, M. L., & Wareham, J. (2016). Designing for digital transformation: Lessons for information systems research from the study of ICT and societal challenges. *MIS Quarterly, 40*, 267–277.
36. Sachs, J. D., Schmidt-Traub, G., Mazzucato, M., Messner, D., Nakicenovic, N., & Rockström, J. (2019). Six transformations to achieve the sustainable development goals. *Nature Sustainability, 2*, 805–814.

The Contribution of Digital Transformation Industry (DTI) in Micro- and Macro- Economy

Grigorios L. Kyriakopoulos

Abstract Recently, national economies attempt to retard transformational changes of global economy and confront the economic recession by taking measures regarding protectionist measures and growing introduction of sanctions and trade restrictions partially caused by the Covid-19 pandemic. Besides, at a human resource side, the pursuing of high-quality and crisis-free economic growth is also attributed to an imperative need of following new styles of leadership, the adaptability towards digitalized economies, the adoption of Industry 4.0 forms of industrialization, as well as the introduction of a planning system based on new technological paradigms and novel patterns of production. In the relevant literature, the Digital Transformation in Industry (DTI) is extended to a wide range of applications, including the hospitality industry, single-industry "smart" cities, environmental concerns, Exploration and Production (E&P) industry. All these applications showed that DTI plays a decisive role in the contexts of micro- and macro-economy, especially in the sectors of entrepreneurship and manufacturing. Conclusively, the main DTI challenges and future prospects have been also signified.

Keywords Digital transformation industry · Microeconomic development · Macroeconomic development · Industry 4.0 · Smart cities · Entrepreneurship · Manufacturing

1 Introduction

During the last decade, the global economy has undergone sharp and steady transformational changes. As a result, national economies attempt to retard such an unstable and liquefied condition by taking measures like that of strengthening of protectionist measures and growing introduction of sanctions and trade restrictions partially caused by the Covid-19 pandemic. As a result, global economic crisis in the entrepreneurial

G. L. Kyriakopoulos (✉)
School of Electrical and Computer Engineering, National Technical University of Athens, Zografou Campus, 15780 Athens, Greece
e-mail: gregkyr@chemeng.ntua.gr

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_9

sector is determined by the onset of qualitatively new equipment, the technological spur of advanced technologies, as well as a radically different system of economic relations. Besides, at a human resource side, the pursuing of high-quality and crisis-free economic growth is also attributed to an imperative need of following new styles of leadership, the adaptability towards digitalized economies, the adoption of Industry 4.0 forms of industrialization, as well as the introduction of a planning system based on new technological paradigms and novel patterns of production [19]. In the relevant literature, the Digital Transformation in Industry (DTI) is extended to a wide range of applications, including the following:

Hospitality industry [20, 21]. Indeed, digital technologies should play a decisive role in the national economic energy sector, while directly impacting on the hospitality industry. It is noteworthy the practical importance of determining the hospitality industry business structures and, to a broader sense, the financial importance/dimension of digital transformation of the energy sector. The enterprise expenses in the hospitality industry can be carried out by considering those energy complex activities that co-exist at the materialization of such a digital transformation concept, as well as the assessment of the hospitality industry risks emerged within the framework of the chosen research area. It is also important for researchers and policy planners to consider those key aspects of the interconnection of domestic power grid companies with enterprises in the hospitality industry, because the degree of influence by the digital transformation tools of the economy of the national energy sector can feasibly support enterprises in the hospitality industry to be clustered and maintained operative. In such a way, promising technological trends in the energy sector are revealing the influential role of digital energy on the development of the hospitality industry through the transition of business in the form of the digitization of individual tasks up to the digital transformation of the whole industry [20]. In a similar study the hospitality industry is also regarded as one of the most attractive, fast developing business areas and company executives have an acute problem of forming a new management system that meets the challenges of the global digital environment. Through the pilot implementation of DTI-based projects in the hotel and restaurant business of the industry 4.0, they were shown the prospects of developing those mechanisms of adaptation to the emerging problems and grasp the opportunities of the digital transformation of the hospitality industry, enabling such enterprises to organize effective management and increase their competitiveness [21].

Single-industry "smart" cities [7]. Modern cities are experiencing a digital transformation that is mainly reported through the adoption of Information and Communication Technologies (ICT). Such an urban digitalization can support competitiveness, improve the quality of life, establish social interactions among citizens, business and government. All these are attributes of the "smart city" definition. In this context, there is the definition and functionality of "single-industry" cities that are in great demand for "smart" solutions. In such a way problems emerging in single-industry cities they can be considered as one of the main priorities of national policy. For instance, in Russia the single-industry cities have been determined as one of the core-foundation pillars of the Russian economy but, simultaneously, they are proven among the most vulnerable elements of the socio-economic space. Contrarily to the today designed measures of downsizing of production and consumption, an economy digitalization proposed single-industry cities to follow a new development model of joint social and economics characteristics that enhances the efficiency of the economic mechanism based on the introduction of digital technologies and platform solutions into the economy and management of the city. Then, companies are in the position to choose the appropriate model of a single-industry city being based on a comprehensive assessment of its competitiveness. Such a selection can be decided by considering theoretical and empirical data of competitiveness of single-industry cities under digital transformation of the economy and to develop guidelines for digital transformation of the single-industry city depending on the model developed [7].

Digital transformation of manufacturing industry by adopting the principles of circular economy [17]. The today overuse of raw material to meet high living standards is unavoidably resulting in resource scarcity and cost explosion of materials, making governments overstrained to dispose the constantly accruing amounts of wastes generated, nationally and globally. In such a negative environmental perspective, it is always challenging to adopt such measures and policies of materials circulation and regaining them for more rounds of use. In such a circulated system of production-consumption-disposal-production, this closed material cycle can further eliminate the overwhelming production of wastes. In this point, it is crucial the adoption of digital transformation potentials to enable a transition from a linear economy towards a circular economy. Key-enabling factors can materialize the aforesaid organizational shift but, at the time being, there are only a few researches that investigated the exact ways under which digital technologies could turn to a circular economy transition at the manufacturing sector. In such a research study, nine success factors were introduced to implement this organizational shift based on digital transformation technologies. Subsequently, there were organized two dimensions: the first one consists of three phases (manufacturing, usage, and reutilization/recycling) of a product lifecycle. The second dimension depicts the design levels of business engineering (strategic-, system-, and information levels). In such a way, the nine success factors were described for each level of the framework along the product lifecycle in the context of digital transformation, enabling challenging issues to be disclosed and overcome recommendations to be proposed in the context of realizing the principles of circular economy among manufacturing companies [17].

Environmental concerns [14]. An important and stressful indicator of environmental concern is the uncontrolled disposal of plastics industry, e.g., in Europe this plastic industry sector employs 1.5 million people and its 60,000 businesses that totally generate revenue of 350 billion. This industrial sector should be particularly impacted by the expansion of circular economy and digital transition, bringing structural and workforce changes that require reconsidering of traditional roles and all traditionally-associated skills, being also determining on changes at businesses' economic models, job offers, designing shift of production methods, as well as different ways of wastes recovery. In such a DTI context, the introduction of cobotization (human–robot collaboration) and blockchain are valuable counterparts, all supporting those strategies in alignment with growing skills hybridization, rechanneling businesses' plans, and enriching training bodies to achieve higher revenues [14].

Exploration and Production (E&P) industry which is a specific sector within the oil and gas industry that is referring to the early stage of energy production and it involves an upstream segment of the oil and gas industry through oil and gas exploration activities. In particular, E&P encompasses the processes and the methods involved in locating potential sites for oil and gas drilling and extraction. In this context, the "exploration and production" activities contain the creation of geological surveys, the holding of land rights, as well as the production activities, which include onshore and offshore drilling [16]. In this organizational environment, digital transformation for the upstream industry can support the industrial transforming by using digital oilfields, digitization, and digitalization within local business ecosystems. Subsequently, DTI can profoundly impact on how the E&P industry should evolve to meet future challenges and to improve businesses profitability [16].

2 DTI in the Contexts of Micro-Economy and Macro-Economy

Nowadays, the fast-evolving changes in the global economy are characterized by the transition to the sixth technological order and the development of the Fourth industrial revolution concept [6]. Such accelerated economic transition is predominately achievable through the development of innovative technologies, the DTI, and the modern information and communication technologies (ICTs) all being implemented by industrial enterprises [13]. Therefore, the analysis of innovation indicators should be aligned with the software ICTs in the wider context of transition to a digital economy. Such an analysis revealed those drivers and barriers of the innovative industrial development and identified the constraints of industrial production through innovative solutions, paving the ways to minimize them [13].

2.1 DTI Characteristics and Operation in the Entrepreneurship Sector

Internet of Things (IoT) technologies, such as edge computing, sustain high potential for the digital transition towards sustainability, but they are vulnerable to significant carbon footprint due to the use of scarce raw materials and increasing energy consumption in the processes of manufacturing, operating, and recycling. In this respect the Green IoT (G-IoT) has been proposed to reduce such carbon footprint, though of low sustainability achievement due to the advent of Edge Artificial Intelligence (Edge AI), which imposes the consumption of additional energy. Therefore, the design and the development of Edge-AI G-IoT systems can be practically used in Industry 5.0 for improving operator safety and operation tracking. It also remains challenging the evaluation of the energy consumption needed, as well as the carbon footprint identified in different countries and applications of such Edge-AI G-IoT systems in the future [3].

In the entrepreneurship context benchmarking against current technology is able to significantly reduce the engineering time required for data reconciliation, rectification, and standardization. Instead of spending 80% of their efforts on such activities, process engineers and data scientists started to spend most of their time on real-time process analysis and decision-making, through cloud-based architectures developed under a cooperative project between Vitro and Microsoft. Such architectures represented a typical paradigm of how an enterprise, in this case the glass industry, could be easily adaptable to digital transformation, but it can be also applied to other industry sectors, such as the chemicals, petro-chemicals, pharmaceutical, agricultural, and metallurgical industries. Such a broad applicability enabled the data collection and the processes' running at or close to optimal conditions minute by minute, day by day, and week by week, as product portfolios and markets change [10].

In a wider business perspective, enterprise architectures can play an influential role to the sustainability of software systems enabling them to induct design changes for evolving business requirements. They also provide high-level abstraction by representing structural and behavioral properties of software system while representing multiple views to address the needs of diverse stakeholders of business organizations. Therefore, it is critical research to define various types of architectures that are applicable in software systems design which address various problems within the context of customer and system requirements [22].

2.2 DTI Characteristics and Operation in the Manufacturing Sector

The process of digital transformation is ongoing and widespread actually covering the strategic agendas of all companies, independently from size and industrial type. In this respect, small and medium-sized enterprises (SMEs) are constantly challenged to integrate the process of digital transformation into their strategy towards sustainability and problem-specific approaches [2]. In this challenging and problem-solving approach, a DTI applicability of manufacturing interest is that of the food industry. In such a context, it is research work to be devoted to the diagnostics of the food packaging under air-tight conditions. Such a diagnosing method of the air-tightness of the food products package under the conditions of in-line production can be developed through a prototype of a self-learning software and hardware vision system that performs the diagnostics of the air-tightness of food packaging in a flow production environment [15]. This novel technical vision has been based on the use of advanced methods in the field of artificial neural networks and machine learning, revealing that the development vectors of modern innovative elaborations, as well as a general trend in the scientific and technical literature can offer a valuable view of how innovative systems of technical vision, methods of artificial neural networks and machine learning can influence the DTI-driven enterprises provided "Industry 4.0" growth [15]. It can be also argued that the DTI adoption is of particular importance to be adopted among emerging and developing economies that focus their efforts on overcoming the lagging behind. In such a perspective the introduction of Industry 4.0 can support, firstly, the competitiveness of production and attracting investment in the economy and, secondly, help to increase efficiency in optimal resource use. Therefore "digital transformation" can be considered to some extend synonymous to "process transformation" [4].

While it is reasonable different enterprises, different industries, and different sizes have varied paces and operative capabilities to speed up the implementation of digital technologies, it is also significant to denote the necessity of measures to be undertaken by state policies to support digitalization taking into account these varied features, especially among SMEs and industrial enterprises. In drawing such state policies, the identification of external and internal barriers also play a decisive role toward digital transformation [12].

Among the most suitable businesses in which DTI could be applicable and adaptable it is that of electronic industry. Such an operative adaptation should consider foreign experience in the implementation of digital transformation technologies for enterprises in the electronic industry, while deploying a model to choose the proper digital transformation technologies and identifying the drivers or barriers concurring at this digital transformation of enterprises in the electronic industry. The key-aspects of consideration are the level of maturity of management processes, the types of finished products as well as the level of competition in the market [11].

3 Conclusions

The digital platform acts as a catalyst for the economics, the initiation of which in any industry leads to a significant reduction in costs and acceleration of operating cycles [21]. Besides, through investment and innovation in IT, adequate strategic tools can be developed in boosting productivity in Europe since it is expected that three quarters of the value of the digital economy will come from traditional-industrial sectors thus it is vital for future managerial and entrepreneurial processes to support their digital transformation [4].

Conclusively, future researches of DTI orientation and applications cannot undermine the fact that industrial processes are inherently characterized as energy-intensive processes, making an imperative need strategic planning of industrial interest should integrate technologies that improve energy performance [1, 18], of environmental care [8], and renewables provision [5, 9].

References

1. Alizadeh, A., Ghadamian, H., Aminy, M., Hoseinzadeh, S., Khodayar, Sahebi, H., & Sohani, A. (2022). An experimental investigation on using heat pipe heat exchanger to improve energy performance in gas city gate station. *Energy, 252*, 123959. https://doi.org/10.1016/j.energy.2022.123959.
2. Förster, M., Kürpick, C., Hobscheidt, D., Kühn, A., & Dumitrescu, R. (2022). Cross-industry methods for strategic planning of the digital transformation of small and medium sized enterprises. *Procedia CIRP, 109*, 322–327. https://doi.org/10.1016/j.procir.2022.05.257.
3. Fraga-Lamas, P., Lopes, S. I., & Fernández-Caramés, T. M. (2021). Green iot and edge AI as key technological enablers for a sustainable digital transition towards a smart circular economy: An industry 5.0 use case. *Sensors, 21*(17), 5745. https://doi.org/10.3390/s21175745.
4. Gigova, T., Nikolova-Alexieva, V., & Valeva, K. (2019). Digital transformation of Bulgarian enterprises in the conditions of industry 4.0. In *International Conference on Creative Business for Smart and Sustainable Growth*, CreBUS 2019, 8840102. https://doi.org/10.1109/CREBUS.2019.8840102.
5. Gilani, H. A., Hoseinzadeh, S., Esmaeilion, F., Memon, S., Astiaso Garcia, D., & El Haj Assad, M. (2022). A solar thermal driven ORC-VFR system employed in subtropical Mediterranean climatic building. *Energy, 250*, 123819. https://doi.org/10.1016/j.energy.2022.123819.
6. Golov, R. S., & Myl'nik, V. V. (2022). Digital transformation of high-tech enterprises in the industry 4.0 paradigm. *Russian Engineering Research, 42*(7), 764–765. https://doi.org/10.3103/S1068798X22070115.
7. Guseva, M. S., & Dmitrieva, E. O. (2020). The competitiveness of single-industry cities in the digital transformation of the economy. *Advances in Intelligent Systems and Computing, 908*, 216–226. https://doi.org/10.1007/978-3-030-11367-4_20.
8. Hoseinzadeh, S., & Astiaso Garcia, D. (2022). Techno-economic assessment of hybrid energy flexibility systems for islands' decarbonization: A case study in Italy. *Sustainable Energy Technologies and Assessments, 51*, 101929. https://doi.org/10.1016/j.seta.2021.101929.
9. Sohani, J. S. A., Hoseinzadeh, S., & Pourfayaz, F. (2022). The 3E optimal location assessment of flat-plate solar collectors for domestic applications in Iran. *Energies, 15*(10), 3589. https://doi.org/10.3390/en15103589.
10. Jiao, Y., Finley, J. J., Ydstie, B. E., Polcyn, A., & Figueroa, H. (2022). Digital transformation of glass industry: The adaptive enterprise. *Computers and Chemical Engineering, 157*, 107579. https://doi.org/10.1016/j.compchemeng.2021.107579.
11. Kossukhina, M. A. (2021). Digital transformation technologies of the enterprises in the electronic industry of Russia. In *Proceedings of the 2021 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering*, ElConRus 2021 (pp. 1898–1900). https://doi.org/10.1109/ElConRus51938.2021.9396528.
12. Mezentseva, E. (2022). Digital transformation of Russian industry: The specifics of large, medium and small enterprises. *Lecture Notes in Information Systems and Organisation, 54*, 307–319. https://doi.org/10.1007/978-3-030-94617-3_22.
13. Pasmurtseva, N. (2020). Russian industry innovative activity in the process of transition to the digital economy: Trends, threats and opportunities. *E3S Web of Conferences, 208*, 03009. https://doi.org/10.1051/e3sconf/202020803009.
14. Phung, C. G. (2019). Implications of the circular economy and digital transition on skills and green jobs in the plastics industry. *Field Actions Science Report, 19*, 100–107.
15. Polyakov, R. K., & Gordeeva, E. A. (2020). Industrial enterprises digital transformation in the context of "industry 4.0" growth: Integration features of the vision systems for diagnostics of the food packaging sealing under the conditions of a production line. *Advances in Intelligent Systems and Computing, 908*, 590–608. https://doi.org/10.1007/978-3-030-11367-4_58.
16. Priyadarshy, S. (2017). Digital transformation essential for E&P industry to thrive in new economy. *World Oil, 238*(1), 66–67.

17. Riesener, M., Dolle, C., Mattern, C., & Kres, J. (2019). Circular economy: Challenges and potentials for the manufacturing industry by digital transformation. In *2019 IEEE International Symposium on Innovation and Entrepreneurship, TEMS-ISIE 2019*, 9074421. https://doi.org/10.1109/TEMS-ISIE46312.2019.9074421.
18. Sohani, A., Delfani, F., Fassadi, C. A., Hoseinzadeh, S., & Panchal, H. (2022). A conceptual optimum design for a high-efficiency solar-assisted desalination system based on economic, exergy, energy, and environmental (4E) criteria. *Sustainable Energy Technologies and Assessments, 52B*, 102053. https://doi.org/10.1016/j.seta.2022.102053.
19. Temirova, T. O., & Abdulov, R. E. (2022). Digital transformation of the economy and industrialization based on industry 4.0 as a way to leadership and high-quality economic growth in the world after the structural economic crisis. *Studies in Computational Intelligence, 1032* SCI, 522–527. https://doi.org/10.1007/978-3-030-96993-6_57.
20. Torkunova, J., & Khabrieva, M. (2022). Impact analysis of digital transformation of the energy sector economy on hospitality industry. *Lecture Notes in Civil Engineering, 190*, 105–112. https://doi.org/10.1007/978-3-030-86047-9_11.
21. Verevka, T. V. (2019). Digital transformation of enterprises of the hospitality industry: Global experience and prospects. In *Proceedings of the 33rd International Business Information Management Association Conference, IBIMA 2019: Education Excellence and Innovation Management through Vision 2020* (pp. 629–640).
22. Vobugari, S., Madhan, K. S., & Somayajulu, D. V. L. N. (2018). Roadmap for building effective complex enterprise architecture in digital transformation: An experience-based industry best practices summary. In *Proceedings of the 2017 International Conference on Smart Technology for Smart Nation, SmartTechCon 2017* (pp. 1627–1632). https://doi.org/10.1109/SmartTechCon.2017.8358640.

Institutions and Tools for Activating the Export Potential of High-Tech Industry at the Regional Level

Anastasia Y. Nikitaeva and Anna S. Deynichenko

Abstract In the context of the digital transformation of society and the Industry 4.0 gaining momentum, the role of high-tech industry and its products in the economies of industrial countries is increasing. In this regard, increasing the export potential of the high-tech industry can improve the economic performance and competitiveness of the country's economy. At the same time, the issue of finding ways to increase the export potential of the high-tech industry remains under-researched. The authors conducted a scientometric and content analysis based on the study of data from SciVal and ScienceDirect. The results of the analysis showed an increase in the demand for research on the problems of improving institutions and tools for the export activities of enterprises at the regional level. The authors further investigated the institutions and tools for activating the export activities of high-tech enterprises in the Rostov region of Russian Federation. This region was chosen for the case study as a typical Russian region with a high level of export potential. As a result, a model of institutions and tools for the development of the export potential of the high-tech industry of the Rostov region within the framework of an integrated digital system was proposed.

Keywords High-tech industry · Export potential · Digitalization · Regional industrial development

A. Y. Nikitaeva · A. S. Deynichenko (✉)
Southern Federal University, 105/42 Bolshaya Sadovaya Str, Rostov-on-Don 344006, Russian Federation
e-mail: pavliukevich@sfedu.ru

A. Y. Nikitaeva
e-mail: aunikitaeva@sfedu.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_10

1 Introduction

The analysis of the world practice of economic development indicates the existence of a positive relationship between the level of export potential of high-tech industry and the economic growth of the state. In the context of the increasing spread of Industry 4.0, accompanied by the introduction of cutting-edge technologies into industrial production, the use of automated, smart and cyber-physical systems, the emergence of distributed digital chains and value creation networks, the global demand for high-tech industrial products is increasing [9]. This leads to the acquisition of competitive advantages by countries and regions with high export potential in the corresponding segment of the economy.

This determines the importance not only of the development of high-tech industry, established as a strategic priority for the modernization of the Russian economy, but also of increasing its export potential. To solve this problem, the government is actively developing institutions and tools and implementing a set of measures to support the production and activation of export activities of high-tech enterprises in the regions of the country, including through the introduction of the latest digital systems into this process [10]. In the conditions of increasing uncertainty and the destruction of a significant part of traditional export models, the importance of creating a flexible and adaptive institutional and instrumental construct to support the export activities of high-tech industry enterprises is only increasing.

At the same time, a number of circumstances need to be considered during the study. Firstly, Russian regions are characterized by a high level of differentiation in industrial, export, innovation, and management potential [12]. Secondly, the reorientation to the establishment of an economy at a higher technological level has not been fully implemented until now [17]. It should also be noted that it is advisable to revise existing solutions in this area, taking into account the advantages and risks of the digital economy. Thus, the search for effective institutions and tools to activate the export potential of the high-tech industry at the regional level is relevant. At the same time, there are not enough studies that would take into account all these circumstances and offer options for boosting exports adapted to the regional environment and taking into account the possibilities of the digital economy in the analyzed scientific field.

With this in mind, the purpose of this study is to search for institutions and tools for implementing a high-tech development track and successfully promoting relevant products to world markets that are adequate to specific regional conditions.

The Rostov Region of Russia was chosen as a model region for the case study. This is determined by several factors. Firstly, the region is characterized by a fairly high export potential due to its geographical location, established economic relations, and the level of socio-economic development. Secondly, the region is quite typical in a number of ways for Russian regions, which makes it possible to use the findings and results of the study for other territories of the country. Thirdly, in the region, significant attention is paid at the strategic and institutional levels to the development of export potential.

The study covers three main objectives. Firstly, to determine the theoretical foundations for the institutional and instrumental support for exports based on literary analysis. Secondly, to analyze the case of a specific region of Russia to determine the conditions for supporting industrial exports. Thirdly, to propose solutions to improve export support for a specific regional system (using the capabilities of the digital economy).

This determined the originality and novelty of the presented research. Firstly, within the framework of study, the analysis of tools and institutions for the development of industrial exports is combined. This is important because, according to research, economic instruments themselves lose effectiveness without an adequate institutional environment. Secondly, such an analysis was carried out using a combination of scientometric and qualitative analysis methods, including a case study. Thirdly, consideration of general trends and real regional specifics of export support for enterprises in the high-tech sector in digital reality was implemented. It allows us to propose an original conceptual model and digital platform for the development of the export potential of the high-tech industry of the Rostov region.

The logic of the article is represented by the following structural elements: First, a theoretical analysis of scientific papers on the issues of determining factors, tools, and institutions to support the export of high-tech industry enterprises was carried out. Furthermore, the methods and materials of the study are disclosed. After that, the results of the case stage of the implementation of export support in the Rostov region of Russia as a typical region of a country with high export potential are presented. Based on the results, conclusions are presented, including limitations and future research directions.

2 Literature Review and Theoretical Background

In the modern economic literature, various aspects of the development of high-tech industries are characterized by a fairly high degree of elaboration.

The high-tech sector of the economy is represented by a set of high-tech industries, enterprises, and research and design institutes that develop, produce, repair, and modernize high-tech products [6]. The high-tech sector includes many industries [7].

The high-tech industry sector plays a key role in the development of the state's economy [13]. In the era of large-scale digitalization of economic, political, and social processes through the use of cutting-edge digital technologies, high-tech products are in great demand in the world market. In this regard, states have a need to increase the pace of production of high-tech products and increase the export potential of the high-tech industry [13]. This requires the development of institutions and tools to activate, support, and ensure the export activities of high-tech enterprises at the regional level.

As part of the study, the authors conducted a scientometric analysis of the subject field using the apparatus and data of the SciVal, Scopus, and ScienceDirect systems of the Elsevier ecosystem. The development of the export potential of

Table 1 Scientometric indicators of topic cluster TC.24—Industry; Innovation; entrepreneurship in the SciVal system [25]

Scientometric indicator	2011–2020	2016–2022
Scholarly output	115.687	89.618
Field-weighted citation impact	1.23	1.19
International collaboration	26.729	22.715
Views count	5,149.076	3,522.43
Citation count	1,548.916	673.797
Topic prominence percentile	98.997	98.997

high-tech industries at the regional level is associated with increasing the efficiency of their functioning and the pace of their production. With this in mind, the authors chose Scival Topic Cluster TC.24—Industry; Innovation; Entrepreneurship. Table 1 presents scientometric indicators reflecting the relevance of scientific research in this cluster.

The results of the analysis showed that scientific research in this thematic area is in high demand. There is a positive trend in the number of scientific publications as well as indicators reflecting the citation level; international cooperation in the study of industry, innovation, and entrepreneurship is growing. The Topic Prominence percentile is close to the highest indicator of 100 and is equal to 98. Publications related to the use of innovative digital solutions that contribute to the development and increase in the volume of production of high-tech industries are particularly in demand and have a high impact.

In turn, 15.374 publications were selected in the Sciencedirect system using the keywords "export potential of high-tech industry." Having narrowed the field of research to the study of specific institutions and tools that contribute to the development of the export potential of the high-tech industry, 3.648 scientific publications were identified. The analysis of the annual dynamics of the number of publications on this topic allows us to define the annual growth in the number of publications. So, for 10 years, the interest of researchers in this scientific area has grown 3 times (Fig. 1).

Based on the analysis of publications indexed in SCOPUS, a selection of the most relevant publications (1137 articles) was made according to the keywords "industrial AND export AND support". A network map of keywords was built using the VOSviewer software product (Fig. 2) [34].

The analysis shows that, currently, the support of industrial exports is closely linked to digital transformation, data, interactions, and industrial policy. While specific institutions and tools find less attention in scientific publications.

The analysis of bibliometric indicators and scientometric data made it possible to identify a number of articles most closely related to the research topic. The content analysis of these studies made it possible to identify the scientific results most closely related to the subject of this paper.

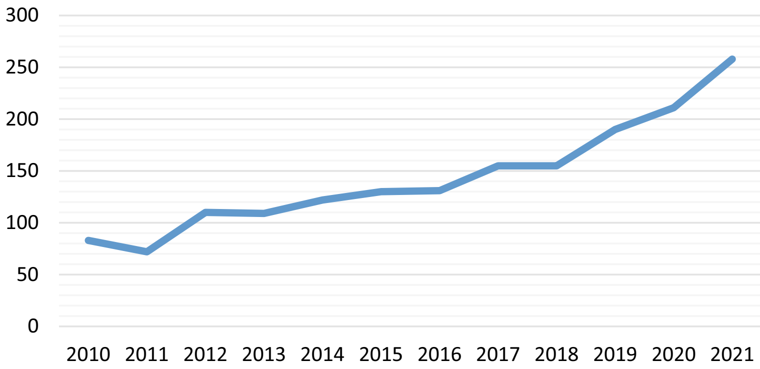

Fig. 1 The number of publications on the research of institutions and instruments for the development of the export potential of high-tech industry [26]

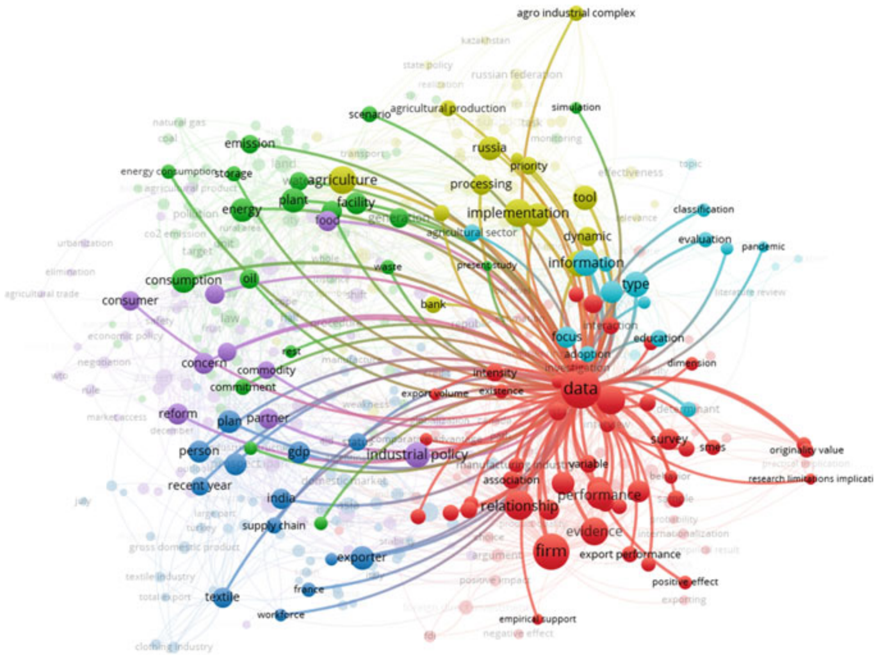

Fig. 2 Network visualization for publications connected to industrial export support

Shoufu Lin et al. adhere to the positions according to which the effectiveness of technological innovations plays a very important guiding role in industrial development and determines the overall trajectory of the development of the high-tech industry [19].

Zhi Yuan Lü and Mu Zhang consider the effectiveness of financial incentives for the high-tech sector from the point of view of the activities of specific enterprises and regions, using the tools of the DEA static analysis model to assess the pure technical efficiency, scale efficiency, and comprehensive efficiency of the new generation of high-tech industry financial support. Using this digital model when planning the volume of high-tech products produced, the authors identify the most promising regions for the activation of export activities of high-tech enterprises [24].

In their research, Bofei Yang and Shengjun Zhu claim that state financial institutions play a key role in promoting digital innovation in high-tech industries. Using a set of data on high-tech industries in China, the authors pay attention not only to the direct impact of public funds on the innovative dynamics of high-tech industries, but also to their indirect effects and the articulation of public and private funds. Empirical results confirm that state financial institutions can increase the innovative efficiency of high-tech industries in terms of the development of patents and new digital products. However, the share of public funds should be maintained at a certain level in order to avoid excessive dependence of high-tech industry enterprises on public funds. Public funds are needed more in lagging regions and immature industries with a lack of financial resources and other factors for innovation in high-tech industries [2].

Guowei Dong, Ari Kokko, and Haoyong Zhou examine the role of ownership (state and foreign) in the relationship between innovation and exports. Analyzing a large set of data on Chinese manufacturing firms for 2000–2007, the authors found that state ownership has a positive impact on the relationship between innovation and exports. Researchers connect this effect to the privileged access of state-owned firms to additional resources and networks that strengthen their ability to use innovation to create exports [8].

Based on the research of the impact of both internal and external forces on China's solar photovoltaic industry exports during 2007–2016, Xiangdong Zhu, Canfei He, and Zhutong Gu determined that policy incentives are essential in stimulating PV exports by compensating for the shortage of industrial bases [22]. The authors also managed to identify a significant impact of regional specifics on the realization of the export potential of high-tech industry companies, in particular, in the context of the introduction of protectionist restrictions.

Silvaa Jesus and co-authors propose methods of data mining to predict the export activity of a company. The following methods are distinguished: Synthetic Minority Oversampling Technique, K-Means Clustering, Generalized Regression Neural Network, Feed Forward Back Propagation Neural Network, Support Vector Machine, Decision Tree, and Naive Bayes. Artificial neural networks showed 85.7% of the ability to distinguish and classify companies according to their competitive profile. The analysis covers the stages of measurement, evaluation, and classification of companies based on the proposal of 16 key factors of export potential [18].

Based on the analysis of 53 countries and regions with the closest high-tech product trade relationships with China, Wang J. & Du Y. built the Gravity Model and identified the main factors influencing the export of high-tech products in China since 2006 [21]. Along with recommendations on the strategic choice of countries for exporting high-tech products, the authors show that China should actively participate in the development of various trade rules. This once again underlines the empirically proven great role of institutions in the activation and provision of high-tech industries.

Malik et al. show in even more detail how informal (cultural features) and formal (government policy) institutions affect high-tech exports [20].

Bierut and Dybka, analyzing the impact of institutional and technological factors on the export of high-tech products, note that higher patenting increases overall exports; higher R&D transforms export structure; and most institutions also have either a direct or transformational impact on exports [1]. According to the results of this study (based on data for 28 countries in the European Union over the period 1995–2017), exports of manufactured goods benefit most from a higher level of freedom of international trade, improved quality of regulation (credit market, business, and labor market) and institutions that ensure the stability of the value of money (especially those that maintain low and stable inflation).

In turn, Ce'line Carrere, based on a gravity model that includes 130 countries and is estimated with panel data over the period 1962–1996, proved that regional agreements have generated a significant increase in trade [3].

The incentives and limitations of innovation-oriented development of high-tech industry in an institutional context (taking into account the role of the state) are also studied in various works in relation to industry, regional specifics, or features of various economic entities [16], including directly in its export part [4, 11, 23].

It is possible to conclude that, despite the significant attention paid to the analysis of the factors affecting the development of the high-tech industry sector and the export of its products, there is no agreement on the role of these factors. At the same time, the importance of taking into account territorial and sectoral specifics in the formation of tools and institutions for the development of industrial exports is recognized. The majority of the authors also testify in favor of a systematic approach to solving relevant issues. This determines the importance of analyzing and evaluating the institutional support for the export activities of the high-tech industry and developing recommendations for specific regional systems.

3 Materials and Methods

The presented study was conducted using a systematic, regulatory-targeted, and resource-based approache. Initially, the methods of scientometric and bibliometric analysis were used in the research. Based on that, the most important publications in the thematic field under consideration were identified. Their content analysis made it possible to determine the conditions for further research of institutions and tools for the development of the export potential of high-tech industry in relation to a specific regional system of the Russian Federation. The Rostov Region of Russia was chosen as a model region for the case study. It allows to assess both the availability and effectiveness of the existing export support system.

The study further carried out a qualitative analysis of the institutions and tools for activating the export activity of the region on the example of the Rostov region, since this region has a fairly high level of export potential of high-tech industries due to the concentration of large high-tech manufacturers on its territory [5]. Qualitative analysis allowed us to get the most realistic vision of the institutional structure of the development of the export potential of the high-tech industry of the Rostov region. This method allowed us to describe the existing institutions and tools and to determine the causal relationships between the institutional structure and the level of development of the export potential of the high-tech industry in the region. Formal and informal institutions of the Rostov region related to the export activities of high-tech enterprises were studied in detail. Tools for supporting the export activities of high-tech enterprises of the region were identified on the basis of information provided by federal executive authorities of the Russian Federation, regional authorities of the Rostov region, as well as specific development institutions (Export Support Center of the Rostov region, Export Council under the Governor of the Rostov Region, Rostov Regional Agency for Entrepreneurship Support, as well as the Chamber of Commerce and Industry of the Rostov region) [27–33]. The authors identified the shortcomings of the existing regional institutional framework of the high-tech sector of the Rostov region, which allowed us to build our own integrated conceptual model of institutions and tools for the development of the export potential of the high-tech industry of the Rostov region, based on digital interdepartmental interaction.

4 Results

The efficiency of the high-tech industry sector, its further modernization, as well as the development of the export potential of high-tech industries directly depend on the functioning of institutions and tools aimed at improving the current state of the export potential of the high-tech industry sector and the mechanism of their interaction at the federal and regional levels [14]. The system of considered institutions and instruments for the development of the high-tech export of the Rostov region is presented in Table 2.

The current scheme has a number of imperfections, including the lack of a unified system of interconnected functioning of institutions and tools; a complex and heterogeneous structure; violation of the hierarchy of subordination between institutions; overlapping tools in terms of providing consulting services; excessive bureaucracy; irregularity of functioning; low awareness of enterprises about the existing institutions and support tools; the unprocessed mechanism of control and supervisory activities; high time and transaction costs of enterprises for the provision of services, which proves a relatively small indicator of the share of high-tech industry in the total exports of the Rostov region.

As a means of removing the limitations identified during the study, it is proposed to create an end-to-end integrated system to support the export of high-tech products. The technological core of such a system should be a common digital platform [16]. The growth of the production of high-tech goods will occur due to stimulating and preferential measures aimed at the development of the latest scientific technologies, the creation of new industries, and the modernization of old ones. The functioning of this mechanism will expand the export potential of high-tech companies in the region. Figure 3 shows a conceptual model of institutions and tools for the development of the export potential of the high-tech industry of the Rostov region. The proposed system includes five entities with a linear-functional organizational structure, whose

Table 2 Institutes and instruments for the development of the export potential of the high-tech industry of the Rostov region [15, 27–33]

Institutions	Instruments	
Formal institutions		
Federal executive authorities	Government of the Russian Federation	Development of a policy in the field of manufacturing and export of high-tech products
	Ministry of Economic Development of the Russian Federation	
	Ministry of Industry and Trade of the Russian Federation	Adoption of strategies for the implementation of the developed policy at the federal level
Regional executive authorities	Government of the Rostov region	Implementation of policy in the field of production and export of high-tech products at the regional level
	Ministry of Economic Development of the Rostov Region	
	Ministry of Industry and Energy of the Rostov Region	Implementation of strategies for the developed policy at the regional level
Development institutions	Export Support Center of the Rostov region	Search and selection of a foreign buyer. Support of the export contract. Organization of fairs, exhibitions, business missions. Export acceleration
	Expert Council under the Governor of the Rostov Region	Recommendations on the identification and reduction of administrative barriers, on measures of state support for export activities
	Rostov Regional Agency for Entrepreneurship Support	Provision of loans. Provision of consulting, educational, and property services
	Chamber of Commerce and Industry of the Rostov Region	Promotion of entrepreneurship in the region. Examination and certification of the origin of goods for export. Provision of expert and evaluation services

(continued)

Table 2 (continued)

Institutions	Instruments	
Informal institutions		
Society regulation	Culture	Customs and traditions formed in society form a mentality that affects the consumer ability of an individual
	Norms of morality	
Regulating the activities of a high-tech enterprise	Corporate culture	They have an impact on the increase in the costs of the enterprise, determine the level of motivation to work and the quality of work
	Business culture	

activities are aimed at developing and implementing tools that contribute to increasing the growth rate of production of high-tech of the region. The interaction between these institutions should be carried out using digital platform that provides information exchange and decision-making.

The authors selected five institutions based on the results of the analysis of the existing institutional system. These institutions need to reform and adjust their functional characteristics in the context of the interconnectedness of actions to solve the task of activating the export activities of high-tech enterprises. In this regard, an attempt was made to build a conceptual model that combined five separately functioning institutions into a single integrated system. The construction of this model using a linear-functional organizational structure is explained by the convenience of management, combining a clear division of labor with a hierarchy of management levels, flexibility, and rapid adaptation to external and internal shocks.

The Federal executive authorities develop vectors directions for the development of the high-tech sector, taking into account the quantity and quality of available resources, the availability of production and technical bases, labor resources, scientific developments, and the conjuncture of the world and domestic markets, and also approve an action plan (strategy) to increase the export potential of Russian high-tech products. Regional executive authorities develop and approve their own set of measures (tools) for the development of high-tech industry production in the Rostov region.

The activities of the Center for the Development of the High-Tech Industry Sector of the Rostov region are aimed at creating favorable conditions for the functioning of high-tech enterprises through the implementation of financial incentive mechanisms, tax and credit preferences, assistance in the registration of all necessary documents, licenses, and reducing time and transaction costs of enterprises. Particular attention should be paid to the creation of territories of advanced socio-economic development within the framework of the proposed system, whose residents can only be enterprises and sole proprietors specializing in the production of high-tech products, which will increase the motivation of enterprises to create and develop activities in the field of production of high-tech goods. Since the government of the Russian Federation

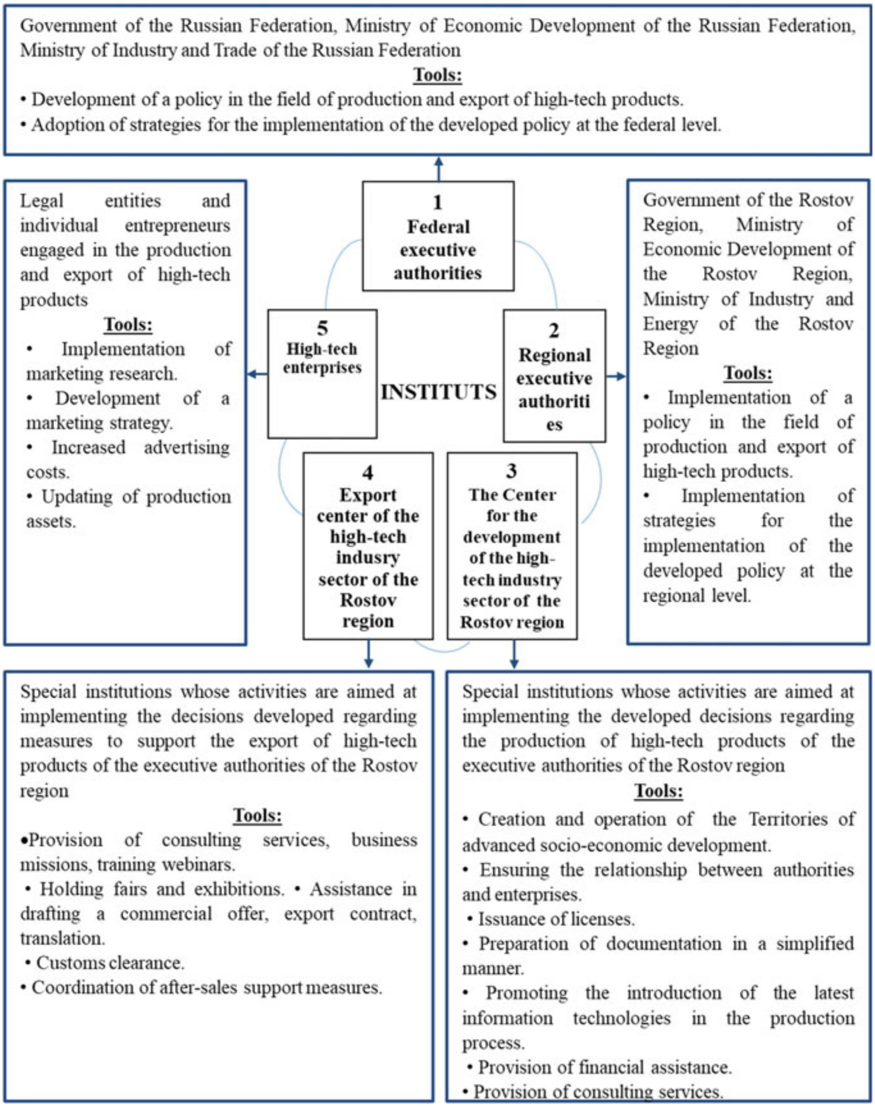

Fig. 3 Conceptual model of institutions and tools for the development of the export potential of the high-tech industries of the Rostov region

has announced a course for the introduction of digital automated technologies in the manufacturing industry, this institute provides material and technical assistance in the implementation of the achievements of the Industry 4.0 in manufacturing.

The Export Center of the High-tech Industry sector combines a set of competencies currently belonging to special institutions for the development of the export potential of the region, namely, the Export Support Center of the Rostov Region, the Export

Council under the Governor of the Rostov Region, the Rostov Regional Agency for Entrepreneurship Support, and the Chamber of Commerce and Industry of the Rostov region. That is, this institution helps to stimulate growth and simplify export procedures for high-tech goods. The tools for implementing the functions of the Export Center in the high-tech industry sector include searching for a potential buyer; drafting a commercial offer; services for translating information and documentation into a foreign language; assistance in concluding a foreign trade contract; consulting services; conducting business missions and training webinars; customs clearance; and coordination of after-sales service of high-tech products abroad.

High-tech enterprises are the last institutions included in the structure of the proposed system. The production of high-tech products can be carried out by legal entities or sole proprietors. Manufacturers of high-tech products implement the following tools to improve production: updating fixed assets; attracting highly qualified specialists; conducting research and development within the enterprise; as well as developing export potential: conducting marketing research; developing a marketing strategy; increasing advertising costs; searching for partners.

Within the framework of the proposed model of the functioning of institutions and tools for developing the export potential of high-tech industries, it is necessary to introduce a system of digital interaction between all institutions to reduce time and material costs and improve the efficiency of the digital integrated system.

The proposed model in the future is able to increase the export potential of the high-tech industry of the Rostov region due to the digitally integrated functioning of the system of joint activities of institutions and tools that contribute to the creation and improvement of conditions for the production of high-tech products in the region and their further export to the world market.

5 Conclusion

The study showed that the issues of institutional and instrumental support for high-tech exports are relevant in economic science and practice. At the same time, the development and adoption of the most effective solutions in this area are connected with the peculiarities of specific regional systems. In the Rostov region, within the framework of this direction, federal and regional institutions are functioning, implementing a set of measures (tools) to support the production and activation of export activities of high-tech enterprises. However, this mechanism is insufficiently effective due to a number of circumstances, the main one of which is the absence of a single digital integrated system reflecting the process of manufacturing high-tech products at all stages, from the development by state executive authorities of a unified economic policy in the field of high-tech sector development to the implementation of measures to coordinate after-sales service of high-tech products abroad. In this regard, the authors of the study proposed a model of institutions and tools that contribute to the development of the export potential of the high-tech industry of the Rostov region, functioning within one integrated digital system. The proposed model of the export support mechanism has several important characteristics. Firstly, it involves taking into account the universal components of the macro level, but it is also focused on the regional capabilities of authorities and public organizations. Secondly, the author's scheme covers institutions and instruments in one system. Thirdly, it is assumed that the institutions and tools for boosting exports are quite closely related to the general conditions for the development of high-tech industries in the regional dimension. In addition, thanks to the integrated digital platform, enterprises have the opportunity to use new solutions of the digital economy. The proposed model is quite universal and can also be used in other regions of Russia to increase the efficiency of export support for high-tech products. It should also be noted that it is most appropriate to use the proposed conceptual model for regions similar in geographical and economic characteristics in the Rostov region, which acted as a model region for the case study.

The limitations of this study are related to the complexity of assessing the effectiveness of the functioning of institutions for the development of the high-tech industry in the region as well as the lack of a unified methodology for assessing the level of export potential of the high-tech industry in the region. Future research will be related to the implementation of these two vectors of scientific research.

References

1. Bierut, B., & Dybka, B. (2021). Increase versus transformation of exports through technological and institutional innovation: Evidence from Bayesian model averaging. *Economic Modelling, 99*, 68–80. https://doi.org/10.1016/j.econmod.2021.105501.
2. Bofei, Y., & Shengjun, Z. (2022). Public funds in high-tech industries: A blessing or a curse. *Socio-Economic Planning Sciences, 83*, 68–80.
3. Carrère, C. (2006). Revisiting the effects of regional trade agreements on trade flows with proper specification of the gravity model. *European Economic Review, 50*(2), 223–247. https://doi.org/10.1016/j.euroecorev.2004.06.001.
4. Chebukhanova, L. V., & Zimakov, A. M. (2022). Resource support of innovative small and medium-sized enterprises for space industry development in Russia. *Acta Astronautica, 200*, 626–634. https://doi.org/10.1016/j.actaastro.2022.09.033.
5. Deynichenko, A.S. (2021, November 18–20). Overview of the export activities of manufacturers of high-tech products of the Rostov region [Paper presentation]. In *XVI International Conference Russian Regions in the Focus of Change*, Yekaterinburg, Russia. Retrieved from https://elibrary.ru/item.asp?id=48037287.
6. Gavrilova, S. V. (2014). Conceptual foundations of the definition of the high-tech sector of the economy and the functioning of high-tech companies. *Economics, Statistics and Computer Science, 2*, 53–57.
7. Garina, E. P., Shpilevskaya, E. V., & Andryashina, N. S. (2016). The study of approaches to the definition of a high-tech product in production. *Bulletin of the Mininsky University, 1*, 27–36.
8. Guowei, D., Ari, K., & Haoyong, Z. (2022). Innovation and export performance of emerging market enterprises: The roles of state and foreign ownership in China. *International Business Review, 31*(6), 56–49. https://doi.org/10.1016/j.ibusrev.2022.102025.
9. Habel, J., Jarotschkin, V., Schmitz, B., Eggert, A., & Plötner, O. (2020). Industrial buying during the coronavirus pandemic: A cross-cultural study. *Industrial Marketing Management, 88*, 195–205. https://doi.org/10.1016/j.indmarman.2020.05.015.

10. Konig, W. (2020). Energy efficiency in industrial organizations—A cultural-institutional framework of decision making. *Energy Research & Social Science, 60*, 101–114. https://doi.org/10.1016/j.erss.2019.101314.
11. Nobuhiro, H. (2021). Impact of tighter controls on Japanese chemical exports to Korea. *Economic Modelling, 94*, 631–648. https://doi.org/10.1016/j.econmod.2020.02.006.
12. Nikitaeva, A. Yu. (2017). The institutional structure of the region in the context of innovative development of industry. *Journal of Institutional Research*, *9*(1), 134–149. https://doi.org/10.17835/2076-6297.2017.9.1.134-14.
13. Nikitaeva, A.Yu., & Deynichenko, A. S. (2021). Development of high-tech industry in the South of Russia: opportunities for increasing export potential. *Natural Sciences and Humanities Research Magazine*, *38*(6), 254–261.
14. Pedro, C., & Jorge, N. (2020). Sociotype and cultural evolution: The acceleration of cultural change alongside industrial revolutions. *Bio Systems, 195*, 104170. https://doi.org/10.1016/j.biosystems.2020.104170.
15. Pryor, F. L. (2007). Culture and economic systems. *The American Journal of Economics and Sociology, 66*(4), 817–855.
16. Qiaozhi, W., Pauline, D., & Yong, C. (2017). Building institutional capacity for industrial symbiosis development: A case study of an industrial symbiosis coordination network in China. *Journal of Cleaner Production, 142*(4), 1571–1582. https://doi.org/10.1016/j.jclepro.2016.11.146.
17. Şener, S., & Sarıdoğan, E. (2011). The effects of science-technology-innovation on competitiveness and economic growth. *Procedia - Social and Behavioral Sciences, 24*, 815–828.
18. Silvaa, J., Borré, J., Castillo, A., Castro, L., & Varelae, N. (2019). Integration of data mining classification techniques and ensemble learning for predicting the export potential of a company. *Procedia Computer Science, 151*, 1194–1200.
19. Shoufu, L., Ruoyun, L., Ji, S., & Fei, W. (2021). Dynamically evaluating technological innovation efficiency of high-tech industry in China: Provincial, regional and industrial perspective. *Socio-Economic Planning Sciences, 74*, 11–19.
20. Tariq, H., Tao, X., & Chunhui, H. (2021). The transformation of national patents for high-technology exports: Moderating effects of national cultures. *International Business Review, 30*(1), 101–117. https://doi.org/10.1016/j.ibusrev.2020.101771.
21. Wang, J., & Du, Y. (2017, June 16–18). A study of china's high-tech products trade flow and export potential based on gravity model [Paper presentation]. In *International Conference on Services Systems and Services Management*, Dalian, China. https://doi.org/10.1109/ICSSSM.2017.7996280.
22. Xiangdong, Z., Canfei, H., & Zhutong, G. (2021). How do local policies and trade barriers reshape the export of Chinese photovoltaic products? *Journal of Cleaner Production, 278*(1), 123995. https://doi.org/10.1016/j.jclepro.2020.123995.
23. Yan, G., & Haochen, Z. (2022). Spillovers of innovation subsidies on regional industry growth: Evidence from China. *Economic Modelling, 112*, 325–342. https://doi.org/10.1016/j.econmod.2022.105869.
24. Zhi, L., & Zhang, M. (2021). Evaluation on financial support efficiency of new generation high-tech industry in China. *Journal of the Information Technology and Quantitative Management, 199*, 254–261.
25. Information system of scientometric indicators Scival. (2022, September 9). *Scientometric indicators of Topic Cluster TC.24 Industry; Innovation; Entrepre-neurship.* https://www.scival.com/.
26. ScienceDirect information system of scientometric indicators. (2022, September 9). *Publications on the research of institutions and instruments for the development of the export potential of high-tech industry.* https://www.sciencedirect.com/.
27. Ministry of Economic Development of the Russian Federation. (2022, September 15). *Portal of foreign economic activity.* Retrieved from http://www.ved.gov.ru/rus_export/regionalprogram/.

28. Ministry of Industry and Trade of the Russian Federation. (2022, September 16). *Export support in the constituent entities of the Russian Federation.* Retrieved from https://minpromtorg.gov.ru/presscentre/news/#!gosudarstvennaya_podderzhka_posleprodazhnogo_obsluzhivaniya_vysokotehnologichnyh_tovarov_postavlyaemyh_na_eksport.
29. Government of the Rostov region. (2022, September 15). *Industrial development in the region.* Retrieved from https://www.donland.ru.
30. Autonomous Non-profit Organization "Center for Coordination of Support for Export-oriented small and medium-sized businesses". (2022, September 9). *Export Support Tools.* Retrieved from https://export161.com/services/eksportnaya-akseleraciya.
31. Autonomous non–profit organization - microfinance Company "Rostov Regional Agency for Entrepreneurship Support". (2022, September 15). *Export Support Institutions.* http://www.rrapp.ru/kto-my/o-nas.html.
32. Ministry of Economic Development of the Russian Federation. (2022, September 25). *Portal of foreign economic activity. Export support in the constituent entities of the Russian Federation.* Retrieved from http://www.ved.gov.ru/rus_export/regionalprogram/.
33. Ministry of Industry and Trade of the Russian Federation. (2022, September 17). *Export support in the constituent entities of the Russian Federation.* Retrieved from https://minpromtorg.gov.ru/presscentre/news/#!gosudarstvennaya_podderzhka_posleprodazhnogo_obsluzhivaniya_vysokotehnologichnyh_tovarov_postavlyaemyh_na_eksport.
34. VOSviewer software visualization based on Scopus information system data. (2022, October 21). Publications on the research of institutions and instruments for the development of the export potential of high-tech industry. Retrieved from https://www.scopus.com/search/form.uri?display=basic#basic.

Types of Digital Industrial Platforms: Case Study of a Gas Company

Wadim Strielkowski, Victoria Akberdina, Olga Smirnova, Alena Ponomareva, and Anna Barybina

Abstract Following the digital transformation of economic industries, the issue of digital industrial platforms that constitute new market structures and provide value accumulation for participants in industrial ecosystems is becoming relevant. A digital industrial platform represents a hybrid ecosystem that provides efficient networking through the use of end-to-end digital technologies aimed at increasing the competitiveness and innovation/technological development of participants in industrial ecosystems. The aim of this research is to provide a typology of digital industrial platforms according to the criteria of functionality and manageability. The theoretical framework of the study is represented by the market-based, institutional and networking approaches. The period of existence of digital industrial platforms is just over 10 years, thence the data for assessing their functionality and economic efficiency are just in the process of conceptualization. Therefore, to date, the basic method of studying digital platforms in industries is an extended case study. One of the world's largest gas industry companies, Gazprom, was selected as a case study for validating the typology of digital industry platforms. The research focused on the functionality, architecture and management type of Gazprom's four digital platforms: the counterparty interaction digital platform, continuous production management

W. Strielkowski
Cambridge Institute for Advanced Studies, 23 King Street, Cambridge CB1 1AH, UK
e-mail: strielkowski@gmail.com

Czech University of Life Sciences Prague, Kamýcká 129, 165 00 Praha-Suchdol, Prague, Czech Republic

V. Akberdina (✉) · O. Smirnova · A. Ponomareva · A. Barybina
Institute of Economics of the Ural Branch of the Russian Academy of Sciences, 29 Moskovskaya Str, Ekaterinburg 620014, Russian Federation
e-mail: akberdina.vv@uiec.ru

O. Smirnova
e-mail: smirnova.op@uiec.ru

A. Ponomareva
e-mail: ponomareva.ao@uiec.ru

A. Barybina
e-mail: barybina.az@uiec.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_11

digital platform, supply chain management digital platform and technology vision digital platform. As a result, the authors confirmed the typology of digital industrial platforms by the criterion of functionality: type I platform (a digital ecosystem of the interaction of industrial ecosystem participants), and type II platform (a set of end-to-end production technologies forming the business model of the industrial enterprise). The typology was supplemented by a new criterion—the 'manageability' of the platform, which made it possible to introduce additional types of digital industrial platforms: centralised, decentralised and mixed. The results stemming from this research are intended to provide a better understanding of the phenomenon of digital industrial platforms and can be used in the development of strategies for the digital transformation of industrial markets.

Keywords Digital platform · Digital industrial platforms · Gas industry · Ecosystem · Gazprom

1 Introduction

Technological revolutions yield new forms of organisations that are better adapted to the new value creation methods in the new technological environment. This is also true of the markedly growing trend of digitalisation of the economy, which has spawned a new kind of business organisation known as 'digital platforms'. Companies with a business model representing a digital platform have the highest capitalisation values. The cumulative market capitalisation of just four companies: Alphabet (Google's parent company), Amazon, Microsoft and Apple were over $5.7 trillion in December 2020, which exceeds the total market capitalisation of the entire Euronext stock exchange and a third of the value of the Standard & Poor's 100 U.S. stock index [18]. The 'big tech' platform firms have become so highly capitalised that they have become richer and more influential than many countries [10, 43]. Lately, there has been a significant activation of research covering the development of a digital platform economy—the so-called 'gig economy', as defined in academic literature, which influences the formation of a networking institutional environment of participants in industrial ecosystems [25, 46, 48]. The gig economy covers many sharing platforms (e.g. Lyft, Airbnb and Uber), micro-work platforms (e.g. Amazon's Mechanical Turk) or the 'mass work' platforms (e.g. Fiverr, Deliveroo and Upwork) [47]. However, the cited cases belong predominantly to the service and development sector.

When it comes to the industrial manufacturing, digital platforms are just at the onset. The experience of corporations and the conclusions of academic literature shows the increasing role of digital industrial platforms. The industry is actively forming vertically and horizontally interconnected networks [4, 29] that are creating value and changing industrial markets [25]. The present paper aims at highlighting the development trends of digital industrial platforms and at showing their diversity.

Therefore, *the aim of the study* is to validate the typology of digital industrial platforms according to the criteria of functionality and manageability, based on a case study in respect of one of the world's largest gas companies, Gazprom PJSC. The main *research questions* of the paper are: (1) What types of digital industrial platforms can be distinguished on the basis of their functionality? (2) In what way the functionality of a digital industrial platform affects the platform management type?

The answers to these questions will allow us to expand knowledge of digital platforms in the industry, add extra awareness about their architecture and functionality, as well as about the type of management.

2 Theoretical Frameworks

The review of the current research literature devoted to the functionality of digital platforms makes it possible to formulate several tendencies inherent in the economy and economic agents operating in the new environment of the digital platform proliferation. The digital platform concept is already common in economic literature as a symbol of the digital age. Digital platforms represent quite a powerful factor in the transformation of economic relations. Today, according to Osipov [37] and other researchers, they are side-lining such postulates of economic formation as 'marketability' and 'regularity'. The following wording, out of the many definitions of a digital platform, seems to be the most concise and best characterising its functional essence. A digital platform is 'a digital infrastructure that creates value by enabling two or more groups to interact' [31].

Networking in industry is viewed by scholars as a conjugate process involving the integration of mutually beneficial interests between businesses and customers, as well as other actors such as suppliers, informal networks, regional business and industry networks, higher education institutions and research centres. Strengthening of such interaction contributes to maximising socio-economic effects and stirring innovation activities [8, 18, 42, 44, 49].

To address the posed research questions, the following theoretical framework will be followed: First, the authors shall rely on the *market (industry-specific) approach*, which makes it possible to identify potential industrial markets where digital platforms are in the process of active formation or where all necessary conditions for this have already been shaped [1, 5, 20, 23]. Industry specifics in individual sectors, technological readiness and digital maturity determine in the aggregate the pace and quality of the digital transformation of business models in industry, as well as the potential for the formation of digital ecosystems.

The fundamental core of platforms supposes organising a bond between buyers and sellers, creating an institutional environment that allows its users to gain benefits and obtain contracts while minimising transaction costs. In fact, this type of institutional environment was practised in economic and social life well before the digital age. The format of offline platforms has been known since long ago in the form of fairs, exhibitions, newspapers, magazines, organisation of conferences and many other social events. However, the technological transformation and the spread of ICT have led to a change in the organisation pattern of platforms—from physical to virtual nature (from offline to online mode). The digital organisation of platforms has brought its main effect—an increase in the number of users, which ultimately enhances the outcome value for each user [37, 39]. The enhancement of this value for platform users, depending on their number, is primarily provided by the network effect and the scale effect. The participants in digital networking platforms, without being tied to specific activities, get an opportunity to enter new markets. This yields a favourable effect of digital platforms—lowering the market entry barriers. If a company is operating on a digital platform, its size is not a dominant factor influencing its competitiveness. However, on the one hand, by levelling the participants' rights and opportunities and through increasing consumer awareness of all market conditions, the digital platform creates due conditions for purer competition. On the other hand, by dictating the conditions for the interaction of agents within the digital platform, it can influence the economic behaviour of both the producers and consumers, as well as establish the price of its end products based on the charges for its digital services.

The second theoretical framework of the present study is *the institutional approach* which will enable one to understand the actual substance of platformization in industry as a global and dynamic process of hybrid reality formation (fusion of physical and virtual realities) driven by the development and spread of multilateral platforms [17, 19], and to realise the digital platform regulation particularities [15, 36]. The key role of digital platforms as mediatory transaction institutions is the accumulation of digital and non-digital information, as well as tangible, intangible, financial and other resources, and providing ecosystem participants with access to these resources. By the end of 2021, the Markets-and-Markets analysts noted a significant increase in spending by both public and private global companies on Big Data processing technologies. The total worldwide corporate expenses on Big Data tools reached $162.6 billion by 2021 [30]. Research And Markets analysts forecast that the Big Data analytics market will grow at an average rate of 11.9% from 2020 to 2028. This report shows that Big Data analytics is a driving force of the entire digital environment, since their analysis provides information representing a commercial value. The issue of legal safeguarding of personal data and user privacy, as part of the operation of digital platforms, is currently under active discussion. In particular, in 2019, the EU introduced a new Platform for Business Regulation. The key aspects handled by this regulation include ensuring the transparency of relations, dealing with unfair practices and improving the trading environment for digital platform users. In 2020, the EU Commission published its proposals for a New Digital Markets Act (DMA) and a New Digital Services Act (DSA) [13, 14]. The objectives of these Acts involve the creation of a safe digital space protecting the rights of all users dealing with digital services, as well as the provision of equal conditions for the stimulation of innovations and growth of competitiveness both in the EU and globally. The formation of digital platforms in Russia is institutionally based on the Russian Digital Economy Programme and the regulations governing its realisation [11, 12].

The third approach to be relied on is *the networking approach* that makes it possible to understand the principles of interaction between active participants in digital platforms [23, 32, 34, 45]. The digital transformation of industry brings a global change to business models in general, with the value creation process shifting to the network space involving interaction between different partners and the intersection of individual business models in the cross-industrial environment.

Numerous information network effects take place at the level of the global information economy. These are essentially synergistic network effects expressed in various forms. The simultaneous effect of Moore's law, the Internet, computer involvement and the new financial instruments has led to the 'rapid innovations' period. The diminishing marginal productivity law no longer applies in the network economy, unlike the traditional economy. Direct network effects and positive feedback generate increasing marginal productivity. At the same time, the integration and networking processes involving developers, producers, sellers and consumers of intelligent information goods, as well as the processes adding value to network effects, are significantly scaled up.

And finally, *the fourth framework* of our research is the trends of gas industry's development. As a high-quality fuel and relatively clean energy, natural gas is essential for adjusting the energy structure of the global economy [54]. Global tendencies in gas consumption and trends in gas mining in countries with high reserves determine the multi-scenario demand for natural gas in the world [22, 41]. Against this background, a large-scale digital transformation of the gas industry is taking place—the latest technologies allow gas companies to create digital twins of their assets [52], the demand for robots to perform technical safety tasks in regions with extreme temperatures is growing at a tremendous rate [53] and digital tools based on artificial intelligence solve monitoring and forecasting tasks [26]. Nevertheless, there are unresolved problems in the industry itself related to the efficiency of the transition to shale gas [51], desertification of the territories where gas mining has ended [38], focusing on investments in the recovery of the natural environment and people's places of life [9].

The above theoretical frameworks will allow the authors to focus on the conclusions relative to the active functionality of digital industrial platforms and their management models.

3 Methods and Data

The period of existence of digital industry platforms is just over 10 years. Within this period, the scope of data for assessing their functionality and economic efficiency has just been in the process of conceptualisation. Therefore, to date, the basic method of studying digital platforms in industries is the *extended case study*. Its methodology is presented in academic literature [7, 24, 35, 50]. These methods enabled the authors to realise the case-based context-sensitive research strategy.

In the course of the research, the functionality of different types of digital platforms in industry, as presented in the authors' previous studies, will be shown on the case platform [2, 3].

Type I digital industrial platform is a digital ecosystem focused on creating value in industrial production through direct buyer–supplier interaction, as well as digital transactions between them. This type includes two types of platforms:

- *An information and communication platform* allowing for the information exchange and operational communication between industrial market participants (examples of this platform type are electronic catalogues of industrial goods, enterprise potential products catalogues, etc.).
- *A transactional platform* providing communicative, financial and legal support of transactions (examples of this platform type are public and private procurement platforms).

Type I platforms represent the first evolutionary step in the construction of more sophisticated digital industrial platform models.

Type II digital industrial platform is a set of interconnected production techniques conjoined by end-to-end digital technologies securing the product lifecycle on the basis of the industrial Internet of Things (IoT) and modelling of digital twins. The core of this platform is the product and its digital twin being in the focus of all participants' actions. The involved parties represent the development and design segment, the core production segment, the outfit segment, the supply segment and the consumer segment.

This methodology will be used to implement the case study and validate the typology herewith introduced. It will also be important to explore the management type of digital industrial platforms for each of their subtypes. For this purpose, the methodology by Mishra-Tripathi [33] and Flechsig et al. [16] will be used, and the centralised and decentralised types of digital platforms in industry will be identified [6, 27].

Figure 1 presents a centralised management system for a digital industrial platform, which is specifically characterised by a hierarchical management structure. The platform developer and owner stores and processes all the participants' data, takes decisions unilaterally, restricts the participants' access to the data, and is in charge of operation security Fig. 2.

The decentralised management model is achieved through the introduction of the blockchain technology. The decentralised digital industrial platform is defined as 'a type of digital ledger system based on distributed ledger technology, comprising an infrastructure of services and communities of independent users endowed with equal or predetermined rights that are distributed across the tiers of the decentralised management model to ensure sustainability of this system' [28]. The blockchain represents a digital technology with great potential for application in various types of industrial platforms. Another distinguishing feature of decentralised management systems is decision-making accord, absence of transaction intermediaries, availability of information to all platform participants, formalisation of interaction and equality of participants.

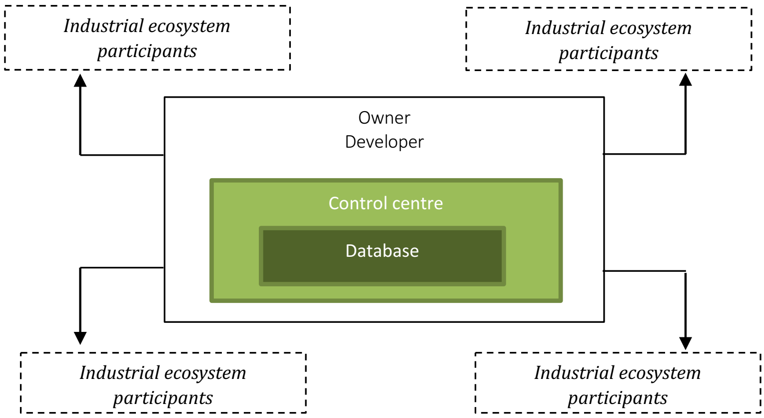

Fig. 1 Centralised digital platform management system

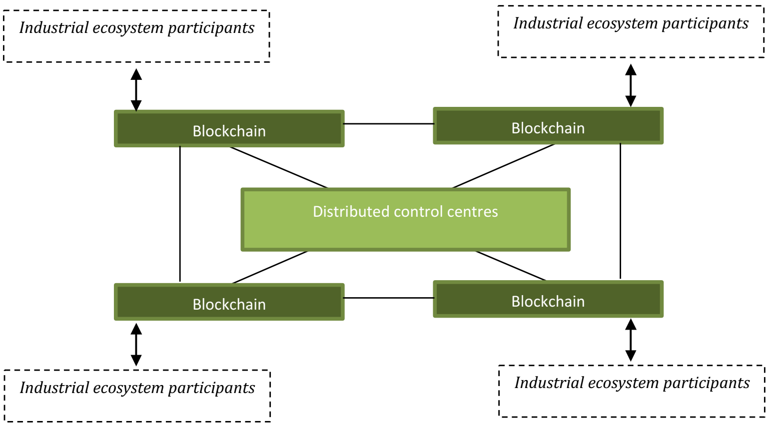

Fig. 2 Decentralized digital platform management system

Gazprom PJSC, a major gas company in Russia and worldwide, was chosen as a case study with a view to validate the typology of digital industrial platforms. Gazprom PJSC's core activities include a complete cycle from gas exploration to the sale of gas to end consumers. Gazprom accounts for 16% of the world's gas reserves and 12% of the global gas production, while in Russia Gazprom owns 71% of the reserves and realises 68% of gas production. Gazprom PJSC ranks 17th in S&P Global Platts' list (2018) of the largest energy companies [40].

4 Results and Discussion

There are four digital platforms, set up and efficiently operated by Gazprom PJSC, that are fundamentally different in functionality and type.

4.1 Gazprom's Digital Counterparty Integration Platform (CIP)

This platform (https://gazpromneft-marketplace.ru/) represents the gas company's digital ecosystem and is the simplest and easiest in terms of organisation and management. The platform brings together the offerings of Gazprom PJSC's subsidiaries with a proven track record and presents high-quality products and services to all company's counterparties from various spheres. A total of 80% of Russian businesses cooperate with the Gazprom group. The ecosystem platform is particularly valuable for the small and medium-sized business partners seeking new sale markets and scale-up. Gazprom, as the largest developer of IT solutions in the industry, provides its partners with the services involving the development of digital business models and corporate products, the provision of financial and insurance services, and the promotion of small and medium business' products and services in Gazprom's ecosystem. The CIP-Gazprom platform is a classical two-way platform—a marketplace that is of value to the platform users in terms of integrating the partners' offers on the platform's digital storefronts Fig. 3.

The CIP-Gazprom digital platform, in the terminology herewith accepted, is a type I platform, 'transactional platform' subtype. The classical marketplaces, even in such sectors as the gas industry, are designed according to the decentralised principle.

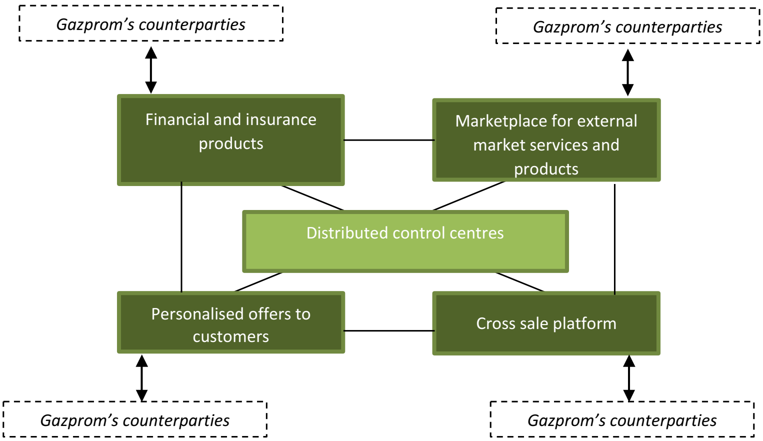

Fig. 3 Chart of the Digital counterparty integration platform (CIP)

4.2 Digital IIoT Continuous Production Management Platform—Zyfra Industrial IoT Platform Oil & Gas (ZIIoT O & G)

The ZIIoT O&G digital platform (https://idp.zyfra.com/) represents a technology constructor for designing industrial automation systems in the oil and gas industry. The platform provides great extensibility through its tools for the development, deployment and support of external applications. Furthermore, it includes an integrated object model and modern microservice architecture and quickly adapts IT infrastructures to meet Gazprom's enterprises' business challenges. The platform is based on the open-source components and is not bound to any specific supplier. The ZIIoT O&G development is the first Russian production management system that is completely ready for industry scaling Fig. 4.

The pilot ZIIoT O&G platform was successfully implemented by a number of Gazprom subsidiaries, with over 100 industrial objects connected to this platform. The distributed facility sensors transmit information to the platform, which accumulates the data on all technological, production and logistics chains, allowing for the formation of digital twins of the said processes.

According to the terminology of this article, the ZIIoT O&G platform is a type II platform characterising the company's digital technology business model with a combined management system. On the one hand, the designed centralised scheme for

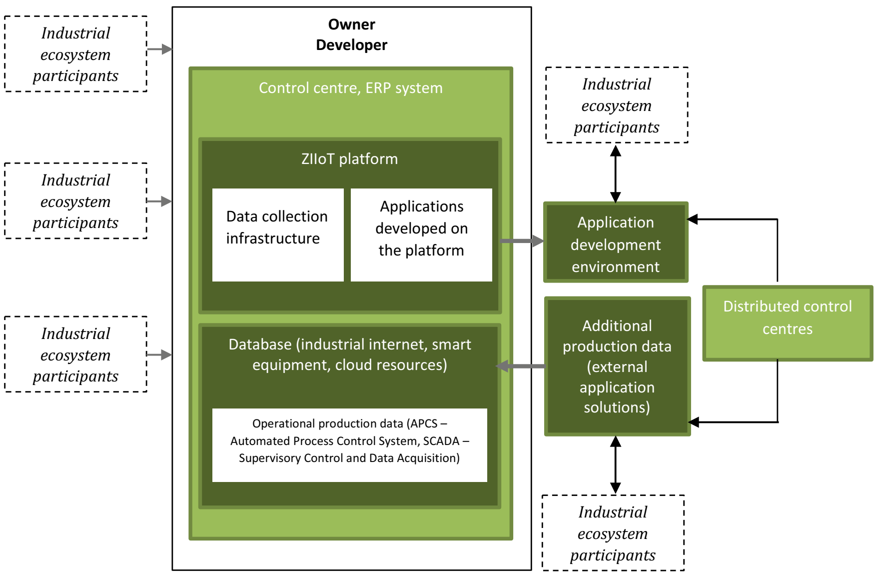

Fig. 4 Chart of the Digital IIoT continuous production management platform—Zyfra Industrial IoT Platform Oil & Gas (ZIIoT O&G)

the collection, storage and processing of Big Data increases the efficiency of different-type data usage, improves the decision-making quality and results in the company's increased productivity. On the other hand, the platform is based on the open-source components and is not bound to a specific supplier, allowing for decentralisation.

4.3 ISource Gazprom Digital Platform

The iSource digital platform (under development) is developed on the basis of Gazprombank's e-trading platform and Gazprom's subsidiary, Gazpromneft-Supply. The platform represents a 'digital twin' of the supply chain, which registers, monitors, and adjusts the procurement and supply processes, as well as the relevant financial transactions, in a virtual environment. The purpose of the platform is in increasing the transparency of procurement and logistics business processes. The digital twins of business processes enable the company and its counterparties to monitor the performance of contractual agreements and the actual project realisation process in real-time mode Fig. 5.

The services forming the core of the iSource digital ecosystem follow the customer journey from the moment of request to resource generation, allowing for the greater efficiency of business processes and risk reduction. In addition, the core of the digital service ecosystem also includes financial services—bank guarantees and factoring.

According to the terminology of this paper. the iSource platform is a Type II platform characterising the company's digital technology business model with a centralised management system—total integration of end-to-end production and supply chains.

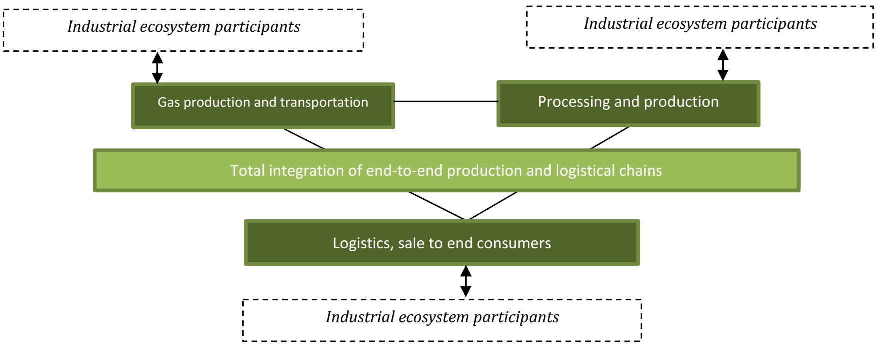

Fig. 5 Chart of Gazprom's iSource digital platform

4.4 *Digital Technological Vision Platform*

Digital Technological Vision (https://gazprom-neft.digital/radar#/radar) is a strategic initiative of the Gazpromneft company, which integrates and coordinates all the company's efforts towards the development of the full potential of digital technologies in the oil and gas industry. Digital initiatives are evaluated and ranked within the framework of this initiative. In addition, various projects related to the development and the use of digital technologies in the company's business are launched. The Digital Technological Vision platform is a proprietary methodology for analysing promising technologies through the prism of the company's needs. The core of the platform is the creation and maintenance of the digital technology database, to be accessed by all technology and business sectors of the company, when planning the use of digital technologies, looking for digital tools to match their objectives and evaluating information products, technologies and solutions Fig. 6.

The Digital Technological Vision's customisable filters can be used to see:

- 'digital technology maturity' in terms of its real application;
- digital technologies needed by the company—at present and in the future;
- technologies which the company is ready to use and those to be prepared for.

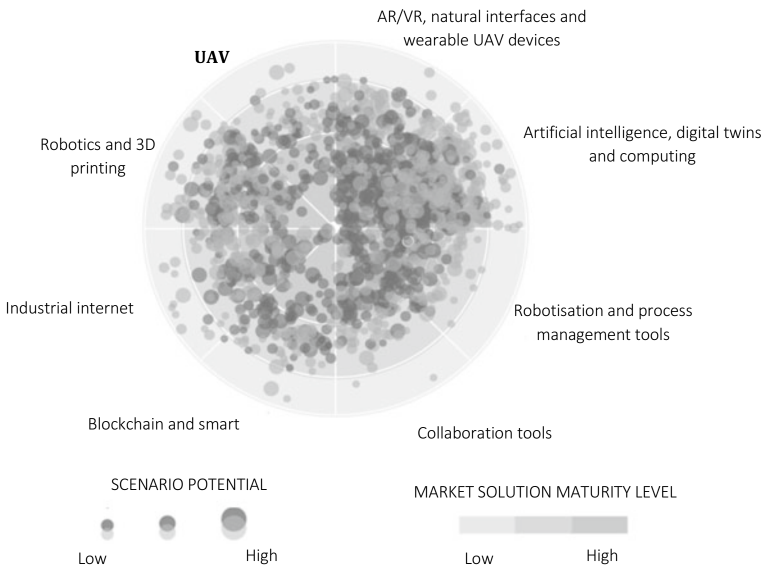

Fig. 6 Gazprom's digital technological vision platform

According to the terminology of this paper, Gazprom's Digital Technological Vision Platform is a type I platform, subtype 'information and communication platform', which provides an open exchange of information about the technological solutions applied in Gazprom's business units and subsidiaries. This platform belongs to the centralised type in terms of management.

5 Conclusion

In the present research, the authors validated the typology of digital industry platforms based on the functionality criteria, proposed by the academic literature, and supplemented this typology with the manageability criterion. The detailed study of the digital platforms operated by the major gas company Gazprom allowed the authors to show that Type I digital platforms (counterparty digital ecosystems) are characterised by a decentralised management system. In turn, Type II digital industrial platforms (digital twins of business processes) are characterised by the centralised or mixed management systems.

Our study shows that digital industrial platforms are going to become more widespread in the future. Among the risks that may negatively affect the economic and social development of society is the market monopolisation risk. Every digital platform is set at the entry point for the distribution of benefits and contracts and can control access to the markets. Powerful technology and industry giants can assign champions and outsiders throughout the entire industry they control. In order to prevent the risks of the abuse, the development of appropriate legislation, as well as the diffusion of technologies to ensure data security and integrity, is needed. The digital infrastructure represented by the digital platforms has to become more open for control and should not interfere with the democratic foundations of society and should not impede the due functioning of market forces ensuring free competition.

When these digital industry platforms are organised in good faith, their participants gain a number of unconditional benefits. In the first place, this means the access to innovations, reduced transaction costs and expansion into the new markets. From this point of view, interterritorial networking of economic agents reaches the new cross-national levels, but can be limited by agents' logistic capacities in the physical world. The inclusion of companies in industry digital platforms provides them an access to the global digital space, increases the chances of international financing of projects through digital crowdfunding and blockchain, expands the possibilities of structuring export transactions through the use of smart contracts and much more.

Acknowledgements The article was prepared under the state assignment of the RF Ministry of Science and Higher Education entrusted to the Institute of Economics, Ural Branch of the Russian Academy of Sciences.

References

1. Akatkin, Y.M., Karpov, O.E., Konyavsky, V.A., & Yasinovskaya, E.D. (2017). Digital economy: conceptual architecture of the digital industry ecosystem, *Business Informatics, 4*(42), 17–28. https://doi.org/10.17323/1998-0663.2017.4.17.28
2. Akberdina, V., & Barybina, A. (2022). Digital platform for regional industry: prerequisites and functionality. In V. Kumar, J. Leng, V. Akberdina, & E. Kuzmin (Eds.), *Digital transformation in industry. lecture notes in information systems and organisation, 54*, 109–120. https://doi.org/10.1007/978-3-030-94617-3_9
3. Akberdina, V. V., & Pyankova, S. G. (2021). Digital transformation of industry: methodological aspects. *Proceedings of the Free Economic Society of Russia, 227*(1), 292–313. https://doi.org/10.38197/2072-2060-2021-227-1-292-313
4. Akberdina, V. V., & Smirnova, O. P. (2017). Networked conjugate production in the context of the fourth industrial revolution. *Transbaikal State University Journal, 23*, 104–113. https://doi.org/10.21209/2227-9245-2017-23-7-104-113
5. Alexandrova, E., & Poddubnaya, M. (2020). Digital technologies development in industry sectors and areas of activity. In T. Antipova (Ed.), *Integrated Science in Digital Age 2020. ICIS 2020. Lecture Notes in Networks and Systems,* 136, 112–124. https://doi.org/10.1007/978-3-030-49264-9_10
6. Astakhova, T. N., Kolbanev, M. O., & Shamnin, A. A. (2018). Decentralised digital platform for agriculture. *Bulletin of Nizhny Novgorod State University of Engineering and Economics, 6*(85), 5–7.
7. Burawoy, M. (1998). The extended case method. *Sociological Theory, 16*(1), 4–33. https://doi.org/10.1111/0735-2751.00040
8. Chandna, V. (2022). Social entrepreneurship and digital platforms: Crowdfunding in the sharing-economy era. *Business Horizons, 65*(1), 21–31. https://doi.org/10.1016/j.bushor.2021.09.005
9. Crețan, R., Guran-Nica, L., Platon, D., & Turnock, D. (2017). Foreign Direct Investment and Social Risk in Romania: Progress in Less-Favoured Areas. In *Foreign direct investment and regional development in East Central Europe and the Former Soviet Union* (pp. 305–348). Routledge. https://doi.org/10.4324/9781351158121-15
10. Cusumano, M.A., Gawer, A., & Yoffie, D.B. (2019). *The business of platforms: strategy in the age of digital competition, innovation, and power*. New York, NY: HarperCollins Publishers. http://link.library.eui.eu/portal/The-business-of-platforms--strategy-in-the-age/9dnPDXjgBpc/
11. *Decree of the Russian Federation Government "On the management system for implementing the russian digital economy programme" No. 1030*. (2017). Retrieved May 18, 2022, from http://government.ru/
12. *Enactment of the Russian Federation Government "On Approval of the Russian Digital Economy Programme" No. 1632-r.* (2017). Retrieved May 18, 2022, from http://government.ru/
13. European Commission. (2020a). *Digital Markets Act. Proposal for a Regulation of the European Parliament and of the Council, on Contestable and Fair Markets in the Digital Sector*. Retrieved December 14, 2022, from https://ec.europa.eu/info/sites/info/files/proposal-regulation-single-market-digital-services-digital-services-act_en.pdf
14. European Commission. (2020b). *Digital services act. proposal for a regulation of the european parliament and of the council, on a single market for digital services and amending directive 2000/31/EC*. Retrieved December 14, 2022, from https://ec.europa.eu/info/sites/info/files/proposal_for_a_regulation_on_a_single_market_for_digital_services.pdf
15. Feld, H. (2019). *The case for the digital platform act: market structure and regulation of digital platforms.* Roosevelt Institute.
16. Flechsig, C., Völker, M., Egger, C., & Weske, M. (2022). Towards an integrated platform for business process management systems and robotic process automation. In *International*

conference on business process management (pp. 138–153). Cham: Springer. https://doi.org/10.1007/978-3-031-16168-1_9
17. Frolov, D. (2021). Blockchain and institutional complexity: An extended institutional approach. *Journal of Institutional Economics, 17*(1), 21–36. https://doi.org/10.1017/S1744137420000272
18. Gawer, A. (2022). Digital platforms and ecosystems: Remarks on the dominant organisational forms of the digital age. *Innovation, 24*(1), 110–124. https://doi.org/10.1080/14479338.2021.1965888
19. Geliskhanov, I. (2018). Digital platform: A new economic institution. *Quality-Access to Success Journal, 19*(S2), 20–26.
20. Gerrikagoitia, J. K., Unamuno, G., Urkia, E., & Serna, A. (2019). Digital manufacturing platforms in the industry 4.0 from private and public perspectives. *Applied Sciences*, *9*(14), 2934. https://doi.org/10.3390/app9142934
21. Hänninen, M., & Paavola, L. (2020). Digital platforms and industry change. In H. Lehtimäki, P. Uusikylä, & A. Smedlund (Eds.), *Society as an Interaction Space* (pp. 213–226). Springer.
22. Jia, A., He, D., Wei, Y., & Li, Y. (2021). Predictions on natural gas development trend in China for the next fifteen years. *Journal of Natural Gas Geoscience, 6*(2), 67–78. https://doi.org/10.1016/j.jnggs.2021.04.005
23. Karhade, P., Kathuria, A., Malik, O., & Konsynski, B. (2020). Digital platforms and infobesity: a research agenda. In A. Garimella, P. Karhade, A. Kathuria, X. Liu, J. Xu, & K. Zhao (Eds.), *The role of e-business during the time of grand challenges. web 2020. lecture notes in business information processing,*(pp. 418, 67–74). https://doi.org/10.1007/978-3-030-79454-5_7
24. Khan, S., & Van Wynsberghe, R. (2008). Cultivating the under-mined: Cross-case analysis as knowledge mobilisation. *Forum: Qualitative Social Research, 9*(1), 34. Retrieved August, 27, 2022, from http://www.qualitative-research.net/index.php/fqs/article/view/334/730
25. Kiel, D., Müller, J.M., Arnold, C., & Voigt, K.I. (2017). Sustainable industrial value creation: benefits and challenges of Industry 4.0. *International Journal of Innovation Management, 21*(08), 1740015. https://doi.org/10.1142/S1363919617400151
26. Koroteev, D., & Tekic, Z. (2021). Artificial intelligence in oil and gas upstream: Trends, challenges, and scenarios for the future. *Energy and AI, 3*, 100041. https://doi.org/10.1016/j.egyai.2020.100041
27. Kud, A. (2021). Decentralised information platforms in public governance: Reconstruction of the modern democracy or comfort blinding? *International Journal of Public Administration.* https://doi.org/10.1080/01900692.2021.1993905
28. Kud, A.A. (2019). Substantiation of the term "digital asset": economic and legal aspects. *International Journal of Education and Science, 2*(1), 41–52. https://doi.org/10.26697/ijes.2019.1.06
29. Lasi, H., Fettke, P., Kemper, H., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business & Information Systems Engineering, 6*, 239–242. https://doi.org/10.1007/s12599-014-0334-4
30. MarketsandMarkets. (2022). *Big data market by component, deployment mode, organisation sise, business function (finance, marketing & sales), industry vertical (bfsi, manufacturing, healthcare & life sciences) and region—Global forecast to 2026* Retrieved December 14, 2022, from https://www.marketsandmarkets.com/Market-Reports/big-data-market-1068.html
31. Markeyeva, A. V., & Gavrilenko, O. V. (2019). Digital platform as a new economic actor and a new instance of social control. *Moscow University Bulletin. Series 7. Philosophy, 5*, 29–48.
32. Mattila, J., & Seppälä, T. (2015). *Blockchains as a path to a network of systems-an emerging new trend of the digital platforms in industry and society* (No. 45). ETLA Report.
33. Mishra, S., & Tripathi, A. R. (2020). IoT platform business model for innovative management systems. *International Journal of Financial Engineering, 7*(03), 2050030. https://doi.org/10.1142/S2424786320500309
34. Montero, J., & Finger, M. (2021). *The Rise of the new network industries: regulating digital platforms.* Routledge.
35. Nguyen, D. C., & Tull, J. (2022). Context and contextualisation: The extended case method in qualitative international business research. *Journal of World Business, 57*(5), 101348. https://doi.org/10.1016/j.jwb.2022.101348

36. Nooren, P., van Gorp, N., van Eijk, N., & Fathaigh, R. Ó. (2018). Should we regulate digital platforms? A new framework for evaluating policy options. *Policy & Internet, 10*(3), 264–301. https://doi.org/10.1002/poi3.177
37. Osipov, Yu. M., Yudina, T. M., & Geliskhanov, I. Z. (2018). Digital platform as an institution of the technological breakthrough era. *Economic Strategies, 5*, 22–29.
38. Rîșteiu, T. N., Creţan, R., & O'Brien, T. (2022). Contesting post-communist economic development: Gold extraction, local community, and rural decline in Romania. *Eurasian Geography and Economics, 63*(4), 491–513. https://doi.org/10.1080/15387216.2021.1913205
39. Rochet, J.-C., & Tirole, J. (2003). Platform competition in two-sided markets. *Journal of European Economic Association, 1*(4), 990–1029. https://doi.org/10.1162/154247603322493212
40. S&P Global. (2022). Th*e S&P global commodity insights. top 250 global energy company rankings*. Retrieved December 14, 2022, from https://www.spglobal.com/commodityinsights/top250/rankings
41. Sasaev, N. I. (2022). Strategic analysis of trends in the development of the Russian Far East gas industry. *Economic Analysis: Theory and Practice, 21*(3), 416–441. https://doi.org/10.24891/ea.21.3.416
42. Savic, M., Lawton Smith, H., & Bournakis, I. (2020). Innovation and external knowledge sources in knowledge intensive business services (KIBS): Evidence from de-industrialised UK regions. *Entrepreneurship & Regional Development, 32*(9–10), 805–826. https://doi.org/10.1080/08985626.2020.1789751
43. Scott Morton, F., Bouvier, P., Ezrachi, A., Jullien, B., Katz, R., Kimmelman, G., Melamed, D., & Morgenstern, J. (2019). *The Stigler Report*. Committee for the study of digital platforms, market structure and antitrust subcommittee, stigler center for the study of the economy and the state. Retrieved December 14, 2022, from https://research.chicagobooth.edu/-/media/research/stigler/pdfs/market-structure---report-as-of-15-may-2019.pdf
44. Simchenko, N. A., & Filonov, V. I. (2020). Institutional design of networking development in digital economy. *Economy and Management: Theory and Practice, 6*(3), 73–78.
45. Srinivasan, A., & Venkatraman, N. (2018). Entrepreneurship in digital platforms: A network-centric view. *Strategic Entrepreneurship Journal, 12*(1), 54–71. https://doi.org/10.1002/sej.1272
46. Stewart, A., & Stanford, J. (2017). Regulating work in the gig economy: What are the options? *The Economic and Labour Relations Review, 28*(3), 420–437. https://doi.org/10.1177/1035304617722461
47. Tan, Z. M., Aggarwal, N., Cowls, J., Morley, J., Taddeo, M., & Floridi, L. (2020). The ethical debate about the gig economy: A review and critical analysis. *Technology and Society, 65*, 101594. https://doi.org/10.1016/j.techsoc.2021.101594
48. Tassinari, A., & Maccarrone, V. (2020). Riders on the storm: Workplace solidarity among gig economy couriers in Italy and the UK. *Work, Employment and Society, 34*(1), 35–54. https://doi.org/10.1177/0950017019862954
49. Vagapova, E.A. (2012). Development of inter-municipal cooperation: forms, principles, methods. *Bulletin of Chelyabinsk State University. Economy, 39*(24(278)), 64.
50. Van Velsen, J. (2017). The extended-case method and situational analysis. In A. L. Epstein (Ed.), *The Craft of Social Anthropology* (pp. 129–150). Routledge.
51. Vesalon, L., & Creţan, R. (2015). 'We are not the Wild West': Anti-fracking protests in Romania. *Environmental Politics, 24*(2), 288–307. https://doi.org/10.1080/09644016.2014.1000639
52. Wanasinghe, T. R., Wroblewski, L., Petersen, B. K., Gosine, R. G., James, L. A., De Silva, O., & Warrian, P. J. (2020). Digital twin for the oil and gas industry: Overview, research trends, opportunities, and challenges. *IEEE access, 8*, 104175–104197. https://doi.org/10.1109/ACCESS.2020.2998723

53. Yu, L., Yang, E., Ren, P., Luo, C., Dobie, G., Gu, D., & Yan, X. (2019). Inspection robots in oil and gas industry: a review of current solutions and future trends. In *2019 25th International Conference on Automation and Computing (ICAC)* (pp.1–6). IEEE. https://doi.org/10.23919/IConAC.2019.8895089
54. Zuoqian, W. A. N. G., Zifei, F. A. N., Zhang, X., Baolei, L. I. U., & Xi, C. H. E. N. (2022). Status, trends and enlightenment of global oil and gas development in 2021. *Petroleum Exploration and Development, 49*(5), 1210–1228. https://doi.org/10.23919/IConAC.2019.8895089

The Comparative Analysis of the Electric Vehicle Markets in the Context of Green and Digital Solutions

Olga Romanova and Alena Ponomareva

Abstract In today's world, the promotion of electric vehicles has become the number-one priority of the low-carbon economic development paradigm in developed and major developing countries. In contrast to mature economies, the Russian electric vehicle market is only at the initial stage of its formation. The article discusses the opportunities for promoting a high-tech, environmentally friendly electric vehicle industry in Russia. The methodological framework of the study is based on the theories of sustainable and long-term technical–economic development. The methods of comparative and structural analysis and SWOT analysis are used. We hypothesize that in Russia there are prerequisites and opportunities for creating a new high-tech electric vehicle industry, which implements ESG principles. The paper determines the current trends in the development of the global electric vehicle market and identifies the key factors affecting its dynamic growth. The authors systematize the experience of advanced countries relating to direct and indirect measures of state support for the development of electric vehicles and EV charging infrastructure. Based on the SWOT analysis results, the real opportunities and risks associated with the unfolding of the Russian electric vehicle market are established. We substantiate that it is of great importance for Russia to develop the electric vehicle industry from the standpoint of the environmental agenda as well as the creation of a new high-tech industry that stimulates the emergence of numerous related end-to-end technologies. We have found that the country's regional and municipal authorities and the Russian business are keenly interested in advancing the electric vehicle industry. The main findings of the study can be useful when formulating regional programs for the development of electric vehicles and adjusting regional industrial policy of the constituent territories of the Russian Federation.

Keywords High-tech production · Electric vehicles · ESG principles · SWOT analysis · Decarbonisation of the economy

---

O. Romanova · A. Ponomareva (✉)
Institute of Economics of the Ural Branch of the Russian Academy of Sciences, 29 Moskovskaya St., Ekaterinburg 620014, Russian Federation
e-mail: ponomareva.ao@uiec.ru

O. Romanova
e-mail: romanova.oa@uiec.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_12

1 Introduction

In today's unpredictable, unstable, and complex conditions, some development trends not only remain unchanged, but gain in importance. Among such trends are the increasing topicality of green solutions and ESG principles, implemented both in the practice of the largest industrial corporations and in decisions taken by state authorities at various levels. The low-carbon agenda being implemented in Russia not only keeps its relevance in the face of a new reality, but also creates new opportunities for the emergence of modern high-tech and environmentally friendly industries. The transition from fossil fuel vehicles to electric ones is known to be one of the sustainable trends in the world economy today.

The retrospective analysis of the emergence and evolution of the EV industry indicates the presence of alternating stages of interest and complete indifference in this type of transport. The first electric vehicle appeared 50 years earlier than its rival with an internal combustion engine; however, electric cars saw serial production only in the first decades of the twenty-first century. The global green energy boom typical of this period was the key reason behind the growing demand for electric vehicles characterized by zero emissions and allowing to abandon petroleum as a resource for gasoline production. But what are Russia's chances to fit into this trend? The study aims to identify opportunities for the development of a high-tech, environmentally friendly electric vehicle (EV) industry in Russia.

To attain the stated purpose, we set the following objectives: to analyze the development trends in the global electric vehicle market; to systematize measures to support the production and use of electric vehicles in the global economy; to clarify the goals, factors, and measures for stimulating the development of the electric vehicle market in Russia; to reveal the regional practice of transitioning to the EV infrastructure in Russia; and to carry out a SWOT analysis of the development of the electric vehicle market in Russia.

The transport sector, as is known, generates 68% of all emissions from the combustion of fuel [2, 32], and internal combustion engine vehicles consume such an amount of gasoline which, to be produced, requires about 44% of oil extracted worldwide.

This fact has made EVs a priority goal within the low-carbon economic development paradigm implemented in the world's largest economic centers. The underlying trends and the most plausible development scenarios for the global electric vehicle market, as well as a comparative analysis of various government support measures for electric transport and charging infrastructure, confirmed that the increase in demand for environmentally friendly EVs became a logical continuation of the green energy boom in the car industry.

In contrast to the existing studies devoted to the country-specific features of the EV market, our research concentrates on the regional specificity of the Russian transport electrification.

2 Development Trends in the Global Electric Vehicle Market

The advancement of electric vehicles has become a top priority for the low-carbon economic development paradigm in the world's leading economic centers. It is of particular importance to systematize the main EV trends in the global economy in order to identify the opportunities and risks of this process in Russia.

High growth rates of the global electric vehicle market. A clear trend in the development of the global electric vehicle market is not only the absolute growth in the number of electric vehicles (Table 1), but also its high growth rates (Fig. 1).

The 2010s witnessed the steady growth of the electric vehicle market. If in 2010 the global EV fleet was only 17,000 units, then by the end of 2020 their numbers exceeded 10 million vehicles. China demonstrated the highest growth rates during 2015–2020, and the country's share increased from 24% in 2015 to 44% in 2020. With the absolute 8 times growth of the electric car fleet in Europe over the same period, its share in the structure of the global market in 2020—31%—remained at the level of 2015. Among the world's leading industrial powers, the lowest growth rates

Table 1 Global electric vehicle fleet, thousands

Countries	2010	2015	2018	2019	2020
World, including	17	1,245	5,094	7,123	10,196
Europe	7	380	1,239	1,738	3,160
China	2	293	2,289	3,349	4,509
USA	4	404	1,123	1,450	1,778

Source Compiled by the authors based on [25]

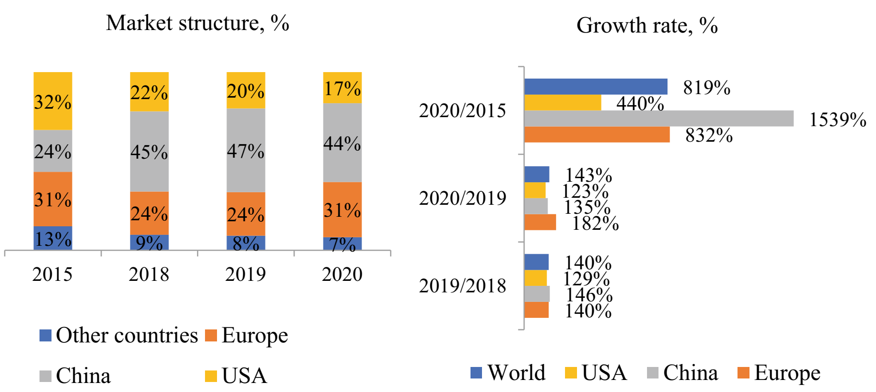

Fig. 1 Structure and dynamics of the global electric vehicle market. *Source* Compiled by the authors based on [25]

of the EV fleet for the period of 2015–2020 were recorded in the USA, where the number of electric vehicles increased from 404 thousand units up to 1,778 thousand units, that is, an increase of 4.4 times. However, its share in the global market almost halved from 32% in 2015 to 17% in 2020.

The main factor hindering the more rapid development of the electric vehicles production during this period is the relatively small demand caused by the high cost of the EV battery, low single-charge mileage, and the poor state of infrastructure [6]. But in the highly developed economies, these problems are successfully solved [15]. For example, with an increase in the EV production, the battery cost significantly lowered, the weighted average price of which decreased from $395/kWh in 2015 to $135/kWh in 2020. At that, there was a simultaneous increase in the average single-charge mileage from 200 to 340 km over the same period (Fig. 2).

Market growth is fueled by the ever-increasing number of electric vehicle models, reaching 370 in 2020. In some countries, there is an increase in the number of registrations of hybrid electric vehicles, that is, EVs that combine a conventional internal combustion engine system with an electric propulsion system. However, the leading positions are still occupied by battery electric vehicles, whose share in the Netherlands was 82% of all EV registrations, Norway—73%, the United Kingdom—62%, and France—60% [5, 24].

Globally, the largest variety of models in 2020 was found in the SUV segment. Over 55% of the models declared worldwide are SUVs and pickup trucks. SUVs are the fastest-growing market segment in Europe and China [34]; they also make up the largest market share in the US. SUVs tend to be more expensive than smaller cars, which usually results in higher profits. By the end of 2020, more than 20 countries around the world announced a ban on selling conventional vehicles or allowed selling of only new vehicles with zero emissions.

Even amid the pandemic, governments of some developed countries expanded incentives to protect the EV industry from a downturn in the car market. In 2020, the increase in electric vehicle registrations was 41%, while the pandemic-caused decline in car sales worldwide was 16% [24].

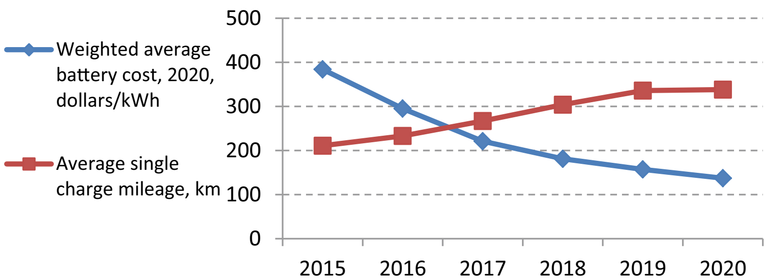

Fig. 2 EV battery cost and single-charge mileage in 2015–2020. *Source* Compiled by the authors based on [29]

Development of the modern EV charging infrastructure. The development of the charging infrastructure is one of the most important factors in the promotion of electric transport [31]. According to the global practice, the largest number of charging stations are privately owned [3]. In 2015, there were 1.3 million private charging points and 190,000 publicly accessible charging points. If the structure of public chargers is largely influenced by government incentive policies, then the structure of the private charger market follows the general structure of the global electric vehicle market.

A number of countries, such as France, have defined and legally formalized the requirements for the infrastructure and mandatory equipment of all new residential and public buildings with EV charging points [20, p. 1286]. The Federal Government of Germany has prepared the Charging Infrastructure Master Plan, which aims to create a network by 2030 to charge about 10 million electric vehicles [14]. Charging points are planned to be created in parking lots, supermarkets, hotels, and in the central areas of large cities [30]. The German government has obliged all gas stations to create comprehensive conditions for charging electric vehicles.

R&D activities. To ensure the successful development of the electric vehicle market, it is necessary to intensify targeted research activities supported by both the state and business. The key area is the design and production of batteries and cells [8]. Currently, more than 97% of the global demand for batteries is supplied by imports from the countries of Southeast Asia, primarily China [2].

To reduce this dependence, serious studies are being carried out in the EU to organize the national production of batteries. Since 2020, the German Federal Ministry of Education and Research has been implementing the Competence Cluster Recycling & Green Battery (greenBatt) with funding of 100 million euros. Within the framework of the project, there are four competence clusters: intelligent battery cell production (InZePro), recycling and green batteries (greenBatt), battery utilization concepts (BattNutzung), analytics and quality assurance (AQua). The four new competence clusters are an important step in the further development of the project, which focuses on turning Germany into one of the leaders in the battery market and reducing dependence on supplies from China.

In 2017, the European Battery Alliance platform was launched in the EU, which brought together more than 120 companies. The Alliance aims to ensure the functioning of a complete battery value chain.

Research in the field of battery production will significantly reduce the cost of electric vehicles, promote zero-emission electric vehicles, which will help preserve the environment and improve human health.

EV production and use stimulation policies in the global economy. The policy on stimulating the production of electric vehicles is country-specific, which is determined by the level of the car market development, the presence of automakers, and the financial capacity of the state [7, 11, 12]. The global measures for road transport electrification can be divided into two models—American and European. The latter is more stringent and aims to completely phase out internal combustion engine vehicles, with a potential ban on selling traditional cars. The American model is softer, with no federal requirements for the promotion of electric vehicles, and EVs sales are mainly stimulated at the initiative and at the level of individual states.

Until recently, among the most effective measures to stimulate the production and use of electric vehicles were benefits and discounts, tax incentives, etc. [12, 26]. However, with an increase in the EVs production and the growing evidence of their cost-effectiveness, the focus is shifted toward reducing operation costs rather than stimulating sales. It was also found that the convenience of using an electric car is an attractive factor for buyers [11].

Non-monetary support measures consist in granting certain rights to EVs owners. For example, in a number of cities in Norway, the United Kingdom, the USA, Germany, France, etc., EVs owners have a preferential access to restricted highway occupancy vehicle lanes [17]. According to experts, Norway is one of the leaders in stimulating the electrification of transport. Among the Norwegian EV incentives are the following: no VAT and purchase/import tax on EVs, reduced annual transport taxes, abolished fees for municipal parking lots, electric vehicles are allowed to use public transport lanes [16]. As a result, internal combustion engine cars are significantly more expensive for the buyer both when buying one and over the course of servicing one. It is highly likely that half of Norway's car fleet will be converted to electricity by 2025. There have been proposals to ban selling traditional cars from 2025 [18, 33].

3 Goals and Factors in the Development of the Russian Electric Vehicle Market

The electric vehicle market in Russia. The EV market in Russia has not seen any significant developments in comparison with its rapid growth in the EU, China, the USA, and other developed countries. By boosting the advancement of the EV market, countries pursue various goals. For example, Denmark, the Netherlands, Norway, etc., work toward environmental and energy independence goals. However, some countries support electric vehicle technologies in order to solve specific economic problems, such as forming and winning new markets for high-tech products [19] and stimulating national innovation systems [9]. A number of nations, namely, the USA, China, Germany, and France, are interested in electric vehicle technologies to revive stagnating industries.

EV technologies prioritization in Russia seems to be predetermined by national environmental goals, primarily in the largest industrial cities, and by the growing output of electric vehicles as high-tech products, which are designed and produced through a number of end-to-end technologies that enhance the overall technological level of the Russian car industry.

The above analysis of the development trends in the global electric vehicle market allows identifying the common factors that affect the dynamic growth of EVs in all countries. This is the state policy in the first place, that, on the one hand, tightens the requirements for harmful transport emissions, and on the other, subsidizes the transition to EVs and stimulates the progress of charging infrastructure. The second factor is large business that has invested heavily in electric transport and is striving to keep its share in this promising high-tech market. The third factor is consumers, whose requirements for the environmental friendliness and efficiency of vehicles are constantly increasing. Among the crucial factors is also the availability of capacious traction batteries that allow electric vehicles to run long without charging the battery repeatedly and significantly reduce charging time. The last factor having a decisive impact on the attractiveness of electric vehicles is the cost of batteries. Many researchers believe that the last two factors are the key ones for the development of electric transport [27, p. 96].

Although there has been no mass production of electric vehicles in Russia so far, in the first decade of the twenty-first century, Moscow, Siberia, and the Far East initiated the trial use of foreign-made electric vehicles. Mostly, these were second-hand cars imported from Japan, which continue to dominate the market today [25] (see Table 2).

Russian-made EV models are at various phases of readiness. In 2020, a presentation of an electric car developed by KAMAZ PTC together with Peter the Great Saint Petersburg Polytechnic University (SPbPU) was held. In the city of Togliatti, ZETTA LLC launched serial production of electric vehicles under the Zetta brand. An experimental batch of Russian electric vehicles EL Lada was released in 2012. It was the first environmental-friendly EV project in Russia. EL Lada cars were first used as passenger taxis in the city of Kislovodsk, but the lack of a vast charging points network made it impossible to completely replace gasoline-powered taxis in the city with electric vehicles. To date, only five electric taxis operate in Kislovodsk, which are allowed to enter the conservation park.

To eliminate the significant gap between the developed countries and Russia in manufacturing electric vehicles, in August 2021 the Government of the Russian Federation adopted "The Concept for the Development of Production and Use of Electric Road Transport in the Russian Federation for the Period up to 2030." It is going to be implemented in two steps: from 2021 to 2024 and from 2025 to 2030. By the end of the first stage, it is planned to produce at least 25,000 electric vehicles and open 9,400 charging stations across the country. The key indicators of the second stage are as follows: the share of electric cars should be at least 10% of all vehicles

Table 2 EV brands in the Russian car market in 2020

Brand	Number, units	Market share, %
Nissan	9747	85
Tesla	457	6
Mitsubishi	346	4.3
Jaguar	167	2.1
Lada	96	1.2

Source Compiled by the authors based on [25] manufactured; start of production of battery cells; commissioning of at least 72,000 charging stations and at least 1,000 hydrogen filling stations [28].

The phased implementation of the Concept resulted in a more than twofold increase in the total fleet of EVs in Russia from 11,000 vehicles in 2021 to 23,300 vehicles at the end of the first half of 2022. Unfortunately, the share of electric cars (including plug-in hybrids) is only 0.05% of the total car fleet (45 million units) [4]. The bulk of them (60%) is still concentrated in Siberia and the Far East, although the growth rate of electric cars in the central regions of Russia is higher.

At the beginning of 2020, Moscow became the leader in the number of electric vehicles in Russia with 2,161 EVs registered [13]. The Russian capital has long been used advanced technologies in the field of urban transport, such as electric buses, electric bicycles, and electric scooters. The first electric bus was launched in 2018, and in 2022 there were more than a thousand of them. By 2030, the entire fleet of the capital's buses will be replaced by electric buses.

The first EV manufacturer in Russia—Motorinvest in the Lipetsk region—started serial production of electric vehicles in 2022 with 2,000 eco-friendly electric cars to be manufactured by the end of the year. The first model to roll off the assembly line is the Evolute i-Pro sedan. The launch of such a factory in today's difficult conditions indicates that high-tech production, and electric vehicles in particular, remain a top priority of the state industrial policy [22, 23].

The Moscow car manufacturer Moskvich has resumed operations at the plant and plans to produce about 600 cars by the end of 2022, of which 200 vehicles will have electric motors. It is going to be a SKD assembly implemented with the help of eastern partners. The key point is that Moskvich is creating an electric car model on its own platform.

Sanctions pressure on Russia has made major changes to the structure of the country's EV fleet. As mentioned above, the largest share of the Russian electric vehicle market (85%) was taken by Nissan. However, in October 2022, Nissan and Mercedes-Benz announced they were pulling out of Russia. At the same time, the Chinese company Skyworth made its debut in Russia with the Skywell ET5 electric crossover designed on its own platform.

Development of the EV charging infrastructure is the most important task in transport electrification. In 2014, PAO Rosseti instituted the All-Russian Program for the Development of Charging Infrastructure for Electric Transport [1], which concentrated on the large-scale R&D for producing basic technological solutions in the field of electric transport. Among the anticipated effects was the improvement of the environmental situation in large cities of the Russian Federation, which, as practice shows, should improve the quality of life of the population. Other important outcomes included stimulation of innovation activity, commercialization of R&D results in the power grid complex, adoption of technical solutions for combining traditional distribution network facilities with the charging infrastructure. However, this program was never implemented, although some of its provisions were introduced in some constituent territories of the Russian Federation.

Among the activities performed, we can name a network of 20 charging stations created in Saint Petersburg in late 2014–early 2015, and an intelligent charging infrastructure established in Skolkovo, where only electric transport was allowed to move around the Skolkovo territory.

The Russian government has assembled a list of regions where a pilot for the creation of infrastructure for electric transport was launched with the first 258 charging points installed in 2022. The projects on creating fast charging stations will be supported by state industrial policy instruments. In 2023, these projects can receive co-financing of up to 60% of the total costs. The average EV battery charging time at such stations is 20 min.

Stimulating the production and use of EVs in Russia. Every country institutes its own measures to encourage the transition to the most environmentally friendly mode of transport. According to analysts, electric vehicles in Russia will be in demand both among corporate clients and ordinary consumers. The state's commitment to ESG principles in industry is proved by serious measures adopted to stimulate the advancement of electric vehicles. For example, to expand the production of Evolute i-Pro, a subsidy of 925,000 rubles is provided. Without the subsidy, the price of an electric car is 2.99 million rubles [10]. In addition, Evolute electric vehicles will be included in the preferential car loan program. While the current measures for supporting auto loans provide an extra 20% discount, the discount for electric vehicles is 35%.

In Moscow, Saint Petersburg, the Krasnodar region, etc., electric vehicles are provided with a number of benefits, such as free parking, no transport tax, and no payment for using particular toll roads. In Siberia, the transport tax has already been abolished in Zabaykalsky, Krasnoyarsk, Kemerovo, and Omsk regions and the Republic of Buryatia. Since 2018, Rosseti Siberia has been taking the initiative to abolish this tax in all regions of Siberia. There are also debates about offering additional benefits for EVs owners.

In 2022, the authorities of the Omsk region approved a regional program on equipping the territory with EV charging stations [21], which implies lower payments for allocating charging points on municipal and state-owned land. To increase the number of EV chargers, the owners of traditional filling stations are proposed to install additional EV charging systems.

The progress of the electric vehicle industry in Russia will be stimulated through the full production cycle, from designing EVs to recycling battery systems and ensuring the cybersecurity of the vehicle and IT infrastructure. These transport electrification measures will be accompanied by the development of related end-to-end technologies.

The policy focused on stimulating the production and use of electric vehicles confirms the state's interest in this high-tech, environmentally friendly product.

Regional practice of transport electrification. The spread of electric vehicles in different regions of the Russian Federation indicates a growing interest in this type of transport from consumers as well as federal and regional authorities. Consumers' interest is due to the increasing attention to the environmental qualities of vehicles, their safety, and usability. State authorities at all levels declare that there is no alternative to the low-carbon development agenda. Moreover, EV manufacturing is able not only to revive the car industry, but also establish a new high-tech production and create high-tech jobs.

Prospects for the development of electric transport in Russia were discussed at the International Fair INNOPROM in Ekaterinburg in July 2022. The experts were completely unanimous regarding the high prospects of this type of transport. Their opinion is confirmed by a number of surveys about the annually growing need of Russians for an environmentally friendly and safe transport. The experts also expressed confidence that the widespread use of electric transport in Russia is just beginning and has a great future. For example, Sinara Group presented the Sinara-6253 electric bus in Ekaterinburg, which is capable to travel nearly 250 km on a single charge. All its digital solutions allow integrating electric buses into the Smart City system. It is worth noting that three-quarters of the parts used in assembly work are made in Russia. It is obvious that passenger transport will be the driver for the introduction of EVs in Russia.

Currently, the EV production is concentrated mainly in the central part of Russia. At the same time, the regions with the largest EV fleet are Siberia, the Far East, and the center of the country. The Urals, a highly developed industrial center of Russia, traditionally lags behind in the number of EVs. Only 7% of the total EV fleet in Russia are registered in the Greater Urals. At that, their largest number, 210 units, was registered in the Sverdlovsk region (Table 3).

Despite the small number of electric vehicles in the Urals, their sales rate is quite high. For example, in 2020, 69 new electric vehicles were registered in the region, while in 2021 this number increased to 172, that is, an increase of 2.5 times.

To ensure the faster development of the electric vehicle market in the regions, it is necessary to enhance the network of charging stations not only in large cities, but also on interregional routes and highways. Analysts highlight that the lack of charging stations between cities limits EV sales growth.

While Rosseti is the central organization responsible for the EV charging infrastructure across Russia, within the Greater Urals there are two regional companies—Rosseti Ural and Rosseti Tyumen. Rosseti Ural have already installed 22 charging stations, 10 stations are planned for launch by the end of 2022, and another 32 stations

Table 3 EVs registration: top brands and regions

Top-5 brands, units		Top-5 regions			
		Russia, units		Greater Ural, units	
Nissan	11,765	Moscow	2,161	Sverdlovsk region	210
Tesla	1,660	Primorsky region	1,652	Tyumen region	165
Porsche	674	Irkutsk region	1,540	Republic of Bashkortostan	139
Audi	522	Krasnodar region	1,085	Chelyabinsk region	135
Mitsubishi	465	Khabarovsk region	861	Perm region	123

Source Compiled based on data from Autostat [13] by 2025. Rosseti Ural is introducing an ecosystem for managing its charging infrastructure and working out models to interact with market participants. One of the important parts of the ecosystem is the EV charging stations management software.

Rosseti Tyumen installed three charging stations each in Tyumen and Surgut. Until 2025, another 18 new stations will be launched in Tyumen and on federal roads connecting Tyumen with the cities of Omsk and Tobolsk.

Charging stations in the territory of the Greater Urals are mostly free. However, local entrepreneurs believe this fact hinders the further progress of the charging infrastructure. In contrast to private chargers, free ones are often out of work or poorly maintained.

According to experts, only slow charging stations will remain free in the future, which will be located, for example, at shopping centers, and all fast chargers will require payment. Private business is increasingly interested in building up a network of charging points. Private high-speed chargers have already appeared on the highways of the Greater Urals. In 2022, three fast charging stations were placed on the Tyumen-Omsk highway; one high-speed EV charger is located between Ekaterinburg and Chelyabinsk. Although the Urals region is still lagging behind in terms of the EV fleet and infrastructure, there are enough opportunities there to accelerate the development of electric cars.

Systematization of research in the field of the global electric vehicle market, as well as the analysis of the economic, technological, environmental, resource, and spatial characteristics of Russia have allowed us to conduct a SWOT analysis of the development of the electric vehicle market in Russia (Table 4).

The SWOT analysis shows that Russia has a number of advantages that determine the feasibility of developing the internal electric vehicle market. In addition to environmental well-being, the strengths of the Russian market are its attractiveness for global automakers; a possibility to reorganize large-scale business from manufacturing traditional cars to electric vehicles; vast reserves of rare earth elements, which are the main resource for battery production.

Among the weaknesses, we can note the shortfall in revenues to the Russian budget due to a decrease in demand for motor fuels; poorly developed charging infrastructure; higher costs for electric vehicles compared to vehicles with internal combustion engine. The country has substantial capabilities to promote the EV production, which can serve as a basis for creating a new high-tech industry with high-performance jobs.

Support for the EV industry will have the most significant effect on related high-tech markets, such as new production technologies (digital platforms, digital engineering, digital twins); new materials and additive technologies (composite materials, plastics, production of body panels and components); robotics components (modernization of production systems of enterprises); neurotechnology and artificial intelligence, etc.

As for the opportunities, the following are the most promising ones. An increase in the production of electric vehicles and the subsequent decline in the demand for gasoline will lead to the transformation of oil and gas companies into more effective, so-called "energy corporations." Another important but ignored opportunity is

Table 4 SWOT analysis of the Russian electric vehicle market

Strengths	*Weaknesses*
• Environmental benefits for large cities; • Lower greenhouse gas emissions as a contribution to achieving the goals of the national climate policy; • Large-scale business that can be refocused from traditional vehicle assembly to electric vehicles; • Attractiveness of the Russian market for global automakers; • Substantial reserves of rare earth elements (as a resource for the production of batteries); Price competitiveness of electric vehicles in the future	• Lost income of the Russian budget due to a decrease in demand for motor fuels; • At the initial stage of the electric vehicle market development, EVs are more expensive compared to vehicles with internal combustion engine; • Poorly developed charging infrastructure; • Lack of localized technologies for the production of traction batteries and their components, as well as hydrogen fuel cells
Opportunities	*Threats*
• Creating a Russian high-tech production of electric vehicles stimulating the development of related end-to-end technologies; • Creating high-performance jobs; • Forming a regulatory framework that supports the production and use of electric vehicles; • Diversification of oil and gas companies toward creating "energy companies"; • Commercialization of R&D results in the power grid complex; • Establishing the EV charging stations industry; • Creating sustainable electrochemical systems as an alternative to lithium-ion batteries; • Entering foreign high-tech markets; • Intensification of federal and regional industrial policy	• Limited state financial support under sanctions; • Poor purchasing power of the population; • Limited financial resources of Russian EV manufacturers for large-scale investments in research, development, and new technologies; • Lack of hydrogen fueling stations; • High dependence on rare earth elements imports as a resource for battery production; • Growing imports of electric vehicles and their components

Source Compiled by the authors

enhancing the use of the current industrial policy instruments and developing new ones aimed at supporting the production of electric vehicles.

However, massive anti-Russian sanctions have posed additional threats to the evolution of the Russian electric vehicle market. These are limited state financial support in the context of sanctions; scarce financial resources of Russian EV manufacturers for large-scale investments in research, development, and new technologies; insufficient purchasing power of the Russian population, since in 2013–2020, even before severe sanctions were imposed, people's real income fell by 10% and annual new cars sales—by 42% [25].

4 Conclusion

The conducted study indicated that there exists no alternative to the new environmentally friendly and climate-neutral electric transport. The sufficiency of the charging infrastructure was found to be the determining factor in promoting EVs. We demonstrated that, in contrast to the Russian market, most charging stations worldwide are privately owned. It is of high necessity to intensify the state and private research activity in the EV market, especially in the field of battery design and production.

We have systematized the global measures for supporting transport electrification, which made it possible to single out two predominant models—European and American. The former aims to completely phase out internal combustion engine vehicles, with a potential ban on selling traditional cars. The American model features no federal requirements for the promotion of electric vehicles, and EV sales are mainly stimulated at the initiative and at the level of individual states. The study revealed a shift in the EV support measures that are now centered around reducing operation costs rather than stimulating EV sales. Currently, the electric vehicle market in Russia is in the initial stage of its formation, while the EU, China, and the USA it is experiencing a rapid growth.

The conducted studies have confirmed Russia's commitment to implement the low-carbon agenda of economic development with a special emphasis on electric transport. The Russian car industry strives to keep up with the global trend in promoting EVs as a mode of transport with maximum environmental friendliness, autonomy, and intelligent systems and services with Internet access.

In Russia, there are three possible avenues to expand the production of electric vehicles, these are EVs as such, universal components for using on various car platforms, and hybrids combining a conventional internal combustion engine system with an electric propulsion system. It is projected that by 2030 all key components of electric vehicles, charging infrastructure, batteries, and fuel cells will be manufactured in Russia. However, under sanctions, the Russian car industry is facing the task of recovering the country's auto market by reintroducing a variety of models and configurations and expanding the range of electric vehicles.

The research findings demonstrate that Russia has the necessary prerequisites and sufficient opportunities for the development of a new high-tech EV industry based on ESG principles. The reliability of the results is also proved by the active support of the regional authorities for transport electrification and by Russian experts' conclusions about the growing need of Russians for an environmentally friendly and safe means of transport. Among the directions for future research are in-depth study and identification of regional specificities in promoting EVs in Russia and major developed nations, such as the US and China, where the spatial factor plays a central role in transport electrification.

Acknowledgements The paper was prepared in accordance with the state assignment for the Institute of Economics of the Ural Branch of the Russian Academy of Sciences.

References

1. All-Russian Program for the Development of Charging Infrastructure for Electric Transport. https://www.rosseti.ru/media/zakupki/electro-2.pdf
2. Belov, V. B. (2020). Germany's electric mobility and the European Battery Alliance. *Scientific and Analytical Herald of the Institute of Europe RAS, 1*, 86–93.
3. Ding, Y., & Jian, S. (2022). Strategic collaboration between land owners and charging station operators: Lease or outsource? *Transportation Research Part B: Methodological, 166*, 183–211. https://doi.org/10.1016/j.trb.2022.10.004
4. Electric cars and hybrids in Russia. https://www.autostat.ru/research/product/475/
5. Global EV Outlook. (2021, April). *Accelerating ambitions despite the pandemic*. International Energy Agency.
6. González-Salas, A., Pascual, P. M., Alonso, O. A., de Muguerza, E., & Madrigal, M. (2021). *Transport electrification: Regulatory guidelines for the development of charging infrastructure*. IDB. https://bit.ly/3Flq8y0
7. Hoen, A., & Koetse, M. J. (2014). A choice experiment on alternative fuel vehicle preferences of private car owners in the Netherlands. *Transportation Research Part A: Policy and Practice, 61*, 199–215. https://doi.org/10.1016/j.tra.2014.01.008
8. IEA. (2021). *The Role of Critical Minerals in Clean Energy Transitions*. https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions
9. Iosifov, V. V., & Ratner, S. V. (2011). *Problems and prospects for the development of mechanical engineering in Russia in the post-crisis period*. Yug.
10. Karpukhin, S. (2022, October 26). Russia starts sales of its first electric car Evolute. https://tass.ru/ekonomika/16157587
11. Landbroek, J. H. M., Franklin, J. P., & Susilo, Y. O. (2016). The effect of policy incentives on electric vehicle adoption. *Energy Policy, 94*, 94–103. https://doi.org/10.1016/j.enpol.2016.03.05
12. Lieven, T. (2015). Policy measures to promote electric mobility–a global perspective. *Transportation Research Part A: Policy and Practice, 82*, 78–93. https://doi.org/10.1016/j.tra.2015.09.008
13. Loboda, V. (2022, May 18). There are 16,5 thousand electric vehicles in Russia. https://www.autostat.ru/infographics/51535/
14. Masterplan Ladeinfrastruktur. November 11, 2019. https://www.bundesregierung.de/breg-de/themen/klimaschutz/lade-infrakstruktur-1692644
15. McKerracher, C. (2021). *Hyperdrive daily: The EV price gap narrows*. Bloomberg. https://bloom.bg/3EbxWkj.
16. Mersky, A. C., Sprei, F., Samaras, C., & Qian, Z. (2016). Effectiveness of incentives on electric vehicle adoption in Norway. *Transportation Research Part D: Transport and Environment, 46*, 56–68. https://doi.org/10.1016/j.trd.2016.03.011
17. Mock, P., & Yang, Z. (2014). Driving electrification: A global comparison of fiscal incentive policy for electric vehicles. International Council on Clean Transportation. Washington DC, USA. http://www.theicct.org/sites/default/files/publications/ICCT_EV-fiscal-incentives_20140506.pdf
18. OPEC. (2019). World Oil Outlook 2040.
19. Ratner, S. V., & Iosifov, V. V. (2013). Formation of power engineering markets in China and India. *Bulletin of Ural Federal University. Series Economics and Management, 3*, 52–62.
20. Ratner, S. V., & Maslova, S. S. (2017). State incentives for electric vehicle market development: Best practices. *Finance and Credit, 23*(22), 1284–1299. https://doi.org/10.24891/fc.23.22.1281
21. Regional program for equipping the territory of the Omsk region with charging stations for vehicles with electric motors, approved by the Order No. 8-P of the Ministry of Transport and Roads of the Omsk Region dated May 11, 2022.
22. Romanova, O. A., & Kuzmin, E. A. (2021). Industrial policy: A new reality in the context of digital transformation of the economy. *Lecture Notes in Information Systems and Organisation, 44*, 13–23. https://doi.org/10.1007/978-3-030-73261-5_2

23. Romanova, O. A., Kuzmin, E. A., Vinogradova, M. V., & Kulyamina, O. S. (2021). Cooperation between SMEs and large industrial enterprises: Russian case. *Advances in Systems Science and Applications, 21*(2), 29–41. https://doi.org/10.25728/assa.2021.21.2.992
24. Rozer, M. (2022). Global trends in the development of electric vehicles. *Economist, 7*, 59–73.
25. Semikashev, V. V., Kolpakov, A. Y., Yakovlev, A. A., & Rostovskii, J.-C. (2022). Development of the electric vehicles market in Russia as a necessary condition for benefiting from the global trend towards transport electrification. *Studies on Russian Economic Development, 33*(3), 274–281. https://doi.org/10.1134/S1075700722030133
26. Shi, X., Wang, X., Yang, J., & Sun, Z. (2016). Electric vehicle transformation in Beijing and the comparative eco-environmental impacts: A case study of electric and gasoline powered taxis. *Journal of Cleaner Production, 137*, 449–460. https://doi.org/10.1016/j.jclepro.2016.07.096
27. Sobolev, A., & Poptsov, D. (2021). The measures of state support for the development of electric vehicles in Germany. *Scientific and Analytical Herald of the Institute of Europe RAS, 2,* 93–99. https://doi.org/10.15211/vestnikieran220219399
28. The Concept for the Development of Production and Use of Electric Road Transport in the Russian Federation for the Period up to 2030: Approved by the Resolution of the RF Government of August 23, 2021 No. 2290-r.
29. Tikhomirova, O. B. (2018). Energy efficiency of electric transport. *Transport Systems, 1*(7), 7–14.
30. Volle Ladung Klimaschutz. (2021, March 3). https://www.bundesregierung.de/breg-de/suche/ladepunkte-in-deutschland-1884666
31. WC. (2021). *Electric vehicles and the charging infrastructure: A new mindset?* https://pwc.to/3mkxeei
32. World Energy Outlook 2018. International Energy Agency (IEA).
33. World Energy Outlook 2019. International Energy Agency (IEA).
34. Zhang, X., Hao, X., Liu, Y., Wu, R., Shan, X., & Li, S. (2022). Contribution of potential clean trucks in carbon peak pathway of road freight based on scenario analysis: A case study of China. *Journal of Cleaner Production, 379*(1), 134669. https://doi.org/10.1016/j.jclepro.2022.134669

Adapting ESG Values to the Digital

Analysis of the Relationship Between Regional Indices of Industrial Production and the Environmental Profile

Ali Kahramanoglu, Ludmila Glezman, and Svetlana Fedoseeva

Abstract The sustainable development of enterprises, industries, and complexes in the conditions of formation of the digital economy in industrialized regions must be based on the principles of the ESG agenda with an important factor to control the impact of industrial production on the environmental component of the regional space in terms of the intensification of production carried out in the implementation of import substitution. The paper examines the dynamics of the relationship between the industrial production index and a set of indicators characterizing the ecological state of the regional space. The selected set of indicators, revealing the level of anthropogenic load on the environment of the region, is aggregated into an integrated index of the regional environmental profile. Based on the trend model of the relationship between the industrial production index and the integrated index of the ecological regional profile through the example of one of the industrial centers of the Russian Federation—the Perm Territory—the paper substantiates the tendency of industrial development of the region toward sustainability in the form of coexistence of interrelated trends of industrial growth and the relative stability of indicators of the regional environmental profile. For the Perm Territory, the relationship of the studied indicators is inverse, which is expressed in the presence of the decoupling effect and confirms the introduction of digital and innovative technologies is a prerequisite for the sustainable economic development of industrially-oriented regions in the digital space.

Keywords Industry 4.0 · Sustainable development · Industrial digitalization · Ecologization of production · ESG agenda · Digital economy

A. Kahramanoglu
Bafta Business School, Ondokus Mayis University, Mayis Unv, 55270 Sumsun, Turkey
e-mail: ali.kahramanoglu@omu.edu.tr

L. Glezman (✉) · S. Fedoseeva
Institute of Economics of The Ural Branch of The Russian Academy of Sciences 50, Lenina Street, 620014 Perm, Russian Federation
e-mail: glezman.lv@uiec.ru

S. Fedoseeva
e-mail: fedoseeva.ss@uiec.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_13

1 Introduction

High-tech production, based on the use of innovative technologies, is the basis of the digital economy and necessitates the digital transformation of both the industrial sector and the entire regional spatial and sectoral structure for the successful development of the regional economy in the new environment. These issues are particularly relevant for the old industrial regions of Russia, where economic development is determined by the state of the backbone production industries and complexes, historically formed based on the natural resource and having the most morally and physically obsolete production and technological base, at the same time with a long history of existence, the operation of which causes significant damage to the environment, which is unacceptable in the world ESG agenda [16, 17]. In accordance with international standards, sustainable development is achievable under the condition of ecologization of production and reduction of the industry-related load on the environment, which is achieved through the implementation of the principles of lean production, rational resource management, increasing the depth of resource processing, wasteless production, and technologies to reduce the human factor in production processes, based on the introduction of innovative and digital technologies. Thus, in implementing the processes of production digitalization, the relevant and practically significant task is to determine and assess the relationship and mutual influence of the industrial production index and the environmental component of regional development, due to the significant increase in production capacity by industrial enterprises, due to the implementation of the state policy of import substitution in conditions of tightening sanctions policy of some unfriendly countries.

To solve the indicated problems, the authors set and solved the task of assessing the dependence of the set of environmental characteristics of the regional space and the industrial production index in the region in dynamics, based on the calculation of the integrated index of the environmental profile of the region and the establishment of its dependence on the industrial production index, including the assessment of the strength and direction of the identified relationship by correlation analysis using the Pearson coefficient. Also, a development forecast of the established relationship of the estimated indices was made based on the trend model obtained by the approximation method.

2 Literature Review

At present, scientific interest in the economic category of Industry 4.0 does not weaken and receives a new round of development. Thus, in their work on the transformation of industry and regional aspects of the modern stage of industrial development, Akberdina and Romanova consider the definitions of “fourth industrial revolution,” “Industry 4.0,” “digital transformation of the industry” and “new industrialization,” noting their similarity and highlighting the differences, and also reveal approaches to the industrial development of the region and the territorial location of industry [1]. At the same time, the digital transformation of industrial enterprises is a key factor of spatial competitiveness, determining the direction of regional development and the possibility of increasing the growth rate of the national economy. For example, scientists-economists study the spatial relationship in the processes of digital technology use by manufacturing enterprises at the regional level [13].

There is active research in scientific literature on various aspects of the digital agenda as it relates to industrial production. The reasons and consequences of the introduction of digital technology in relation to the international competitiveness of companies are analyzed. It is noted that in the Industry 4.0 era, the competitive advantages of the entire business community depend on the transformation of individual industries [9]. The uncertainty and complexity of the digital economy in general [11], as well as its multidimensionality from the perspective of the ESG agenda [4, 10] in the use of digital technologies in production processes that lead to a complete transformation of business models through digital platforms [7], is emphasized. The factors and industry specifics of the digital transformation of the industry from the standpoint of environmental efficiency are highlighted [10, 18, 21].

Of interest is a study by a team of scientists that assesses the effectiveness of the transition to Industry 4.0 by cluster analysis based on an index that includes indicators of industry use of digital technologies such as big data, CCS, and CPS models. Based on this, 33 analyzed countries are divided into 5 groups according to the usage level of digital technology in the industry [2].

Some scientists [19] emphasize the importance of sectoral specialization of innovation and digital technology, especially for the industrial sector, in particular for mechanical engineering, which makes it possible to significantly increase the technological capabilities of industrial sectors in the context of Industry 4.0 for the development of the digital economy.

The works devoted to the analysis of the level of industrialization and innovation performance of industrial regions, the development of models of industrial-innovation development of Russian regions [6], and the assessment of the level of socio-environmental-economic well-being of regions [22] seem to be significant.

The team of scientists led by Aturin considers the problems and trends of the digital economic transformation and highlights the areas of modern uncertainty, which are the sources of formation of threats, challenges, and shocks, where they include the environment [3]. The growing tension of the ecological situation in Russia requires identifying and analyzing the main current challenges in the ecological sphere of the country and its individual regions, as well as finding ways to overcome them. First of all, for industrial regions, the ecologization of production and the introduction of new innovative technologies are necessary [5].

In their studies, Romanova and Sirotin call the strategic direction of economic transformation the ecologization of industrial production in industrial regions, where the ecological load on the territory is the highest [15]. The same scientists consider the spread of green digital technologies and their impact on the industry, highlight the key tasks of digital transformation, the directions and models of green digitalization, the potential socio-economic consequences of the introduction of digital technologies in industrial production [20].

Thus, the analysis of scientific sources describing the trends and problems of digitalization of industry and ecologization of production in the digital space indicates the need to determine the conditions for sustainable development of the regional economy, due to the need to consider the multidimensional influence of multidirectional factors of the regional space.

3 Materials and Methods

The selection of particular indicators characterizing the level of anthropogenic impact on the environment was carried out to solve the tasks of analyzing the regional ecological situation. The study is based on the example of the Perm Territory as one of the largest industrial centers of the Russian Federation, which ranks first in the Urals in terms of industrial production. The leading regional industries under study are machine-building, metallurgy, chemical and petrochemical, timber, as well as fuel and paper-pulp industries. The study was conducted in the dynamics for 5 years (2016–2020). The set of particular indicators was aggregated into an integrated index of the regional environmental profile, which is understood as a system of indicators describing and revealing the ecological situation in the region and making it possible to assess the technogenic burden on the regional environment [8].

The methods of normalization by the maximum, considering the direction of the impact of particular indicators, rating, and weighing, were used to calculate the integrated index of the regional environmental profile.

Calculations were performed by the authors' methodology presented in Fig. 1.

In the first stage of the methodology, indicators reflecting the state of the regional environmental profile were selected. The data source was the official statistical indicators for the regions of the Russian Federation, which can be characterized as freely distributed and parametric, to meet the conditions of data relevance. In the second stage of the methodology, normalization by maximum, taking into account the direction of the impact of particular indicators, which made it possible to avoid the complexities associated with the different units of measurement of the indicators, was carried out. The third stage was to determine the weight of the indicators in the integrated index. The method of calculation of averages was used for calculation based on the fact that the selected indicators are equivalent (the goal is not to display the significance of each component in the index, but to diagnose the overall relationship of the integrated index with industrial development), and determining in the final index is their metric value. Accordingly, in the fourth stage, taking into account the calculated weights of indicators and normalized values of indicators, the integrated index of the regional environmental profile was calculated. The fifth and sixth stages provided for the diagnosis of the relationship between the integrated index of the regional environmental profile and the index of industrial production and its interpretation. Verification of the calculated data was performed employing

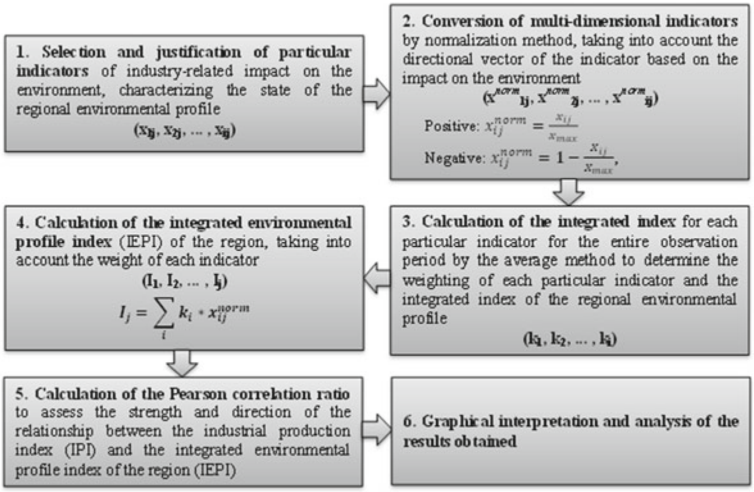

Fig. 1 Calculation method of the integrated index of the regional environmental profile. *Source* Compiled by the authors

analysis of variation using a standard scale for evaluating the results of calculating the variability index.

The study is based on the hypothesis: the industrial production index (data generated by Rosstat) and the calculated integrated index of the regional environmental profile are interrelated. The diagnosis of this relationship and the assessment of its direction and strength require the use of correlation analysis with the use of Pearson correlation since this method allows determining the nature of changes in one indicator in response to changes in another. Accordingly, the type of correlation relationship is established by constructing a correlation field using various functional approximation models. A predictive analysis of the relationship of the indices under study for 5 periods was carried out based on the resulting trend model.

4 Results

The list of particular indicators for the Perm Territory characterizing the state of the regional environmental profile for 2016–2020 is presented in Table 1.

The analysis of the obtained value of the Pearson correlation ratio (Table 2) showed that there was a weak inverse relationship between the industrial production index and the integrated index of the regional environmental profile, indicating that the growth of industrial production has little effect on the ecological situation in the region. This situation confirms the so-called decoupling effect [14], which consists of the following position: the increase in the production of industries does not lead to an increase in the man-made impact on the environment, that is, the indicators

Table 1 Particular indicators of the environmental profile of the Perm Territory for 2016–2020

Indicators	2016	2017	2018	2019	2020
Emission of pollutants into the atmosphere from stationary sources, ktons	308.9	310.8	292.8	293.1	280.8
Captured and neutralized air pollutants, ktons	1041.3	1239.1	918.8	1202.4	981.6
Discharge of polluted wastewater, million cubic meters	357.8	317.1	212.0	209.5	194.2
Use of fresh water, million cubic meters	1593.0	1603.0	1470.0	1251.0	1103.0
Production and consumption waste formed, ktons	38,855.8	41,267.0	45,721.5	46,387.6	47,840.4
Environmental protection costs, RUB mln	11,355.2	10,980.4	13,745.5	16,303.0	15,798.6

Source Compiled by the authors according to Rosstat, https://rosstat.gov.ru

of the environmental profile do not determine. This shows that the Perm Territory is moving in the right direction in terms of ecologization of the region's industrial production.

Given the synthetic nature of the integrated environmental profile index of the region, let us assess the reliability of the correlation ratio using Student's coefficient. At the significance value of 0.05, one can conclude that the data obtained are statistically significant (see Formula 1).

$$t_r(0.41) \geq t_{crit}(0.39) \tag{1}$$

By constructing a correlation field using different functional models of approximation, the most reliable approximation describing the trend model of the relationship between the indices under study was determined to predict the further behavior of the relationship between the studied indices (Fig. 2).

Table 2 Correlation assessment of the dependence of the integrated environmental profile index and the industrial production index in the Perm Territory for 2016–2020

Index	2016	2017	2018	2019	2020	Pearson correlation ratio
Industrial production index, % of the previous year (IPI)	99.7	102.5	100.3	98.9	97.5	−0.08
Integrated environmental profile index (IEPI)	0.58	0.62	0.55	0.69	0.60	

Source Compiled by the authors

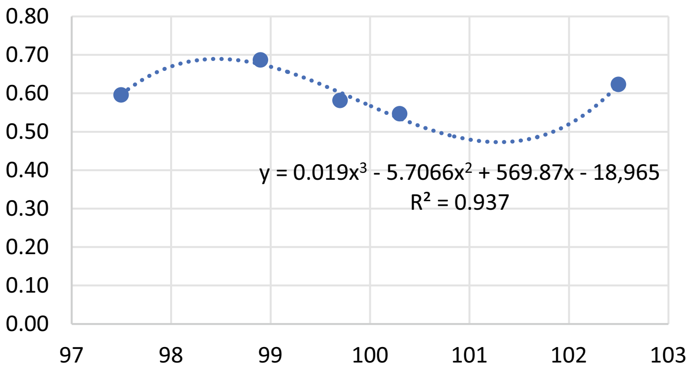

Fig. 2 Polynomial trend of the dependence of the industrial production index and the integrated environmental profile index of the Perm Territory. *Source* Compiled by the authors

The best approximation with the highest degree of reliability of smoothing (determination factor 0.937) is approximation by a polynomial function of the third degree (of the six options considered).

Then the approximation model has the following form (Formula 2):

$$y = 0.019x^3 - 5.7066x^2 + 569.87x - 18,965 \tag{2}$$

Using the obtained trend model (Formula 2), the authors built a forecast of the dynamics of the relationship between indices of industrial production and the integrated environmental profile index of the region for 5 forecast periods (Fig. 3).

The results of forecast analysis of the relationship between the industrial production index and the integrated environmental profile index revealed the perspective strengthening of the existing relationship, which means the weakening of decoupling effect and, therefore, the strengthening of the negative impact of industrial production

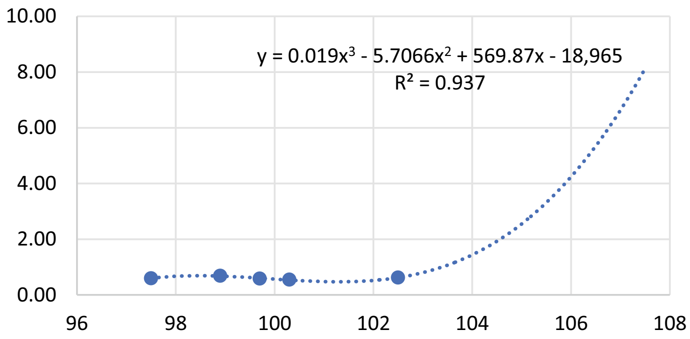

Fig. 3 Forecast of the relationship between the industrial production index and the integrated index of the regional environmental profile for 5 forecast periods. *Source* Compiled by the authors

on the environmental profile of Perm Territory. Since the decoupling effect is one of the basic principles of the green economy, its achievement and preservation becomes a priority task for achieving sustainable regional development. Accordingly, regional authorities and industrialists must intensify and accelerate implementing digital and innovative technologies aimed at production ecologization.

5 Conclusion

The study of the relationship between the industrial production index and the integrated environmental profile index of the region in the dynamics for 5 years through the example of the Perm Territory has shown that the growth of industrial production has little impact on the regional environmental profile. The weak inverse relationship between the industrial production index and the integrated environmental profile index revealed the existence of a decoupling effect caused by the introduction of innovative resource-saving technologies into industrial production and rational resource consumption within the framework of the region's economy ecologization. Thus, in the studied period, the strategy for the development of industrial production in Perm Territory, focused on the introduction of innovative technologies and digitalization of production, consistent with the principles of ecologization and rational resource use, as evidenced by the identified decoupling effect.

However, the results of the predictive analysis of the relationship between the industrial production index and the integrated environmental profile index of the region revealed that in the strategic perspective this relationship is rapidly increasing. Since the orientation of the studied relationship is reversed, i.e., the growth of production has a negative impact on the ecological state of the regional space, the preservation of the decoupling effect through the introduction and increase in the share of digital and innovative technologies seems to be extremely important and a prerequisite for achieving sustainable economic development of industrialized regions in the digital space. Thus, regional authorities and the industrial business community need to intensify and accelerate the introduction of digital and innovative technologies aimed at sustainable resource use and ecologization of production to maintain the decoupling effect and achieve sustainable development of the regional space in the strategic perspective.

The methodological approach considered and tested on the example of Perm Territory can be replicated for use in other regions, subject to adaptation to the specifics of the environmental profile of a particular region. The results obtained can be useful and interesting both to the state authorities to control and correct the state of the ecological space of the region, and to the general public.

Further research on the relationship between indices of industrial production and the regional environmental profile, in terms of studying the nature and dynamics of the decoupling effect, seems promising for achieving green economic growth, which is not accompanied by environmental degradation in the long term.

Acknowledgements The work was performed by the Research Plan of the Institute of Economics of the Ural Branch of the Russian Academy of Sciences.

References

1. Akberdina, V. V., & Romanova, O. A. (2021). Regional industrial development: review of approaches to regulation and determining of priorities. *Economy of Region, 17*(3), 714–736. https://doi.org/10.17059/ekon.reg.2021-3-1
2. Atik, H., & Ünlü, F. (2019). The measurement of Industry 4.0 performance through Industry 4.0 Index: An empirical investigation for Turkey and European countries. *Procedia Computer Science, 158*, 852–860. https://doi.org/10.1016/j.procs.2019.09.123
3. Aturin, V. V., Moga, I. S., & Smagulova, S. M. (2020). Digital transformation management: Scientific approaches and economic policy. *Upravlenets—The Manager, 11*(2), 67–76. https://doi.org/10.29141/2218-5003-2020-11-2-6
4. Bataeva, B. S., Kokurina, A. D., & Karpov, N. A. (2021). The impact of ESG reporting on the financial performance of Russian public companies. *Upravlenets—The Manager, 12*(6), 20–32. https://doi.org/10.29141/2218-5003-2021-12-6-2
5. Burmatova, O. P. (2021). Environmental challenges in regions: Analysis and measures to reduce potential risks. *Economy of Region, 17*(1), 249–261. https://doi.org/10.17059/ekon.reg.2021-1-19
6. Doroshenko, Y. A., Starikova, M. S., & Ryapukhina, V. N. (2022). Identification of industrial and innovative development models of regional economic systems. *Economy of Regions, 18*(1), 78–91. https://doi.org/10.17059/ekon.reg.2022-1-6
7. Erol, I., Peker, I., Ar, I. M., Turan, İ, & Searcy, C. (2021). Towards a circular economy: Investigating the critical success factors for a blockchain-based solar photovoltaic energy ecosystem in Turkey. *Energy for Sustainable Development, 65*, 130–143. https://doi.org/10.1016/j.esd.2021.10.004
8. Glezman, L. V., & Fedoseeva, S. S. (2022). Assessment of the relationship between industrial production and the regional environmental profile. *Transbaikal State University Journal, 28*(4), 96–107. https://doi.org/10.21209/2227-9245-2022-28-4-96-107
9. Götz, M., & Jankowska, B. (2020). Adoption of Industry 4.0 technologies and company competitiveness: Case studies from a post-transition economy. *Foresight and STI Governance, 14*(4), 61–78. https://doi.org/10.17323/2500-2597.2020.4.61.78
10. Khvorostyanaya, A. S. (2022). ESG-strategizing of industrial companies: domestic and foreign experience. *Russian Journal of Industrial Economics*, *15*(3), 334–343. https://doi.org/10.17073/2072-1633-2022-3-334-343
11. Kovacs, O. (2018). The dark corners of Industry 4.0—Grounding economic governance 2.0. *Technology in Society, 55*, 140–145. https://doi.org/10.1016/j.techsoc.2018.07.009
12. Lola, I. S,. & Bakeev, M. B. (2019). Digital transformation in the manufacturing industries of Russia: an analysis of the business tendencies observations results. *St. Petersburg University Journal of Economic Studies, 35*(4), 628–657. https://doi.org/10.21638/spbu05.2019.407
13. Naumov, I.V., Dubrovskaya, J.V., & Kozonogova, E.V. (2020). Digitalization of industrial production in the russian regions: Spatial relationships. *Economy of Region, 16*(3), 896–910. https://doi.org/10.17059/ekon.reg.2020-3-17
14. Polyakov, V. V. (2021). Decoupling as a mechanism for ensuring the reproduction of natural resource capital in the agricultural sector. *Economy and Ecology of Territorial Formations, 5*(1), 6–12. https://doi.org/10.23947/2413-1474-2021-5-1-6-12
15. Romanova, O. A., & Sirotin, D. V. (2021). Environmental and economic efficiency of recycling industrial waste in the Urals. *Economy of Region, 17*(1), 59–71. https://doi.org/10.17059/ekon.reg.2021-1-5.

16. Shakhnazarov, B. A. (2022). Law of sustainable development: A concept and methodology. Transformation of the ESG agenda in the context of sanction restrictions. *Lex russica, 75*(7), 51–63. https://doi.org/10.17803/1729-5920.2022.188.7.051-063
17. Shlihter, A. A. (2020). Business strategies of companies in the context of sustainable development. *World Ecopom and International Relations, 64*(4), 37–44. https://doi.org/10.20542/0131-2227-2020-64-4-37-44
18. Tsenzharik, M. K., Krylova, Y. V., & Steshenko, V. I. (2020). Digital transformation in companies: Strategic analysis, drivers and models. *St. Petersburg University Journal of Economic Studies, 36*(3), 390–420. https://doi.org/10.21638/spbu05.2020.30
19. Tuncel, C. O., & Polat, A. (2016). Sectoral system of innovation and sources of technological change in machinery industry: An investigation on Turkish machinery industry. *Procedia—Social and Behavioral Sciences, 229*, 214–225. https://doi.org/10.1016/j.sbspro.2016.07.131
20. Turovets, J., Proskuryakova, L., Starodubtseva, A., & Bianco, V. (2021). Green digitalization in the electric power industry. *Foresight and STI Governance, 15*(3), 35–51. https://doi.org/10.17323/2500-2597.2021.3.35.51
21. Yüksel, H. (2020). An empirical evaluation of industry 4.0 applications of companies in Turkey: The case of a developing country. *Technology in Society, 63*, 101364. https://doi.org/10.1016/j.techsoc.2020.101364
22. Zabelina, I. A. (2022). Assessment of the socio-ecological and economic welfare of the Russian eastern regions using Sen's extended function. *Economy of Regions*, *18*(2), 398–412. https://doi.org/10.17059/ekon.reg.2022-2-7

Digital Technologies and Circular Value Chains for Sustainable Development

Anastasia Nikitaeva and Olga Dolgova

Abstract Achieving the Sustainable Development Goals is an urgent task not only for governments but also for the management of industrial enterprises. Based on the analysis of the scientific literature and the methodology of building network maps, the close connection between the concepts of digitalization, sustainable development, and circular economy is confirmed. The study also provides an answer to the research question of which digital technologies should be used to build a sustainable circular business model. The set of technologies was identified based on content analysis, including the Internet of Things, big data, artificial intelligence, etc. The paper presents a matrix of digital technologies that are the most promising for creating circular business models. The article presents a system developed by the authors for connecting digital technologies and closed loops for different stages of value creation, for which the introduction of these technologies has the greatest impact on increasing sustainability and circularity.

Keywords Circular economy · Digitalization · Sustainable development · Digital technologies · Industrial value chains

1 Introduction

After the adoption of the Sustainable Development Goals by the United Nations in 2015 [18], the concept of circular economy is becoming increasingly relevant for their practical achievement. For industry, this concept involves changing the existing business models and building new ones based on the principles of a general reduction in the use of materials; increasing the reuse of products by extending their life cycle through repair, reconstruction, and restoration; as well as increasing the processing

A. Nikitaeva (✉) · O. Dolgova
Southern Federal University, 105/42 Bolshaya Sadovaya Str, 344006 Rostov-On-Don, Russian Federation
e-mail: aunikitaeva@sfedu.ru

O. Dolgova
e-mail: oldolgova@sfedu.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_14

and extraction of materials from production and consumption [8]. In this case, the business model is considered as a description of how an organization creates, delivers, and captures value in the existing economic, social, institutional, cultural, and technological context, taking into account the internal logic of enterprise activities and relations with external stakeholders [14]. The circular business model assumes the appropriate characteristics of the value chain and ensures that the negative environmental impact is reduced and the enterprise receives economic effects through more efficient and prolonged use of all types of resources and waste reduction. This is especially true for industrial enterprises, all of whose activities involve working with materials and other resources and have traditionally had a high level of waste generation.

Due to the relative closeness of biological and technological loops in the circular business models of industrial companies, a higher level of sustainability is achieved. In turn, the distribution of value creation, the high role of partnerships, and cyclical loops allow enterprises to use such business models to be more resistant to external shocks and unstable impacts of external environments. Thus, it can be concluded that circular models affect not only the implementation of the concept of sustainable development but are also closely related to resilience. There are different definitions of the term "resilience." In this paper we use the definition of Donella Meadows, who defines resilience as "the ability of a system to recover from perturbation; the ability to restore or repair or bounce back after a change due to an outside force" [12]. The closeness of value chains and the territorial proximity of partners help industrial enterprises with circular business models to recover faster after various shocks.

However, at the moment, only a small number of companies have switched to circular models [13]. The low prevalence of circular business models is caused by a number of factors, including the ignorance of business owners about this concept, low demand for goods made from recyclables, the complexity of restructuring business models, etc. Many scientists believe that cutting-edge digital technologies can help organizations ensure the circularity of their business processes [1, 7, 10, 21]. Today, the definition of the relationship between the circular economy and digital technologies is an urgent issue discussed not only by academics but also by politicians and entrepreneurs [21]. Therefore, the study of the relationship between digitalization, sustainable development, and the circular economy is of high relevance. This vector of research is the first objective of this paper. Another important research issue is the identification of digital technologies for increasing circularity and sustainability in value chains. Thus, the second objective of the study is to identify the main digital technologies for advancing the circularity of each stage of the value chain.

2 Literature Review

In the course of the study, we analyzed a wide array of research literature on the selected subject field. On the basis of scientometric analysis, publications on digitalization, sustainable development, and circularization were analyzed, and a content analysis of works revealing all three concepts in interrelation was conducted. Among the publications under review, several main areas of research can be identified.

Some scientific publications focus *on solving specific applied problems of forming circular business models and achieving sustainable economic development* with the help of information technology. For example, Gong et al. [6] paid special attention to the possibility of using blockchain technology in circular marine plastic debris management. This paper presents the concepts of business models and processing chains based on blockchain technology. Dobermann et al. [4] examine how digital technologies can contribute to increasing the sustainability and circularity of food systems.

Part of the research examines how specific types of digital technologies affect the increasing circularity of business processes. For example, Ellsworth-Krebs et al. [5] consider digital passports not only from the viewpoint of technology, but also as a means to improve communication between participants in the value chain. The authors present the advantages of a digital passport for overcoming barriers in the implementation of the circular economy concept.

Teisserenc and Sepasgozar [16, 17] review the technical literature on blockchain technology and offer a technological basis for the use of blockchain throughout the project life cycle. The model developed by the authors takes into account not only environmental and regulatory aspects but also the implementation of the circular economy concept.

Kolmykova et al. [9] analyzed the current trends in the transformation of global value chains, which are based on the symbiosis of physical and virtual production systems. This symbiosis helps to establish new operational models (including circular production) that contribute to achieving sustainable development goals as well as providing economic growth.

Martn-Gómez et al. [11] provide an overview of the current state of cognitive production and the main digital tools of Industry 4.0. The authors propose a system that allows modeling the metabolism of production systems at all stages of the value chain, which allows implementing measures to increase its sustainability.

A number of studies have also been conducted to examine current approaches and trends in the field of the interaction of digital technologies and circular economy concepts. For example, Howard et al. [7] studied six small and medium-sized businesses operating in different sectors of the economy, from the point of view of their implementation of the concept of a closed-cycle economy. The authors cite various modern management tools and digital technologies that can help small and medium-sized businesses to make their business models more sustainable and cyclical.

Awan et al. [1] conducted a literature analysis, which showed that effective knowledge exchange between different participants in the value chain requires interaction between the circular economy and Industry 4.0 to be organized.

Kottmeyer [10] examines the transformational potential of digitalization. His research focuses not only on the critical social outcomes of this process but also on how to mitigate the negative consequences of digitalization by combining information technology and the circular economy.

Wynn and Jones [21] explore the use of digital technologies by a small number of firms to increase the sustainability of their business processes and conform to the concept of a closed-loop economy. Based on the survey data of representatives of various companies, the authors concluded that for organizations that implement projects within the circular economy, there is no obvious relationship between the use of digital technologies and increasing the circularity of business processes. Despite this statement, researchers note the positive impact of information technologies on achieving sustainable development.

Thus, in the general body of research devoted to various aspects of digital transformation, sustainable development, and the formation of circular business models of industrial enterprises, there are studies devoted to assessing the possibilities of digital technologies for the circulation of the value chain. At the same time, the issue of the potential of digital solutions for creating a circular value chain and ensuring sustainable development in general has not been sufficiently developed to date.

3 Materials and Methods

An analysis of the literature was carried out to check whether there is a relationship between the concepts of “digitalization”, “sustainable development”, and “circular economy”. In a schematic form, the methodology of the study is presented in Fig. 1.

Using the Scopus database, articles on the corresponding selected concepts and keywords published from 2011 to 2022 were selected. 2,000 of the most relevant articles on each of the three topics were selected. Based on the analysis, a hard query was formed, on the basis of which a search for scientific papers was carried out in the Scopus database. A total of 31 articles were found, of which 11 publications were selected as the most relevant to the subject under study. A content analysis was carried out on the publications, and a network map was built using the VOSviewer software [20]. This made it possible to solve both research issues using the methods of scientometrics and theoretical analysis.

4 Results

The main digital technologies identified by researchers as promising for the implementation of initiatives in the field of circular economy are presented in the form of a matrix in Fig. 2.

Some digital technologies were provided by individual authors. ERP systems, social networking, digital fabrication, Bluetooth, cognitive technical systems, GPS, digital passports, open data standards, and fog computing are examples of such technologies.

The most frequently mentioned technologies are artificial intelligence, big data, and the Internet of Things. This is caused by the extremely broad potential of their

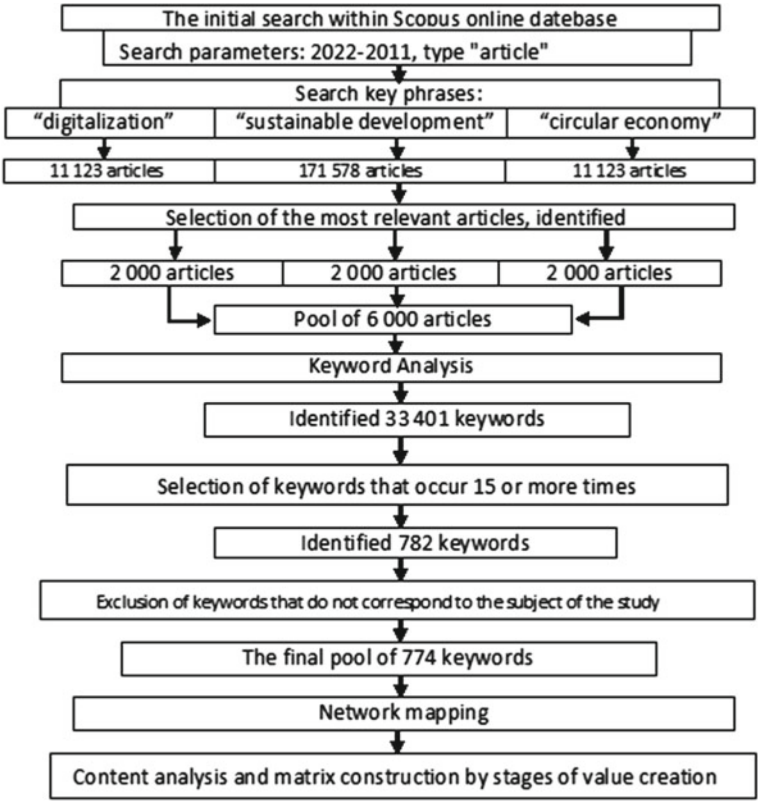

Fig. 1 Methodology overview

application in a variety of fields. Big data makes it possible to carry out research on extensive samples, which allows one to get a more accurate result. The Internet of Things technologies contribute to the regular collection of data on production processes, which allows them to be optimized. The use of artificial intelligence helps in finding patterns, forecasting, image and video processing, robot control, etc.

A network map was built based on the analysis of keywords found in scientific publications on the subject of research, using the VOSviewer software, as shown in Fig. 3.

As can be seen in Fig. 3, there is a strong relationship between all the three concepts in the scientific field, and this relationship is even stronger between the circular economy and digitalization than between the circular economy and sustainable development (since there are many articles in which these keywords are used together, therefore these keywords belong to the same thematic cluster and are highlighted in the same color).

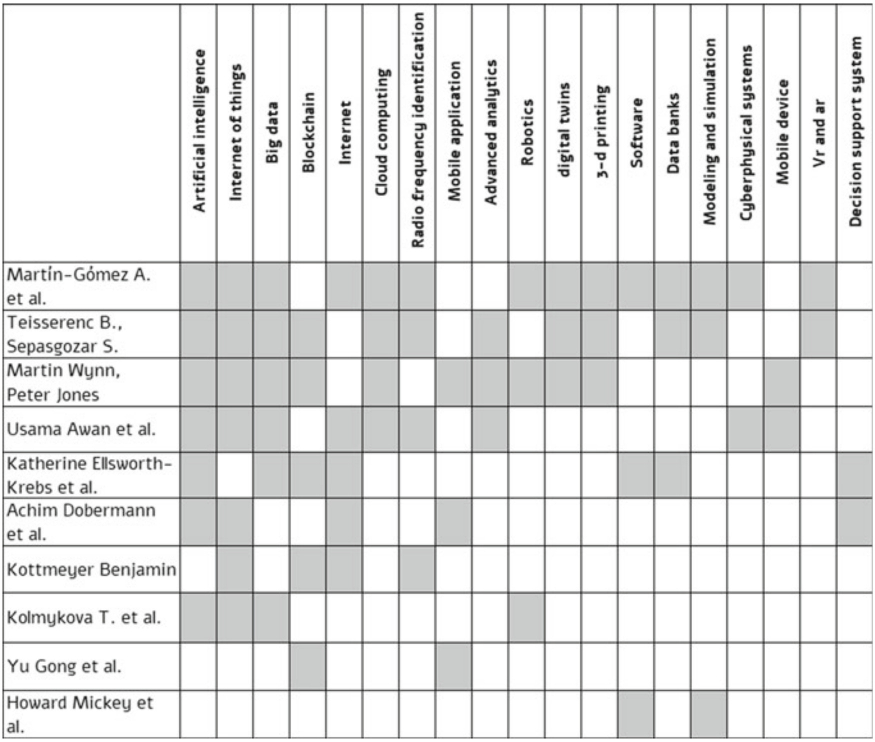

Fig. 2 Digital technologies for business process circulation. *Source* [1, 4–7, 9–11, 16, 17, 21]

It should be noted that the distinctive features of the circular value chain are: (1) its construction is not linear but cyclical form, and (2) the appearance of relatively closed cycles at various stages of the value creation process.

Based on the literature review, a framework was compiled (Fig. 4), which reflects the most effective digital technologies for increasing sustainability and implementing the concept of a circular economy at certain stages of the value chain. According to the results of research, the most versatile technologies are artificial intelligence, big data, advanced analytics, data banks, modeling and simulation, software, remote access, the Internet, cloud computing, virtual reality, and augmented reality. Some of these technologies have already found practical application in industrial companies for increasing the circularity of their business processes.

For example, the Internet of Things is used in supply chains as well as in agricultural production [2].

The identified digital technologies can contribute to increasing the circularity of business models in various ways. Figure 5 shows a framework demonstrating at which stages of the circular value chain different digital technologies can be used by industrial companies.

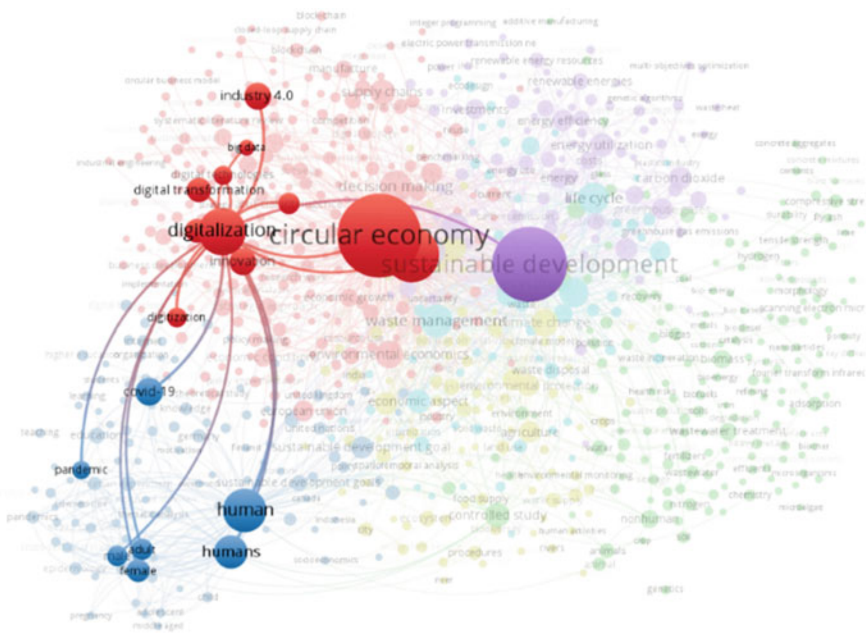

Fig. 3 Network map of keywords by topics "digitalization", "sustainable development", and "circular economy"

<table>
<tr><th>Design</th><th>R&D</th><th>Logistics of supply</th><th>Manufacturing</th><th>Distribution</th><th>Marketing</th><th>Service</th></tr>
<tr><td colspan="7">Artificial intelligence, Big data, Advanced analytics, Data banks, Modeling and simulation, Software, Remote access, Internet, Cloud computing, VR and AR</td></tr>
<tr><td>Digital painting</td><td colspan="6">Decision support system</td></tr>
<tr><td colspan="2">3D modeling</td><td colspan="5">Mobile device</td></tr>
<tr><td></td><td></td><td colspan="5">Global Positioning System</td></tr>
<tr><td></td><td></td><td colspan="3">Blockchain</td><td colspan="2">Social network</td></tr>
<tr><td></td><td></td><td colspan="3">Radio Frequency Identification</td><td colspan="2">Mobile application</td></tr>
<tr><td></td><td></td><td colspan="3">Robotics</td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="3">Digital passports</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>Digital fabrication</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>ERP-system</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>3-D Printing</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>Cyberphysical systems</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>Internet of things</td><td></td><td></td><td></td></tr>
</table>

Fig. 4 Distribution of digital technologies by stages of value creation

The UNIDO scheme was used as a basis for this visualization. It has been modified for the stages of the value chain corresponding to the "smiling curve". Furthermore, it was supplemented with a list of digital technologies that can be effective for increasing the circularity of various stages of the value chain. This image is illustrative, so it shows a maximum of two technologies that are promising for use at this stage.

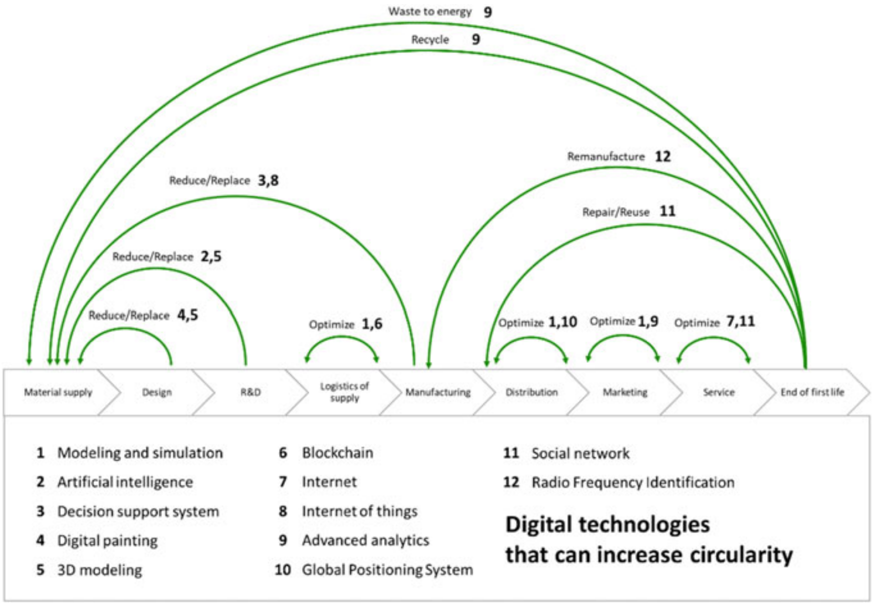

Fig. 5 Circulation of supply chains based on digital technologies. *Source* Developed by the authors based on [19]

According to the authors, this approach makes it possible to increase the practical feasibility of the proposals shown. Most often, enterprises have limited resources and opportunities to implement the technologies of the digital economy. Consistent concentration on one or two digital technologies for the effective creation of closed cycles at different stages of value creation will allow increasing the manageability of the transition to circular business models. The definition of technologies for each closed loop was carried out on the basis of content analysis and an analysis of the practical experience of industrial companies.

Specific cases can be given as an example. The French tire manufacturer Michelin using the Internet of Things organized the collection of tire-related data as part of the implementation of the tire-as-a-service business model, which minimizes fuel consumption and downtime. Group SEB, an international manufacturer of tableware and household appliances, has started using 3D printing technology to manufacture spare parts on demand, thereby eliminating excess inventory and reducing emissions. To minimize the amount of food waste, Walmart tested blockchain technology that allows real-time tracking of food data, including its location [3].

To achieve the greatest economic, social, and ecological effects, it is necessary to consider three interrelated issues in an integrated manner. Firstly, what is the current level of maturity and digital support for the stages and links of the company's value chain? Secondly, which aspects of business model circulation are the enterprise's top priorities in the short term? Thirdly, which digital technologies can provide a strategic transition to a fully circular business model? To get answers to these questions, it is recommended to use the conceptual and analytical framework proposed in the given study.

5 Conclusion

Currently, digital technologies are used in various processes and fields of activity within industrial enterprises. At the moment, there are practically no enterprises that are not at least partially computerized [13]. However, some new technologies can radically change the structure of the existing business processes. For example, the widespread introduction of blockchain technology will significantly transform the interaction of enterprises and modify value chains. More importantly, digital technologies are an integral component of the implementation of strategies for sustainable enterprise development and the construction of circular business models. The essential relationship between digitalization, sustainability, and circulation is confirmed by the authors in this study on the basis of scientometric tools.

According to Neligan et al. [13], 9 out of 10 industrial enterprises in Germany are computerized, while 1 out of 10 companies is fully digitized. The processes, products, and/or tools of such a company are fully virtualized. The onset of Industry 4.0 and, therefore, comprehensive digitalization is getting closer. At this stage of development and use of digital technologies, it is important for industrial companies to choose the right focus for the implementation of digital solutions and connect it with the overall strategy of transformation and development of the business model. In particular, digital technologies make it possible to create effective circular business models and ensure the sustainable development of enterprises.

Based on the results of theoretical analysis and practical experience, we proposed a framework demonstrating at which stages of the circular value chain different digital technologies can be used by industrial companies to develop closed loops.

Despite the fact that many modern technologies can be applied to increase the sustainability and circularity of various stages of the value chain, the introduction of digital technologies should not be an end in itself but a means to achieve the goal. The digitalization process for the closed-type economy concept is more than the introduction of digital technologies; it is a new business model aimed not only at reducing the amount of waste but also at using recyclables, increasing the service life of products, etc. Digitalization as an isolated process will not be able to automatically increase sustainability indicators [3]. In addition, the integrated circular transformation of the value chain requires not the use of separate information technologies but the establishment of a digital platform. This is due to the fact that research has shown that different technological solutions contribute to the creation of closed cycles at different stages of the value creation of industrial companies.

Acknowledgements The research was supported by the Strategic Academic Leadership Program of the Southern Federal University ("Priority 2030").

References

1. Awan, U., Sroufe, R., & Bozan, K. (2022). Designing value chains for Industry 4.0 and a circular economy: A review of the literature. *Sustainability*, *14*(12), 7084. https://doi.org/10.3390/su14127084
2. Brassesco, M. E., Pintado, M., & Coscueta, E. R. (2022). Food system resilience thinking: From digital to integral. *Journal of the Science of Food and Agriculture, 102*, 887–891. https://doi.org/10.1002/jsfa.11533
3. Bressanelli, G., Adrodegari, F., Pigosso, D. C. A., & Parida, V. (2022). Towards the smart circular economy paradigm: A definition, conceptualization, and research agenda. *Sustainability*, *14*(9). https://doi.org/10.3390/su14094960
4. Dobermann, A., Bruulsema, T., Cakmak, I., Gerard, B., Majumdar, K., McLaughlin, M., Reidsma, P., Vanlauwe, B., Wollenberg, L., Zhang, F., & Zhang, X. (2022). Responsible plant nutrition: A new paradigm to support food system transformation. *Global Food Security, 33*, 100636. https://doi.org/10.1016/j.gfs.2022.100636
5. Ellsworth-Krebs, K., Rampen, C., Rogers, E., Dudley, L., & Wishart, L. (2021). Circular economy infrastructure: Why we need track and trace for reusable packaging. *Sustainable Production and Consumption*, *29*. https://doi.org/10.1016/j.spc.2021.10.007
6. Gong, Y., Wang, Y., Frei, R., Wan, B., & Zhao, C. (2022). Blockchain application in circular marine plastic debris management. *Industrial Marketing Management*, *102*, 164–176. https://doi.org/10.1016/j.indmarman.2022.01.010
7. Howard, M., Yan, X., Mustafee, N., Charnley, F., Böhm, S., & Pascucci, S. (2022). Going beyond waste reduction: Exploring tools and methods for circular economy adoption in small-medium enterprises. *Resources, Conservation and Recycling, 182*, 106345. https://doi.org/10.1016/j.resconrec.2022.106345
8. Kirchherr, J., Reike, D., & Hekkert, M. P. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling, 127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005
9. Kolmykova, T., Merzlyakova, E., & Kilimova, L. (2020). Development of robotic circular reproduction in ensuring sustainable economic growth. *Economic Annals-XXI*, 186(11–12), 12–20. https://doi.org/10.21003/ea.V186-02
10. Kottmeyer, B. (2021). Digitisation and sustainable development: The opportunities and risks of using digital technologies for the implementation of a circular economy. *Journal of Entrepreneurship and Innovation in Emerging Economies, 7*, 17–23. https://doi.org/10.1177/2393957520967799
11. Martín-Gómez, A., Ávila-Gutiérrez, M. J., & Aguayo-González, F. (2021). Holonic reengineering to foster sustainable cyber-physical systems design in cognitive manufacturing. *Applied Sciences, 11*(7), 2941. https://doi.org/10.3390/app11072941
12. Meadows, D. H. (2008). *Thinking in systems*. Chelsea Green Publishing Co.
13. Neligan, A., Baumgartner, R. J., Geissdoerfer, M., & Schöggl, J. P. (2022). Circular disruption: Digitalisation as a driver of circular economy business models. *Business Strategy and the Environment*, 1–14. https://doi.org/10.1002/bse.3100
14. Nikitaeva, A. Yu., Kiseleva, N. N. (2021). Reconfiguration of business models of industrial enterprises: Vectors of increasing sustainability in the new realities. *Journal of Volgograd State University. Economics*, *23*(1), 110–120. https://doi.org/10.15688/ek.jvolsu.2021.1.9
15. Summers, J., Smith, L., Harwell, L., & Buck, K. (2017). Conceptualizing holistic community resilience to climate events: Foundation for a climate resilience screening index. *GeoHealth*, *1*. https://doi.org/10.1002/2016GH000047
16. Teisserenc, B., & Sepasgozar, S. (2021). Adoption of blockchain technology through digital twins in the construction Industry 4.0: A PESTELS approach. *Buildings*, *11*(12), 670. https://doi.org/10.3390/buildings11120670
17. Teisserenc, B., & Sepasgozar, S. (2021). Project data categorization, adoption factors, and non-functional requirements for blockchain based digital twins in the construction Industry 4.0. *Buildings*, *11*(12), 626. https://doi.org/10.3390/buildings11120626

18. United Nations. (2015). Resolution adopted by the General Assembly on 25 September 2015. Transforming our world: The 2030 Agenda for Sustainable Development. https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_RES_70_1_E.pdf
19. United Nations Industrial Development Organization. Circular economy and the Montreal Protocol Division. https://www.unido.org/sites/default/files/files/2020-05/Publication_WEB_singlepages_0.pdf
20. Van Eck, N. J., & Waltman, L. (2010). Software survey: VOS viewer, a computer program for bibliometric mapping. *Scientometrics, 84*, 523–538. https://doi.org/10.1007/s11192-009-0146-3
21. Wynn, M., & Jones, P. (2022). Digital technology deployment and the circular economy. *Sustainability, 14*, 9077.

The Impact of Digitalization on the Telecommunications Sector ESG Transformation

Maria Vetrova, Tatyana Solovey, Igor Arenkov, and Dinara Ivanova

Abstract ESG-transformation is about ensuring a course towards compliance with environmental and social priorities, as well as the principles of governance transparency. The introduction of ESG principles and digitalization has become key business development trends in the last decade, as they may help to achieve sustainable development goals at the highest level of economic efficiency. In the last 6 years, the E component (the environment) has become particularly relevant due to the aggravation of the climate, waste management, and resource conservation. However, the COVID-19 pandemic has shifted the focus to the S component due to increased attention to health and social stability. Digital technologies are able to ensure the effective achievement of sustainable development goals, however, not all companies use the benefits of digital transformation equally, and many enterprises are still focused on maximizing short-term profits without taking into account the interests of future generations. This study highlights issues related to the impact of digital transformation on the activities of Russian and international IT companies in the field of sustainable development, and also assesses the level of digital technologies use in achieving sustainable development goals, as well as the company's digital transformation management system in conjunction with sustainable development.

Keywords ESG · Digital transformation · Telecommunications sector · Sustainable development · Digital technologies

M. Vetrova (✉) · M. Vetrova (✉) · T. Solovey · I. Arenkov · D. Ivanova
Saint-Petersburg University, 7/9 Universitetskaya Embankment, Saint Petersburg, Russian Federation
e-mail: m.a.vetrova@spbu.ru

T. Solovey
e-mail: t.solovey@spbu.ru

I. Arenkov
e-mail: i.arenkov@spbu.ru

D. Ivanova
e-mail: d.v.ivanova@spbu.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_15

1 Introduction

In the last decade the digital transformation has globally and radically changed the way people, businesses and society interact and operate. These changes are associated not only with the positive effects such as cost reduction, increased transparency, flexibility and sustainability of business [17], but also with the negative effects such as increasing polarization between developed and developing countries as a result of the digital gap, rising unemployment as a result of automation, worsening global environmental problems as a result of the increase in energy consumption and greenhouse gas emissions by the ICT sector, as well as the annual generation of 50 million tons of electronic waste, 80% of which ends up in landfills or is disposed in environmentally inefficient ways [22]. The International Data Corporation (IDC) predicts that digital transformation spending will reach $1.97 trillion in 2022 and a staggering $6.8 trillion globally by 2023. Therefore, the ongoing digital transformation must take into account the UN 2030 sustainable development goals for the benefit of future generations.

Along with digital transformation, the trend of the last decade was a stronger focus on sustainable development. On January 1, 2016, the 17 UN Sustainable Development Goals for the period up to 2030 officially came into force [21]. Over the next 15 years, during which these universally applicable goals must be achieved, countries will intensify their efforts aimed firstly at ecology and environmental protection, including the fight against climate change, the conservation of biodiversity, marine ecosystems and much more; secondly, at social and economic development, such as quality education, decent work, and economic growth; and thirdly, at other areas, among which we can highlight effective institutions and justice, partnerships for sustainable development, and so on. The amount of funds needed to achieve the UN Sustainable Development Goals is estimated by the World Bank at about $80 trillion dollars; Allianz Group forecasts a higher amount—200 trillion dollars [1]. All this provides a guideline for business transformation with an emphasis on the unity of the three ESG factors: a responsible attitude to the environment (Environmental), high social responsibility (Social), and high-quality corporate governance (Governance).

In order to accumulate the necessary amounts of funds and use them in the chosen direction of sustainable development, a new ecosystem of global finance is being formed in the world; it focuses on the development of the green finance market, which gives priority to companies that adhere to ESG principles. The institutional environment for green finance is still at the stage of formation, but its benefits are available to businesses today, and there are some precedents for greenwashing to improve the ESG rating of companies without real actions, which usually involve high investments with a long payback period. At the same time, digital tools and solutions are able to neutralize the negative effects of the lack of an established institutional environment for ESG transformation and achieve sustainable development goals while maintaining economic efficiency through digital monitoring, automated reporting verification, and impact visualization.

The results of the BCG study based on the results of a survey of 850 companies revealed the relationship between digital technologies and the achievement of sustainable development goals [2]. Successful digitalization of companies gives impetus to the development of ESG principles. Increasing waste and climate problems are orienting business structures primarily towards solving problems within the framework of the E-direction, but in the healthcare industries the S-aspect comes to the fore and G-initiatives prevail in financial institutions. At the same time, digital technologies are able to balance the E, S, and G factors in order to achieve the goals of sustainable development.

One of the drivers of structural shifts is the telecommunications sector, which provides the basis for the information society development [11]. The Russian telecommunications market consists of telecommunications equipment (30% of the market) and communication services (about 70%). Russia's share in the global ICT market is no more than 0.6% at the end of 2020 [16]. At the same time, for the Russian Federation, the telecommunications sector is a backbone and makes a significant contribution to the development of the Russian economy, primarily to digitalization and the development of mining, trade, and real estate industries. Taking into account the fact that the policy of the Russian Federation in the field of telecommunications is formed at a qualitatively new economic, political, and social level, in the face of new challenges, the ESG transformation of the sector is becoming an integral part for maintaining the long-term competitiveness of the industrial and service sectors of the Russian economy.

Thus, this study is aimed, firstly, at identifying the impact of digital transformation on the activities of Russian and international IT companies in the field of sustainable development (SD), secondly, at assessing the level of digital technologies application to achieve the UN-2030 sustainable development goals (SDGs), thirdly, at assessing the company's digital transformation management system and sustainable development and their correlation. One of the key aspects of the study was the assessment of companies' compliance with the key principles of sustainable development: the principle of involvement (consideration of the interests and requests of key stakeholder groups), materiality (correct assessment of the significance of identified problems and risks for stakeholders and determination of the company's impact degree), manageability (presence of sustainable development management tools), transparency, and accuracy of information disclosure.

The study is structured as follows. Section 2 covers literature review on sustainable development, digitalization, and ESG transformation of companies. Section 3 describes the research methodology, and Sect. 4 presents the key results. The conclusion outlines the main conclusions and opportunities for future research.

2 Background

2.1 Sustainable Development

At the 2nd UN World Conference on Environment and Development in 1992 in Rio de Janeiro, a declaration on sustainable development principles achievement was adopted. It bases on the idea of combining environmental protection with the achievement of environmental, economic, and social goals. On September 25, 2015, at the UN Headquarters in New York, world leaders, including heads of state and governments, approved the post-2015 development agenda. They promised to lift humanity out of poverty and "heal" the planet by adopting 17 economic, environmental, and social goals. At the beginning of the twenty-first century the concept of sustainable development has been developed and filled with new plans and views, including decisions on the transition to an inclusive and green economy, which were integrated into such documents as the strategy "Innovation for sustainable growth: bioeconomy for Europe", the Eighth "Program action in the field of environmental protection" of the EU for the period up to 2030.

In 1859, the Irish scientist Tyndall John found and proved the greenhouse effect, which is climatic fluctuations occurred even due to small changes in the Earth's atmosphere. At the end of the nineteenth century, the Swedish physical chemist Svante Arrhenius predicted that due to the greenhouse effect, the temperature of the Earth's surface could change significantly as a result of the concentration of carbon dioxide [20]. In connection with serious threats, in 2015 under the UN Framework Convention on Climate Change an agreement, which regulates measures to reduce carbon dioxide in the atmosphere since 2020, was concluded. The agreement was prepared during the Climate Conference in Paris and adopted on December 12, 2015, and signed on April 22, 2016, by 190 countries and EU. Since 2016, the degree of certainty that climate change is caused by human activities has reached the so-called "gold standard" of five sigma (99.99% probability of a non-random result). On April 4, 2022, the final third volume was published, which is dedicated to reducing the anthropogenic impact on the climate. It emphasizes that countries' current climate targets lead to stabilization of global warming by the end of the century only at a level of about 3 °C [8].

Cutting-edge publications on climate change and biodiversity present catastrophic consequences and call for quick and strong business actions. Achieving carbon neutrality, overcoming the global waste crisis, and halting biodiversity loss are all interconnected with long-term prosperity and the preservation of life on earth. Enterprises play a leading role in solving global problems [4, 6], so ESG transformation is a key task for companies around the world.

2.2 Digitalization

Digital technologies can become a primary tool for achieving sustainable development goals particularly at a high level of economic efficiency. The correlation between digitalization and sustainable development is studied by many authors both from positive [7, 19] and negative aspects [10]. According to the UN, it is possible to achieve the sustainable development goals in all sectors using digital technologies [13]. Digital transformation is essential to obtain positive effects in all areas of sustainable development, including protecting the environment, conserving resources, preserving natural ecosystems and reducing waste and climate-active gases emissions [3], increasing global productivity, ensuring equity and inclusiveness, improving health and well-being of people, as well as to introduce circular supply chains [24].

The most relevant digital technologies for achieving sustainable development goals are the Internet of Things (IoT), big data analytics, blockchain, artificial intelligence, cloud technologies, virtual, and augmented reality [5].

2.3 ESG Transformation

The goals of sustainable development were developed basing on three directions to achieve long-term sustainability: social, environmental, and economic one [12]. The classical approach is aimed at reducing negative externalities such as waste, greenhouse gas emissions, inequality, etc., but this does not always provide the economic basis for the enterprise's activity. This gap at the enterprise level is compensated by the concept of ESG as a strategy to reduce costs and increase efficiency to ensure long-term competitiveness and sustainability [18]. It has been proven that positive ESG indicators can improve the financial state of companies [23]. Therefore, for long-term sustainability and efficiency, it is necessary to change the focus from current profit maximization to a responsible attitude towards the environment and social and corporate responsibility.

Companies annually invest $18 billion into the restoration of natural ecosystems [13], and much more into digitalization—$1.5 trillion [14]. Combining digital technologies with company-level sustainable development goals in the form of ESG principles is necessary to preserve and enhance natural capital and human well-being. Financial capital depends on natural and social capital. Since natural capital may be finite or non-renewable, its availability may limit financial capital and affect long-term economic performance. Financial and natural capital should be considered equally important in assessing the financial risk of a company. A set of recommendations issued by the Task Force on Climate-Related Financial Disclosures indicate that factors such as extreme weather events and changes in temperature or precipitation patterns can lead to lower revenue due to reduced production capacity and higher labor costs due to increased health problems and safety, etc.

Table 1 Effects of digital technologies usage in the field of sustainable development goals of companies

ESG-factor	Sustainable development goals	Digital technologies	Effect
Ecological	SDG 6, SDG 7, SDG 11-SDG 15	Internet of things, robotics and sensors, virtual and augmented reality technologies	Reducing the consumption of raw materials and energy resources, monitoring and reducing greenhouse gas emissions, waste processing and recycling development, etc.
Social	SDG 1-SDG 5, SDG 8, SDG 10	Artificial Intelligence, additive technologies and digital twins	Increasing labor safety, strengthening corporate culture, improving the quality of working conditions, reducing the number of routine operations, improving employee competencies and career opportunities
Govarnance	SDG 9, SDG 16, SDG 17	5G communication technologies and satellite communications, distributed registry systems	Increasing the transparency and reliability of data, the speed of decision-making, the unification and automation of business processes, etc.

Enterprises will be able to effectively respond to modern challenges and fulfill their obligations to various stakeholders, taking into account all the possibilities of combining digital technologies with factors E, S, and G [9]. The introduction of digital technologies and their ability to influence the achievement of sustainable development goals and ESG transformation are becoming increasingly relevant (Table 1).

3 Methods

The following companies were selected as the object of analysis:

- 20 Russian companies in the RAEX-600 rating, including 7 companies from the telecommunications industry, 9 companies from the IT industry, and 4 companies from the Internet service sector (the sample also included international companies operating in Russia)
- Top 10 international IT companies.

Of the 20 companies in the RAEX-600 rating only 2 companies are members of the UN Global Compact network that publicly disclose their practices and report in the field of SD, while 7 companies report on sustainable development in the National Register Corporate Non-financial Reports of the Russian Union of Industrialists and Entrepreneurs (RSPP), which indicates that at least 35% of companies publish reports on activities in the field of sustainable development in the public access.

Of the 10 largest global IT companies, 8 companies are members of the UN Global Compact network, which means that companies follow the 10 principles of the UN Global Compact, contribute to the achievement of the SDGs, and provide all the needed reporting.

The subject of the analysis was digital transformation, its impact on the activities of companies in the field of sustainable development and the publicly disclosed results of this activity, corporate practices (policies, programs and projects in the field of sustainable development and digitalization), reflecting the company's contribution to the SDGs.

The sources of empirical data were corporate non-financial reports, "Sustainable Development" sections in the annual reports of companies in 2020–2021; materials from the companies' websites; corporate strategies, and/or policies in the field of SD and digitalization.

The research methodology is based on the determination of criteria that meet the objectives of the study. Based on these criteria, a qualitative content analysis of the practices of companies in the field of SD was carried out.

In accordance with the objectives of the study, the analysis of the companies' SD-activities was carried out according to the following criteria:

1. Reporting in the field of SD. Disclosure of information on SD-activities and on the use of digitalization tools to achieve sustainable development (disclosure of information about IT, software products and other digitalization tools that are used to achieve the SDGs); completeness and quality of information disclosure in non-financial reports;
2. Integration of the SDGs into the corporate strategy (having a strategy in the field of SD, development and approval of relevant policies);
3. Setting goals in the field of SD and digitalization, their reflection in internal corporate documents; use of an appropriate system of indicators and indicators;
4. Assessing the risks and opportunities associated with digital transformation and affecting the economic, environmental, social and ethical aspects of activities, the use of a risk management system in the company;
5. Identification of key stakeholder groups, their information requests and expectations regarding the company's activities in the field of sustainable development and digital transformation;
6. Having a management system for the company's digital transformation and sustainable development;
7. Identification of SD aspects in the company most affected by digital transformation;
8. Availability of relevant digital transformation programs on the SD aspects.

The assessment of the degree of compliance of the company's activities with the mentioned criteria was carried out on a scale of 1–5 points:

4.5–5 points—the information is fully disclosed, a high degree of compliance with the analyzed criteria. Sustainable development activities are systemic, the areas of activity correspond to the SDGs, the company has developed internal documents that trace the relationship between activities in the field of sustainable development and areas of digitalization, and the relevant performance indicators are approved;

3.5–4.5 points—the information is fully disclosed, a medium–high degree of compliance. The company pays enough attention to the SD aspects, and there are attempts to use digitalization tools to achieve the SDGs, however, the company's SD-activities are not systematic, the areas of activity only partially correspond to the SDGs, and internal documents in the field of SD and digitalization are fragmentary or under development;

2.5–3.5 points—the information is sufficiently disclosed, an average degree of compliance, the company has begun to make attempts to integrate the SDGs and SD-principles into the main activities of the company, the connection with the areas of activity in the field of SD and the digital transformation of the company is poorly traced, only single projects and initiatives in this direction are described, internal documents in the field of SD and digitalization are "not agreed upon", it is not possible to draw a conclusion about the use of digitalization tools regarding corporate social performance (CSP);

1–2.5 points—the information is presented fragmentarily, low degree of compliance, the company is not focused on the SDGs, there are no internal documents in the field of sustainable development and digitalization, single projects, and initiatives are described, it is impossible to draw a conclusion about the impact of digital transformation on SD-activities, there are no relevant indicators;

1 point—the disclosed information about SD-activities and digital transformation does not allow to conduct objective assessment according to the selected criteria.

4 Results

The results of the analysis of the SD-activities of companies included into the sample are shown in the Diagram (Fig. 1.)

The analysis of the activities of companies in the field of sustainable development showed that the average score for 7 criteria was 2.97 out of 5. This result allows us to conclude about the average level of compliance of the company's activities with the chosen criteria and the completeness of their implementation. The companies received the highest result (3.00) according to the criterion "Identification of key stakeholder groups, their requests regarding the impact of digital transformation on the company's activities", which indicates that the majority of the analyzed companies understand the need to communicate with stakeholders and inform them about the results of the company's activities in a timely manner. Companies also received an average result of 3.00 according to the criterion "Digital transformation programs in accordance with SD-aspects", disclosing information about the goals, objectives,

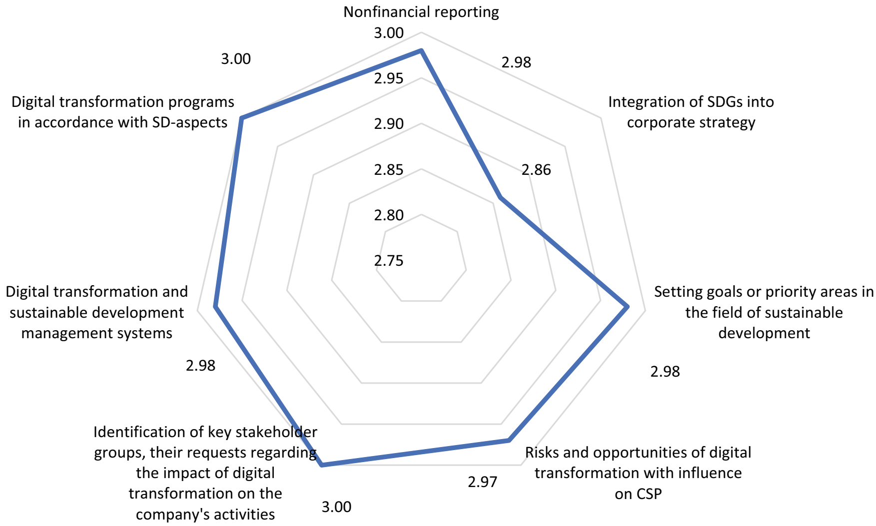

Fig. 1 The results of the analysis of SD-activities and their relation with the digital transformation of the company

programs, and projects in the field of using digital technologies and offering technological solutions for each of the SD-aspects. All companies disclose information about the impact of digital transformation on their core activities, plan their further development and economic performance with the development, implementation and use of the latest technological solutions. A score of 2.98 was given to criteria “Reporting in the field of sustainable development”, the analyzed companies form reports on sustainable development, integrated reports and annual reports containing the section "Sustainable development". However, 11 companies from the sample do not form non-financial reports, but only fragmentarily disclose information about corporate social performance and its relationship with the digital transformation of the company on the website.

The criteria characterizing the process of setting goals in the field of SD and the presence of a digital transformation and sustainable development management system also received an average score of 2.98, which indicates that most of the analyzed companies have developed the relevant internal documents (strategies, roadmaps, programs, policies), where planned indicators, KPIs and departments and/or officials responsible for their achievement are indicated. The criterion related to assessing the risks and opportunities of the company’s digital transformation scored 2.97 points. It is worth noting that 8 companies out of 30 did not disclose information on risk assessment, which led to a decrease in the average score for this criterion. Most companies (22 out of 30) highlight the risks associated with cybersecurity, the use of personal data, and confidential information. The lowest score (2.86) was given to the criterion related to the orientation of companies towards achieving the SDGs. 11 of the 30 analyzed companies did not disclose information about their

SD-activities in the reports, but only posted fragmentary information on the official website. The rest 19 companies that provide non-financial reports are guided by the SDGs when setting strategic goals, and most companies refer to the SDGs in their corporate strategy and/or in their internal documents.

5 Discussions

The study showed that the analyzed companies hold leading positions in their industry and pay great attention to the development of new technological solutions for their main activities in order to minimize the negative impact on the environment, increase work, and internal communication efficiency, and also to improve interaction with all interested parties. At the same time, 11 Russian companies out of 20 included in the sample do not form non-financial reporting, but only fragmentarily disclose information about sustainable development on the website, which may indicate the absence of a systematic approach to corporate social performance or the unreadiness of companies at the current stage to the disclosure of such information.

Most of the analyzed companies form non-financial reporting using more than two international standards in this area, and also undergo independent assurance procedures, which may indicate a fairly high quality of the information disclosed.

Risks related to cybersecurity and personal data protection are included into the list of priorities. At the same time, digital solutions are used to minimize their own negative impact on the environment, as well as the use of various technological solutions to build effective communication with stakeholders, to train employees and to implement labor protection programs and production safety.

At the same time, it is too early to talk about the implementation of a systematic approach to identifying priority areas of activity in the field of sustainable development, which involves identifying stakeholder requests, analyzing socio-economic trends and non-financial risks. When declaring contribution to achieving one or another social SDG, companies often do not formulate specific tasks and define appropriate indicators, which may signal a formal approach and use of the SDGs for "marketing" purposes.

6 Conclusion

Based on the literature review and the conducted research, it can be concluded that telecommunication companies are aware of the importance of integrating the principles of sustainable development into their activities. However, it is too early to talk about a systematic approach, the availability of related strategies in the field of sustainable development and digitalization, as well as the availability of appropriate KPIs. A further area of research could be more detailed studies of the naming of digital signature technologies for the company's activities in the field of sustainable development, as well as issues of ethics and security of the use of personal data.

References

1. Allianz, S.E. (2018). *Allianz global wealth report. economic research. Munchen, 2018.* https://www.allianz.com/content/dam/onemarketing/azcom/Allianz_com/migration/media/economic_research/publications/specials/en/Allianz_Global_Wealth_Report_2018_e.pdf
2. BCG .(2022). *The five digital building blocks of a corporate sustainability agenda.* https://www.bcg.com/publications/2022/building-blocks-of-corporate-sustainability-agenda
3. Demartini, M., Evans, S., & Tonelli, F. (2019). Digitalization technologies for industrial sustainability. *Procedia Manufacturing, 33*, 264–271. https://doi.org/10.1016/j.promfg.2019.04.032
4. Doh, J., Tashman, P., & Benischke, M. (2019). Adapting to grand environmental challenges through collective entrepreneurship. *Academy of Management Perspectives, 33*, 450–468.
5. Esmaeilian, B., Sarkis, J., Lewis, K., & Behdad, S. (2020). Blockchain for the future of sustainable supply chain management in industry 4.0. *Resources, conservation, and recycling, 163*, 1–15. https://doi.org/10.1016/j.resconrec.2020.105064
6. George, G., Haas, M. R., Joshi, H., McGahan, A. M., & Tracey, P. (2022). *The business of sustainability: An organizing framework for theory, practice and impact*. Edward Elgar.
7. Gouvea, R., Kapelianis, D. & Kassicieh, S. (2018). Assessing the Nexus of Sustainability and Information & Communications Technology. *Technological Forecasting and Social Change, 130*(C), 39–44. https://doi.org/10.1016/j.techfore.2017.07.023
8. IPCC .(2022). Sixth assessment report, climate change 2022: Impacts, adaptation and vulnerability. https://www.ipcc.ch/report/ar6/wg2/
9. Khattak, A., & Yousaf, Z. (2021). Digital social responsibility towards corporate social responsibility and strategic performance of hi-tech smes: customer engagement as a mediator. *Sustainability, 14*, 131. https://doi.org/10.3390/su14010131
10. Kuntsman, A., & Rattle, I. (2019). Towards a paradigmatic shift in sustainability studies: a systematic review of peer reviewed literature and future agenda setting to consider environmental (un) sustainability of digital communication. *Environmental Communication, 13*, 567–581. https://doi.org/10.1080/17524032.2019.1596144
11. Kuntsman, A. & Arenkov, I.A (2019). Integrated method for assessing effectiveness of company digital transformation: Russian experience.in *Proceedings of the 33rd International business information management association conference, IBIMA 2019: Education excellence and innovation management through vision 2020*. https://doi.org/10.5171/2019.334457
12. Mensah, J. (2019). Sustainable development: meaning, history, principles, pillars, and implications for human action: Literature review. *Cogent Social Sciences, 5*. https://doi.org/10.1080/23311886.2019.1653531
13. Mulder, I., Blin, A., & Adams, J. et al. (2021). State of finance for nature: Tripling investments in nature-based solutions by 2030. *In UNEP, WEF & ELD (Eds.)* (pp. 1–65).
14. OECD .(2020). *The digitalization of science, technology and innovation*; *OECD Library*: *Paris, France*, 2020. https://www.oecd.org/science/inno/the-digitalisation-of-science-technology-and-innovation-b9e4a2c0-en.htm
15. Ozcan, B., Yakis-Douglas, K., Mellahi, K., Meyer, R., Narula & I. Surdu (2021). *Digitalization and its strategic implications for the multinational enterprise* (pp.462–491). The oxford handbook of international business strategy (1st Edn), Oxford University Press.
16. Russoft .(2021). The 18th annual RUSSOFT Study. Export of the Russian software development industry. https://russoft.org/analytics/rossiyskaya_softvernaya_otrasl_2021/
17. Seele, P., & Lock, I. (2017). The game-changing potential of digitalization for sustainability: possibilities, perils, and pathways. *Sustainability Science, 12*, 183–185. https://doi.org/10.1007/s11625-017-0426-4

18. Schillebeeckx, S. J. (2021). Digital sustainability and its implications for finance and climate change. *Macroecon, 20*, 103–109.
19. Schmidt-Traub, G., Mazzucato, M., Messner, D., Nakicenovic, N., & Rockström, J. (2019). Six transformations to achieve the sustainable development goals. *Nature Sustainability, 2*, 805–814. https://doi.org/10.1038/s41893-019-0352-9
20. Schreiber, V.M. (2015). From the history of research on the greenhouse effect of the Earth's atmosphere. *Biosphere*, 7(3).
21. UN .(2015). *Sustainable development goals.* https://www.un.org/sustainabledevelopment/ru/sustainable-development-goals/
22. UN .(2019). *About 50 million tons of computers, televisions, laptops, set-top boxes, mobile phones and other consumer electronics are thrown out every year.* https://news.un.org/ru/story/2019/01/1347592
23. Zhao, C., Guo, Y., Yuan, J., Wu, M., Li, D., Zhou, Y., & Kang, J. (2018). ESG and corporate financial performance: empirical evidence from china's listed power generation companies. *Sustainability, 10*, 2607. https://doi.org/10.3390/su10082607
24. Weersink, A., Fraser, E., Pannell, D., Duncan, E., & Rotz, S. (2018). Opportunities and challenges for big data in agricultural and environmental analysis. *Annual Review of Resource Economics, 10*, 19–37. https://doi.org/10.1146/annurev-resource-100516-053654

Connectivity of Industrial Markets: Digital Logistics

Understanding the Role of Digital Technologies in Supply Chain Management of SMEs

Shashank Bansal, Vikas Kumar, Archana Kumari, and Evgeny Kuzmin

Abstract The proliferation of industry 4.0, often known as digital technologies, over the last decade has enabled new business models, the digitalisation of products and services, and the integration of every link in the company's value chain: product development and innovation, manufacturing, distribution, digital sales, and customer relationship management. This paper aims to magnify and accelerate the impact offered by integrating the most recent advances in the field of supply chain management. Following a qualitative interviewing approach, this paper explores whether digital technologies can enable or enhance and streamline small and medium enterprises (SMEs) digital supply chain performance. This study also reviews potential barriers to digitalising the supply chain and suggests ways to overcome them. The study shows that digital adoption helps organizations improve data security, connectivity with supply chain partners, traceability, and supply and demand management capabilities. Literature review and interviews identified cost savings, responsiveness, quality improvement, and environmental benefits as key factors driving technology

S. Bansal
School of Management, University of Bristol, Beacon House, Queens Road, Bristol BS8 1QU, UK
e-mail: shashankbansal06@gmail.com

V. Kumar (✉)
Faculty of Business, Law and Social Sciences, Birmingham City University, Curzon Building, 4 Cardigan Str., Birmingham B4 7BD, UK
e-mail: Vikas.Kumar@bcu.ac.uk

Department of Management Studies, Graphic Era Deemed to be University, Bell Road, Clement Town Dehradun, Uttarakhand, India

A. Kumari
Bristol Business School, University of the West of England, Coldharbour Lane, Bristol BS16 1QY, UK
e-mail: archana_mbe2008@yahoo.com

E. Kuzmin
Department of Regional Industrial Policy and Economic Security, Institute of Economics of the Urals Branch of the Russian Academy of Sciences, Russian Academy of Sciences, 29 Moskovskaya St, 620014 Ekaterinburg, Russian Federation
e-mail: kuzmin.ea@uiec.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_16

adoption. On the contrary, a lack of clearly defined goals, cultural issues, high investment, a shortage of skilled labor and legal uncertainty have been identified as barriers to the successful implementation of Industry 4.0 technologies.

Keywords Digital technologies · Industry 4.0 · Supply chains · Barriers · Enablers · SMEs

1 Introduction

Managing supply chains effectively has become vital for businesses' success in today's highly complex and competitive global landscape. Supply chain management (SCM) is defined as a process of coordinating the business functions across the businesses within the firm and across industries within other firms in the supply chain to provide and improve products. Information flows from suppliers to end customers to enhance firm performance and satisfy customer needs, wants, and requests [1]. It is a complex concept that covers the entire production and distribution channels and is responsible for fulfilling customer demand, improving responsiveness, and creating a network among different stakeholders. Supply chain management is an enormous framework involving multiple disciplines such as location, transportation and logistics, marketing and channel restructuring, inventory and forecasting, sourcing and supplier management, product design and release of new products, etc.

Several studies [2, 3] have identified the most effective strategic technology enablers that have transformative and disruptive impacts across supply chains. Industry 4.0 refers to a family of technologies such as the Internet of Things (IoT), additive manufacturing, advanced robotics, big data analytics, blockchain technology, cloud computing, augmented reality, and artificial intelligence (AI) [4]. Digitalisation offers many opportunities to the supply chain concerning storing data from within the firm and externally. For example, smart devices now allow manufacturing firms to share and record customer data to personalise the sales process and product design, leading to shorter changeover time and enhanced service levels [5]. Businesses utilise customer data to understand, analyse, and predict their characteristics and behaviour [6]. The amount of available data can benefit organisations in making better decisions. Still, digitalisation has caused both challenges and fear, speculating numerous threats of job loss in the field of the supply chain. One of the studies argues that companies with excessive use of robotics, artificial intelligence, and blockchain will gain complete control and reduce third-party involvement [7]. Lyall, Gstettner, and Mercier [7] further show how this labour-intensive automation can reduce safety concerns within the operations and the need for workers in remote areas. This study argues that implementing such processes would create more job opportunities for the employees in extracting knowledge from the data and optimising the use of these technologies for supply chain network performance.

As the supply chain is becoming more diverse and distributed, the major challenge and requirement for any organisation are to make it more visible and accessible for all stakeholders. However, small and medium enterprises (SMEs) often lack resources and knowledge and are more vulnerable to the challenges of the fast-changing business environment. Therefore, SMEs can benefit from adopting digital technologies in their supply chains. However, the existing studies on digital technology adoption are mostly centred around large organisations, with little evidence reported on SMEs. Therefore, this study addresses the research question: *What are the drivers and barriers to digital technology implementation in supply chains?*

2 Literature Review

In a study, Muller et al. [8] suggested that to realise the intense potential of the resources and maximise the outcome through digitalisation. However, the process must be backed up by the top management and incorporated into the organisation's atmosphere. Furthermore, to remain sustainable in the competitive global market, incumbents must realise that new market entrants may already acquaint themselves with new business models and the latest technology to threaten the existence of current market players [9]. Therefore, it becomes more important for organisations to bring advancements in their core competencies and business models by offering superior products through superior manufacturing capabilities. For example, the manufacturing sector in India has started making inroads towards enhancing the existing assets rather than increasing capital expenditure. According to Chanda [10], Indian companies adopting smart manufacturing and digital supply chain have increased their operating profits by 40%. Although India has been strengthening its position in global manufacturing in recent years, its annual manufacturing labour productivity is $6000 per employee compared to the $63,400 of China [11]. Furthermore, the government initiatives such as 'Make in India' and 'Green Corridor' have created a niche for market jobs and have increased the hiring of workers in the manufacturing and service sectors. Therefore, government bodies need to provide schemes that enable the adoption of new practices by micro, small and medium enterprises, such as: promoting the development of networking agencies, promoting cross-border traits to enhance technology sharing, strengthening laws regarding privacy protection to avoid the wrong usage of data, and labour and safety management rules must be redesigned to aid the adoption of digitalisation by companies [12].

Industry 4.0 principles necessitate changes in the company's overall functioning by enumerating the technologies of the future, i.e. cyber-physical systems, IoT, blockchain, internet of services, robotics, big data, artificial intelligence, cloud computing, etc. [13]. These technologies not only focus on real-time improvements in process performances in terms of productivity, security, energy efficiency and cost but also helps in developing systems for better communication, intelligent decision making and automation capabilities by supply chain players. In addition, several studies [8, 14–16] have reported on the growing need for companies to transform from traditional supply chains to digitalised supply chains. Supply chain digitalisation will help organisations to address issues like managing information systems for data security and confidentiality laws, effective handling of smart supply chain and delivery of real-time information to all supply chain partners.

Various factors affect the adoption of industry 4.0 technologies. Srivastava et al. [15] emphasise the importance of organisational factors, such as internal resources and staff capabilities, in the process of Industry 4.0 adoption. A study by Dubey et al. [17] shows that implementing digital technologies can eliminate the need for a high volume of production facilities, large bulk inventories, and low-level assembly workers, thus reducing the supply chain cost. Evidence also shows that it can save transportation and tooling costs, enable economical mass customisation and simplify the production processes [18–20]. Digital technology also creates a close relationship between design, manufacturing and marketing. Hence, its usage can help eliminate the time lag between design and product, shorten the lead time, enable on-demand manufacturing and improve process flexibility [21]. Krishnan et al. [12] suggest that top management is the major enabler of Industry 4.0 implementation, whereas government policies enable substantial support for digital transformation. In addition, businesses are under immense pressure to deliver on sustainability and net-zero goals, which has also been an enabler for digital technology adoption [16, 22]. Digital technologies have also been proven to improve quality and help eliminate waste, manage demand uncertainty, and improve performance by reducing supply chain risks [23]. Industry 4.0 emphasises creating a sustainable environment through resource utilisation, recycling and reuse. It also emphasises promoting quality over quantity, green development, optimisation of industry structure and nurturing human talent [22]. Some key digitalisation enablers from existing studies are cost savings, speed responsiveness, quality improvement, and environmental benefits.

From the operational point of view, several studies [24] underline the barriers to adopting digital technologies in supply chain management, such as the lack of standards, increasing need for communication channels, higher requirements for computing networks, meeting regulatory compliance, and contractual ambiguity. A critical barrier to digital technology adoption is the lack of a well-defined goal [25]. Digital transformation in the supply chain could help reduce invoice processing time, cut costs, and enhance efficiency. However, without clear, well-defined objectives, the organisation would not know how to proceed and how the desired results would be achieved. Successful implementation of new systems or processes requires close management, a roadmap and a framework to approach the complexities efficiently. Still, without proper knowledge transfers and the required skills to work with new systems, the workforce would not be able to implement any project [26]. Innovation culture requires skills and competence by employees which are presumably beyond the traditional basic knowledge [37]. Therefore, lifelong learning should be part of the organization's strategic goals [38]. Industry 4.0 imposes additional requirements on employee skills, continuous retraining and advanced training.

The digitalisation of the supply chain is capital-intensive and often acts as a barrier. Therefore, it is essential to choose the correct platform which supports the combination of solutions suitable to the business requirements [26]. Businesses continue with traditional supply chain methods due to lacking capabilities and knowledge to deal with cyber threats and data thefts. This increased risk of security breaches can be caused by the incorrect deployment of technology and can harm confidential data and disrupt the relationship with key partners. Such fears discourage the adoption of digital processes and force companies to rely on traditional communication channels [27]. Changing company culture is also one of the biggest challenges for any organisation, as the employees often struggle to identify the benefits of new digital technologies.

Moreover, added responsibilities and growing job requirements can lead to a higher stress level due to fear of job losses. This would require educating the relevant stakeholders, increasing organisational awareness by encouraging better communication and collaboration and empowering employees to work at each stage of the supply chain with access to critical data [28]. There are ample empirical examples to support the importance of communication, the way data is communicated, and maintaining transparency [35, 36]. Implementing digital technologies can improve the competitiveness of companies; however, organisations need to overcome barriers such as the lack of well-defined goals, cultural challenges, high investment, lack of skilled workforce, and legal ambiguity to adopt industry 4.0 technologies successfully.

In today's increasingly globalised economy, SMEs contribute greatly towards economic development and employment generation [29]. According to many researchers, such as [30, 31], SMEs occupy 70–80% of market space in most emerging countries. SMEs generate employment, contribute to entrepreneurship, and significantly impact supply chain performance. SMEs are also important growth engines in many countries in the current competitive business environment and global marketplace. However, they often have limited financial, management, and personnel capacities based on their owner-manager's competency [31]. Studies show that SMEs are so disparate in size that they cannot apprehend the complexities of supply chain management and are pressed with external pressures such as economic, governmental, political, socio-cultural and technological [32]. Implementing the digital supply chain can provide innovative opportunities for SMEs to improve their customer service and responsiveness, communications, and electronic trading and develop more clarity on business strategies and core competencies. However, SMEs are often ill-equipped to face these new possibilities regarding digital adoption in their supply chains [33]. This study, therefore, aims to understand the barriers and enablers of digital technology adoption in supply chains for SMEs.

3 Materials and Methods

The data gathered in this study was acquired by interviewing the SME owners and managers to fulfil the study's objective. The purpose of conducting semi-structured interviews with SMEs was to understand the enablers and barriers to technology adoption from their perspectives and then try to draw a similarity with the literature review of this paper.

The interviewees were the owners and managers of a restaurant, construction company, manufacturing firm and warehouses. As digital technologies completely transform the methods and practices carried out in businesses concerning communication, data acquisition, and transfer of information systems, those SMEs were targeted that would benefit greatly from the use of technologies in their supply chain network. First, the interviewees were contacted over email and briefed about the research objectives. Following this interview was scheduled with each participant based on their availability. Each interview lasted approximately one hour. The study was conducted during the pandemic. Hence all interviews took place online through Microsoft Teams.

Ethical approval was taken, and all ethical protocols were followed during and after the data collection.

The study is based on interviews and may contain a subjective assessment of the respondents. In view of the fact that a large number of respondents took part in the survey, the results of the survey may contain a perception error. We make a number of assumptions to accommodate these research limitations and conduct a more extensive review of the literature to confirm our findings.

4 Results and Discussions

The findings of this study are based on semi-structured interviews with five SME owner-managers. Table 1 provides an overview of the participants' work experience, their position in the company and their organisation's domain. Based on their knowledge, experience and education, the owner-managers of SMEs set the road map for the organisation, which include forming alliances, maintaining supply chain matrices, setting performance indicators, etc. As fewer departmental interfaces are involved in SMEs, it is often easier to implement changes, and the organisation can adapt quickly to volatile market conditions [34]. These arguments were explored while conducting the interview. As small firms face resource gaps in finance, skills, knowledge and technology, they heavily rely on the capacity and competency of their managers or business owners to play a central role in the business [30, 31].

Table 1 Profiling of interviewees

Participants	Years of experience	Position	Sector
A	20	Managing director	Restaurant
B	12	Manager	Warehouse
C	15	Managing director	Construction
D	7	Managing director	Manufacturer
E	10	Managing director	Restaurant

The findings show that most business owners were implementing digital technology in some way or another to maintain the supply chain network. When asked about the drivers of technology implementation in their businesses, one of the interviewees (Participant A) stated that they run one of the busiest restaurants in the city, and digital technology implementation has created so many opportunities for their business. Earlier, their orders used to be handwritten and then manually transferred to the kitchen, but now the servers use the tablets to take orders and the receipt of which goes to the kitchen for the preparation of the food and to the reception area for billing. Owner A further stated, *"The implementation of technology over the tablet has helped us save the cost of an accountant as all his finances can be easily calculated with the use of software and the entire data gets saved in the cloud. In addition, it requires a minimal maintenance fee in case of any software bug fixes, thus helping us save operational costs"*. When asked if they recognised the enablers and barriers identified in this study as relevant to their business, they were in sync with most of them by identifying cost savings, speed responsiveness, quality improvement, etc., as potential drivers. In contrast, most interviewees also identified a lack of well-defined goals, cultural challenges, high investment, lack of skilled workforce, and legal ambiguity as potential barriers to technology adoption in their supply chains. Most interviewees also observed that acceptance and understanding of digital technology have helped them grow their businesses and have helped them strengthen their relationships with customers by providing them with better services and products.

Though all the interviewees were using digital technologies in their daily operations, it was also noted that most still rely on traditional ways of operating businesses, such as emails and phone calls to contact their suppliers for shipment and delivery instead of real-time information exchange. For example, one of the participants (Participant B) confirmed that they get notified about the order weekly. If there has to be a delivery on an urgent basis, then they have to select the order with maximum priority. Most interviewees reflected upon their backgrounds and explained how their efficacies helped them create a unique business environment. While some (Participants A, C and D) provided insights about their plans to expand the business and implement new technologies by taking bank loans and getting funds from close relatives, others (Participant E) did not want the unnecessary burden that comes with recent assets acquisition. In summary, the interviewees provided an idea of their risk preferences and the ambitious ventures they might carry out soon. While most interviewees possessed and exhibited much knowledge about their domain, they seemed a little less aware of the digital technologies that can be utilised to advance their current businesses and attract more customers.

Some informal comments provided by interviewees also indicated a lack of knowledge of digital supply chain management. However, the study found that the businesses were conducted less formally than large firms, with few employees and manager handling most of the duties and carrying out most of the decisions. This speaks of the need for education in this field because if they approach handling vast volumes of business transactions in future, the process would be totally inefficient as it would be labour-intensive and error-prone manual processes, such as paper-based record keeping and communication through phone calls and emails.

The study, however, has certain limitations. First, due to time constraints, the research was limited to contacting only five SME owners and managers for their profiling data collection. Although the study identified enablers and barriers to digital technology adoption in SCM, the comparison between the supply chain network of multinationals and small and medium-sized enterprises could only be achieved through the findings of previously published articles and reports. Secondly, although an online interview saved time and money concerning travelling, in-person interviews would have provided better insights about participants' current work, especially when the interview topic is seen to be interesting and relevant to their current work. The study emphasises that the discussion on digital supply chain provides a new perspective, a new line of investigation and a future research agenda, particularly in the context of SMEs.

5 Conclusion

This study highlights the importance of adopting digital technologies in supply chains. This study identifies several enablers and barriers to digital technology implementation in supply chains through a comprehensive review of the literature. The study shows that adopting digital technologies such as big data, artificial intelligence, IoT, and cloud computing will help organisations improve data security, communication with supply chain partners, traceability, and demand–supply management capability. The study also identifies enablers and barriers to digital technology adoption in the context of SMEs. The literature review and interviews identified cost savings, speed responsiveness, quality improvement and environmental benefits as key enablers of technology adoption. In contrast, a lack of well-defined goals, cultural challenges, high investment, lack of skilled workforce, and legal ambiguity were identified as barriers to adopting industry 4.0 technologies successfully.

Previous studies have discussed the advantages of stand-alone technologies such as blockchain, big data, cloud computing and artificial intelligence. Still, there is very less empirical evidence of the impact of these technologies in SCM and how they assist SMEs in gaining a competitive advantage. The literature indicates that companies worldwide are finding new ways to improve supply chain performance to reduce working expenses, improve margins, retain and increase market share, and increase responsiveness to customers. It also indicates that by creating readiness for new responsive digital systems, supply chain and procurement can record several benefits such as improved asset utilisation, higher uptime, lower warehousing and inventory costs, efficient delivery of products and more efficient inbound supply chain. This study shows that companies wishing to improve their supply chain performance must rely on technological advancements to satisfy better customer requirements in real time. The study revealed that most SMEs do not have the transaction volumes to justify the investments in technology and therefore are unwilling to make necessary changes in their business processes. For these companies, discipline, planning, committed top-down leadership and education about digital SCM could help them make better-informed adoption decisions.

6 Ethical Statement

The work was performed in accordance with the ethical guidelines of the University of Bristol.

References

1. AL-Shboul, M.A., Garza-Reyes, J.A., & Kumar, V. (2018), Best supply chain management practices and high-performance firms: The case of Gulf manufacturing firms, *International Journal of Productivity and Performance Management*, 67 (9), 1482–1509. https://doi.org/10.1108/IJPPM-11-2016-0257
2. Pettey, C. (2019). *Gartner top 8 supply chain technology trends for 2019*. [Online] Available at: https://www.gartner.com/smarterwithgartner/gartner-top-8-supply-chaintechnology-trends-for-2019/
3. Farahani, P., Meier, C., & Wilke., J. (2016). Digital supply chain management agenda for the automotive supplier industry: shaping the digital enterprise. Springer International Publishing, Switzerland. https://doi.org/10.1007/978-3-319-40967-2_8
4. Yadav, G., Kumar, A., Luthra, S., Garza-Reyes, J. A., Kumar, V., & Batista, L. (2020). A framework to achieve sustainability in manufacturing organisations of developing economies using industry 4.0 technologies' enablers. *Computers in Industry*, 122, 103280. https://doi.org/10.1016/j.compind.2020.103280
5. Feng, Q., & Shanthikumar, J. (2018). How research in production and operations management may evolve in the era of big data. *Production Operation Management, 27*(9), 1670–1684. https://doi.org/10.1111/poms.12836
6. Guha, S., & Kumar, S. (2018). Emergence of big data research in operations management, information systems, and healthcare: Past contributions and future roadmap. *Production Operation Management, 27*(9), 1724–1735. https://doi.org/10.1111/poms.12833
7. Lyall, A., Gstettner, S., & Mercier, P. (2018). The death of supply chain management. *Harvard Business Review*, 49(3). https://hbr.org/2018/06/the-death-of-supply-chain-management
8. Müller, J., Kiel, D., & Voigt, K.-I. (2018). What drives the implementation of industry 4.0? The role of opportunities and challenges in the context of sustainability. *Sustainability*, *10*(1), 247. https://doi.org/10.3390/su10010247
9. Zhong, R., Xu, X., Klotz, E., & Newman, S. (2017). Intelligent manufacturing in the context of industry 4.0: a review. *Engineering*, *3*(5), 616–630. https://doi.org/10.1016/J.ENG.2017.05.015
10. Chanda, N. (2019). *What is I 4.0 and is India prepared for the change.* https://www.proschoolonline.com/blog/what-is-industry-4-0-and-is-indiaprepared-for-the-change
11. Kumar, R., Singh, K., & Jain, S. (2020). A combined AHP and TOPSIS approach for prioritising the attributes for successful implementation of agile manufacturing. *International Journal of Productivity and Performance Management, 69*(7), 139. https://doi.org/10.1108/IJPPM-05-2019-0221
12. Krishnan, S., Gupta, S., Kaliyan, M., Kumar, V., & Garza-Reyes, J. A. (2021). Assessing the key enablers for Industry 4.0 adoption using MICMAC analysis: a case study. *International Journal of Productivity and Performance Management*, *70*(5), 1049–1071. https://doi.org/10.1108/IJPPM-02-2020-0053

13. Trstenjak, M., & Cosic, P. (2017). Process planning in Industry 4.0 environment. *Procedia Manufacturing, 11*, 1744–1750. https://doi.org/10.1016/j.promfg.2017.07.303
14. Mangan, J., Lalwani, C., & Butcher, T. (2008). *Global Logistics and Supply Chain Management*. John Wiley & Sons.
15. Srivastava, D. K., Kumar, V., Ekren, B. Y., Upadhyay, A., Tyagi, M., & Kumari, A. (2022). Adopting Industry 4.0 by leveraging organisational factors. *Technological Forecasting and Social Change*, *176*, 121439. https://doi.org/10.1016/j.techfore.2021.121439
16. Kumar, A., Choudhary, S., Garza-Reyes, J. A., Kumar, V., Rehman Khan, S. A., & Mishra, N. (2021). Analysis of critical success factors for implementing industry 4.0 integrated circular supply chain–Moving towards sustainable operations. *Production Planning & Control*, 1–15. https://doi.org/10.1080/09537287.2021.1980905
17. Dubey, R., Gunasekaran, A., Helo, P., Papadopoulos, T., Childe, S., & Sahay, B. (2017). Explaining the impact of reconfigurable manufacturing systems on environmental performance: The role of top management and organisational culture. *Journal of Cleaner Production, 141*, 56–66. https://doi.org/10.1016/j.jclepro.2016.09.035
18. Wang, Y., Ma, H. S., Yang, J. H., & Wang, K. S. (2017). Industry 4.0: a way from mass customisation to mass personalisation production. *Advances in Manufacturing*, *5*(4), 311–320. https://doi.org/10.1007/s40436-017-0204-7
19. Ekman, B. (2018). Cost analysis of a digital health care model in Sweden. *PharmacoEconomics-open, 2*(3), 347–354. https://doi.org/10.1007/s41669-017-0059-7
20. Yuan, H., Qiu, H., Bi, Y., Chang, S. H., & Lam, A. (2020). Analysis of coordination mechanism of supply chain management information system from the perspective of blockchain. *Information Systems and e-Business Management, 18*(4), 681–703. https://doi.org/10.1007/s10257-018-0391-1
21. Nyman, H., & Sarlin, P., (2014). From Bits to Atoms: 3D printing in the context of supply chain strategies. Hawaii, IEEE*, 47th Hawaii International Conference on System Sciences.* (pp. 4190–4199). https://doi.org/10.1109/HICSS.2014.518
22. Tsai, W., & Lu, Y. (2018). A framework of production planning and control with carbon tax under industry 4.0. *Sustainability, 10*(9), 3221. https://doi.org/10.3390/su10093221
23. Elms, K., & Low, P. (2019). *Global value chains in a changing world. World trade organisation.* https://www.wto.org/english/res_e/booksp_e/aid4tradeglobalvalue13_e.pdf
24. Oesterreich, T., & Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry, 83*, 121–139. https://doi.org/10.1016/j.compind.2016.09.006
25. Alcácer, V., Rodrigues, C., Carvalho, H., & Cruz-Machado, V. (2021). Tracking the maturity of industry 4.0: the perspective of a real scenario. The *International Journal of Advanced Manufacturing Technology*, *116*(7), 2161–2181. https://doi.org/10.1007/s00170-021-07550-0
26. Lin, D., Lee, C. K. M., Lau, H., & Yang, Y. (2018). Strategic response to Industry 4.0: an empirical investigation on the Chinese automotive industry. *Industrial Management & Data Systems, 118*(3), 589–605. https://doi.org/10.1108/IMDS-09-2017-0403
27. Neugebauer, R., Hippmann, S., Leis, M., & Landherr, M. (2016). Industrie 4.0-From the perspective of applied research. *Procedia CIRP, 57*, 2–7. https://doi.org/10.1016/j.procir.2016.11.002
28. Attaran, M. (2020). Digital technology enablers and their implications for supply chain management. *Supply Chain Forum: An International Journal, 21*(3), 158–172. https://doi.org/10.1080/16258312.2020.1751568
29. Koh, S. L., Demirbag, M., Bayraktar, E., Tatoglu, E., & Zaim, S. (2007). The impact of supply chain management practices on performance of SMEs. *Industrial Management & Data Systems, 107*(1), 103–124. https://doi.org/10.1108/02635570710719089
30. Thakkar, J., Kanda, A., & Deshmukh, S. (2008). Supply chain management in SMEs: Development of constructs and propositions Asia Pacific. *Journal of Marketing and Logistics, 20*(1), 97–131. https://doi.org/10.1108/13555850810844896

31. Saad, M., Kumar, V., & Bradford, J. (2017). An investigation into the development of the absorptive capacity of manufacturing SMEs. *International Journal of Production Research, 55*(23), 6916–6931. https://doi.org/10.1080/00207543.2017.1327728
32. Inayatullah, R. N., & Singh, A. (2015). Supply chain management practices in SMEs of India: Some managerial lessons from large enterprises. *International Research Journal of Engineering and Technology (IRJET), 2*(5), 256–269.
33. Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., & Barbaray, R. (2018). The industrial management of SMEs in the era of Industry 4.0. *International Journal of Production Research*, *56*(3), 1118–1136. https://doi.org/10.1080/00207543.2017.1372647
34. Gourova, E. (2010). Knowledge management strategy for Small and Medium Enterprises. In *Proceedings of the International Conference* on *Applied Computer Science*, pp. 639–648.
35. Alshaikh, M., Chang, S., Ahmad, A., et al. (2022). Embedding information security management in organisations: Improving participation and engagement through intra-organisational Liaison. *Security Journal*. https://doi.org/10.1057/s41284-022-00352-3
36. Flynn, G., Nagle, T., & Fitzgerald, C. (2022). Data Evolution in Times of Crisis: An Organisational Mindfulness Perspective. *Information Systems Frontiers*. https://doi.org/10.1007/s10796-022-10275-4
37. Meissner, D., & Shmatko, N. (2019). Integrating professional and academic knowledge: The link between researchers skills and innovation culture. *The Journal of Technology Transfer, 44*, 1273–1289. https://doi.org/10.1007/s10961-018-9662-8
38. Li, L. (2022). Reskilling and upskilling the future-ready workforce for industry 4.0 and Beyond. *Inf Syst Front.* https://doi.org/10.1007/s10796-022-10308-y

Theoretical Prerequisites for Creating a Digital Twin Prototype of Value Chain Reliability Management

Alexey Tyapukhin, Andrey Yumatov, and Raisa Vidishcheva

Abstract The article aims to substantiate the approach to creating a Digital Twin Prototype for managing the reliability of value chains followed by the development of a technical specification for creating a Digital Twin for Chain Management. The research methods of classification, analysis and synthesis, induction and deduction are used. Among the tools applied are binary matrices based on qualitative attributes and dichotomies of objects and components of Chain Management. The article justifies the enlarged structure of the Digital Twin Prototype of Chain Management, clarifies the classification of reliability of chain objects and components, discusses the content of the criterion "reliability" of the management chain "consumer—focus enterprise—supplier", defines variants for reliability indicators of Value Chain Management, and establishes the criteria for the value of consumers for assessing its reliability.

Keywords Chain · Value · Digital Twin Prototype · Reliability

1 Introduction

Great economic performance of enterprises in the modern market is determined by their focus on creating values for end consumers of products and (or) services [23], the transition *of enterprises* from local activities to being a part of chains [21], including value chains, ensuring sustainability of these chains [11], or their reliability [29].

A. Tyapukhin (✉)
Orenburg Branch of the Institute of Economics of the Ural Branch of the Russian Academy of Sciences, 11 Pionerskaya St, 460000 Orenburg, Russian Federation
e-mail: aptyapuhin@mail.ru

A. Yumatov · R. Vidishcheva
Orenburg Branch of the Russian Presidential Academy of National Economy and Public Administration, 26 Kuracha St, 460000 Orenburg, Russian Federation
e-mail: nokia26002005@yandex.ru

R. Vidishcheva
e-mail: vidishcheva-rs@ranepa.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_17

These factors taken into account in the practical activities of enterprises are associated with a significant number of problems: Numerous interpretations of the terms “value” [13], “Supply Chain Management” [28], “sustainability”[10], “reliability”, and their possible combinations; difficulties in identifying the main components of chain reliability management; determining the relationships between them, as well as detecting trends in their transformation under the influence of environmental factors; determining optimal management modes for the reliability of chains at large and their components, in particular; monitoring and measurement of these components, most of which are described by qualitative characteristics.

The solution of the above problems requires a system approach using the appropriate management software based on Digital Twins or “a digital simulation model of a real logistics system, which features a long-term, bidirectional, and timely data-link to that system” [7]. In turn, it is possible to design Digital Twin on basis of Digital Twin Prototype “that contains the set of data/information that is essential to create or manufacture a physical copy from the virtual version” [25].

Since creating the Digital Twin of a virtual (non-physical) object, including chain reliability management, is more complex than creating the Digital Twin of a physical object, the objectives of this study are to form the structure of the criterion “reliability” of the management chain “consumer—focus enterprise—supplier”; to determine variants for reliability indicators of Chain Management; to clarify the criteria for the value of consumers to assess its reliability.

2 Literature Review

Chain as a management object is characterized by ambiguity of interpretations. The term covers such objects as “integration of trading partners’ key business processes” [33], “a series of integrated enterprises” [12], “total systems approach to managing the entire flow of information, materials, and services” [4], “the management of upstream and downstream relationships” [9], etc. If chains are created first, and only then values for end consumers are created, it is advisable to distinguish between chains in statics (enterprises and relationships) and chains in dynamics (processes and flows). In addition, experts talk about several types of chains: Values [23], demands [5], and supplies [21].

Enterprises as objects of management and as links of chains in statics are heterogeneous in the structure and management approaches used. This aspect of the study is clearly shown by the example of the term “value”, the content of which varies from “the amount buyers are willing to pay for what a firm provides” [23] to “a perception that becomes the reference and evaluation in seeing the attributes of products” [34]. It is possible to assume that the first interpretation of the term is preferable for the initial supplier of the chain, which is characterized by mass production, and the second interpretation is typical of its end link, the value of which is “highly individual to each consumer” [19]. At the same time, it is necessary to take into account the stages of the value life cycle, such as desired value, value creation, value appropriation, and perceived value [24]. For example, Bhandal et al. [6] emphasized the need to consider the value of the end consumer when creating Digital Twins of the chains.

The features of the chains leave an imprint on the essence and concepts of managing the reliability of these circuits, which can manifest itself in the following forms: "sustainability" [26], "resilience" (e.g., [8]), "transformability", "adaptability" [22], etc. Each of them characterizes the state of chain links, which requires them to be identified, measured, assesses, analyzed, and corrected [29]. Even in the first approximation, the researcher of chain reliability management issues faces the need to clarify the object of research and study its components. The use of Digital Twins (DTs), which include Digital Twin Prototype (DTP) and Digital Twin Instance (DTI) [17], can significantly facilitate finding the solution to these problems [20].

The special features of DTP management of the virtual (non-physical) object are:

(1) DTP is the basis for creating DTI, and DTP is developed by its consumer and is of value to them. At the same time, in order to create a DTI, the consumer generates demand that is satisfied by suppliers specializing in information technology. That is, when creating DTI, the concepts of Chain Management—values, demands and supplies—are consistently implemented;
(2) DTP can be created either in the traditional way through tangible media or electronically using the appropriate software;
(3) DTP includes a set of management objects (enterprises, relationships, processes, and flows), the analysis of which helps identify their components and shows how the relationships between them are formed. Moreover, each object and component is characterized by quantitative and qualitative parameters that describe not only these objects and components, but also environmental factors that influence their structure and application. These parameters are designed to identify and detail management objects and components in accordance with the sequence "environment → desired value for the consumer → value prototype → management concept → management system → chains in statics → chains in dynamics → value carrier → perceived value of the consumer". In other words, DTP is a set of elementary, impersonal components of management objects for the consumer to select from to create the most appropriate combination of formalized components based on which specific management objects are designed, reflecting the consumer's vision of the specific management situation and allowing him/her to make adequate managerial decisions founded on the appropriate parameters and characteristics [14];
(4) Regardless of the method for creating a DTP, it is advisable to assign the binary code to each object and its component corresponding to the location of this object or component in their totality, ordered both vertically and horizontally. The use of these codes allows implementing the system-based approach to creating a DTP, distinguishing objects and components by their parameters and characteristics, providing for the possibility of their transformation and changing relationships, taking into account the likelihood of their replacement and the adoption of new managerial decisions. At the same time, it is expedient to

distinguish between the system of codes formed in manual mode and necessary for the user when creating a DTP, and the system of codes formed in machine mode, developed automatically when creating a DTI;

(5) DTP is usually used to create a DTI and, accordingly, new physical or virtual (non-physical) objects. At the same time, it is possible to create a DTI "from the reverse", that is, based on the existing management objects and components. In this case, the DTP is utilized as a DTI testing tool, in order to determine its possible inconsistency with these objects [2]. At that, when testing the existing virtual (non-physical) objects, for example, management principles, numerous problems arise, which requires an appropriate methodology to be applied.

3 Methodology

The choice and refinement of the research methodology is based on the following prerequisites:

(1) The objects and components of management should be described by quantitative and qualitative attributes and measured, respectively, by numbers and, at a minimum, by dichotomies;
(2) To identify and substantiate the qualitative characteristics of objects and components of management, as well as their dichotomies, it is advisable to use a descriptive research method based on the analysis of literary sources and/or sociological surveys of specialists at a specific time;
(3) To structure and formalize objects, as well as to classify components of management, it is advisable to use a faceted research method, in which binary matrices are formed, allowing one to obtain "2^x" variants of these objects [1], where the digit "2" corresponds to the number of dichotomies, and x is the number of qualitative attributes of the object or component; and
(4) The binary matrices make it possible to develop the classification of variants of objects and components within the research method of analysis. Based on the outcomes, more complex variants of the object or component can be formed using synthesis. Any combination of variants obtained through binary matrices is processed by means of deduction and induction.

4 Results

The above allows determining the enlarged structure of DTP of Chain Management, which includes four basic blocks: The value chain (of objects), the chain in statics, the management system and the chain in dynamics, and the three-link chain in statics "consumer—focus enterprise—supplier" is selected as the main chain. The focus enterprise performs the functions of integrator when fulfilling the order of the end consumer on the basis of formal relationship with the consumer and supplier. Since the length of the actual chain, as a rule, is more than three links, the functions of the integrator are passed from the focus enterprise to its supplier up to the initial supplier, which allows considering and investigating the actual chain as the integral management object based on creating values of all its links, despite the heterogeneity of this chain.

The basis of DTP of Chain Management is the stages of the value life cycle or its objects. The transition from one stage to another requires forming various types of chains in statics and dynamics, as well as management systems for links and the chain as a whole. This process is repeated at least three times. In this case, the criterion for chains' effectiveness is the correspondence of the desired and perceived value of the end consumer, or the reliability of value objects of this consumer at the stages of the life cycle.

Accordingly, the reliability of value objects of the end consumer is determined by the reliability of Chain Management objects: Enterprises, relationships, processes, and flows. In addition, these objects can be distinguished using the following classification attributes and dichotomies: "state of the chain in time" (static, symbol "0", and dynamic, symbol "1"), and "activities or functions of chain links" (resources processing, symbol "0", and receiving/transferring resources, symbol "1") (Fig. 1) [30].

Each of the chain management objects has its own type of reliability, and it is advisable for them to include entrepreneurial, technological, organizational, and logistical reliability. On the one hand, these can be structured down to elementary types, and, on the other hand, allow creating combinations of them, such as industry, resource, static, and dynamic reliability, up to the reliability of Chain Management.

Figure 2 presents the reliability of main stages of the life cycle of value or its objects and allows making the following conclusions:

(1) When managing the chain reliability, it is necessary to take into account the reliability of the desired value, the value prototype, the value carrier, and the perceived value not only of the end consumer, but also of the links of three-link chains;

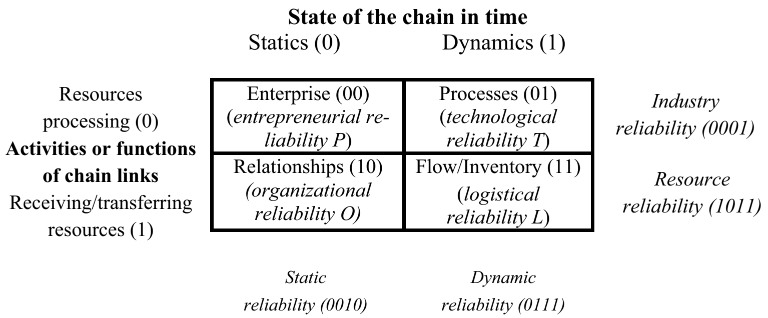

Fig. 1 Classification of Chain Management components, types and codes of their reliability

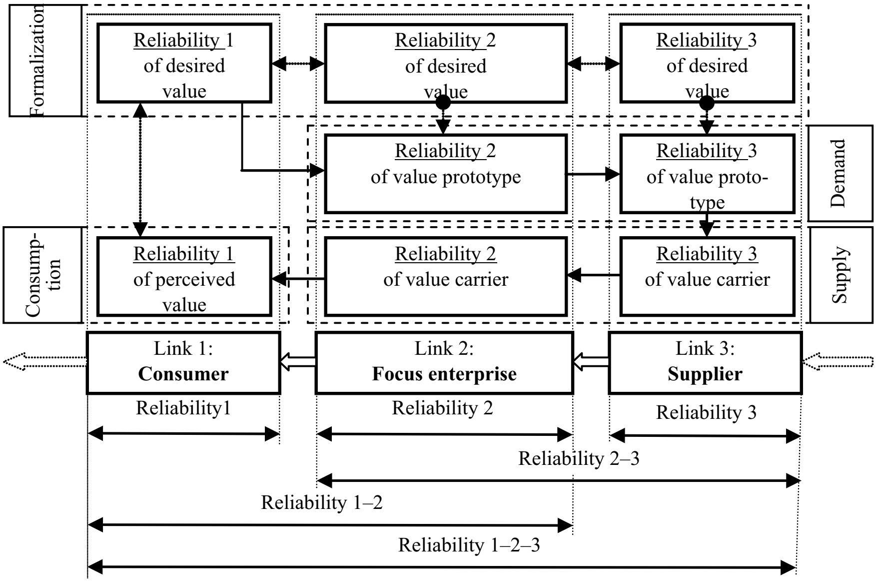

Fig. 2 Structure of the criterion "reliability" of the Chain Management "consumer—focus enterprise—supplier"

(2) When determining the reliability of Value Chain Management, including formalization and consumption chains [30], the reliability of Demand Chain Management, and Supply Chain Management should be considered;
(3) Effective management of the reliability of value chain is dependent on the relationships between the links of the chain, established according to the desired values of these links; and
(4) The reliability of the chain is largely determined by the presence of cross-functional barriers, the elimination of which is the prerogative of logistics management.

As discussed earlier, the reliability of Chain Management objects can manifest itself in various forms: Sustainability, flexibility, resilience, and survivability [29]. At the same time, a particular reliability variant is predetermined by the mode of operation of the Chain Management objects (Fig. 3).

As follows from Fig. 3:

(a) The reliability variant is chosen according to two basic attributes—the goals of links in the value chain and their potentials;
(b) Each reliability variant corresponds to a certain risk level—the lowest for sustainability (risk level 4) and the highest for survivability (risk level 1);
(c) The links in the value chain may be characterized by one or another reliability variant and, accordingly, the level of risk; and
(d) One or another variant of chain reliability can manifest itself when the particular chain management object is affected and functioning (Fig. 2), which allows

Stability of the goals of the management object	**Mode of operation of the management object under negative external influences**	
	Loss and restoration of potential (0)	Loss and change (increase/reduction) of potential (1)
Stable (0)	Sustainability S (00) (Mode: Return)	Flexibility F (01) (Mode: Adaptation)
Adjusted (1)	Survivability U (10) (Mode: Survival)	Vitality V (11) (Mode: Counteraction)

Fig. 3 Classification of variants for the reliability of management object according to the attributes of "potential–goal"

Table 1 Combinations of reliability of link, channels and chain of value

Reliability variants	Types of reliability			
	Entrepreneurial reliability E (00)	*Technological reliability T* (01)	*Organizational reliability O* (10)	*Logistical reliability L* (11)
Sustainability S (00)	S/E (0000)	S/T (0001)	S/O (0010)	S/L (0011)
Flexibility F (01)	F/E (0100)	F/T (0101)	F/O (0110)	F/L (0111)
Survivability U (10)	U/E (1000)	U/T (1001)	U/O (1010)	U/L (1011)
Vitality V (11)	V/E (1100)	V/T (1101)	V/O (1110)	V/L (1111)

establishing combinations of reliability of links, channels and value chains, each of which is indicated by a four-digit binary code (Table 1).

The above information makes it possible to substantiate variants for determining the reliability indicators of Value Chain Management (Fig. 4).

A consumer who is in a certain state and in the specific situation assumes to get the desired value. Since values are created jointly with suppliers, the desired value must be transformed into the value prototype, which is formalized in the form of demand intended for this supplier. When familiarizing with the consumer's demand, the supplier gets the idea of its own desired value, for which to be created it needs to define the goal and have a certain potential.

Based on the agreements of desired values of consumer and supplier, they establish certain relationships, thereby forming the channel in statics. With the standard form of these relationships, the universal DTP should have the typical scenario of these enterprises' behavior, which serves as the basis for converting the value prototype of the supplier into the value carrier, performing processes, and managing resource flows. This value carrier, on the one hand, allows the consumer to assess the perceived value through sensations, impressions, experience, and compare it with the desired

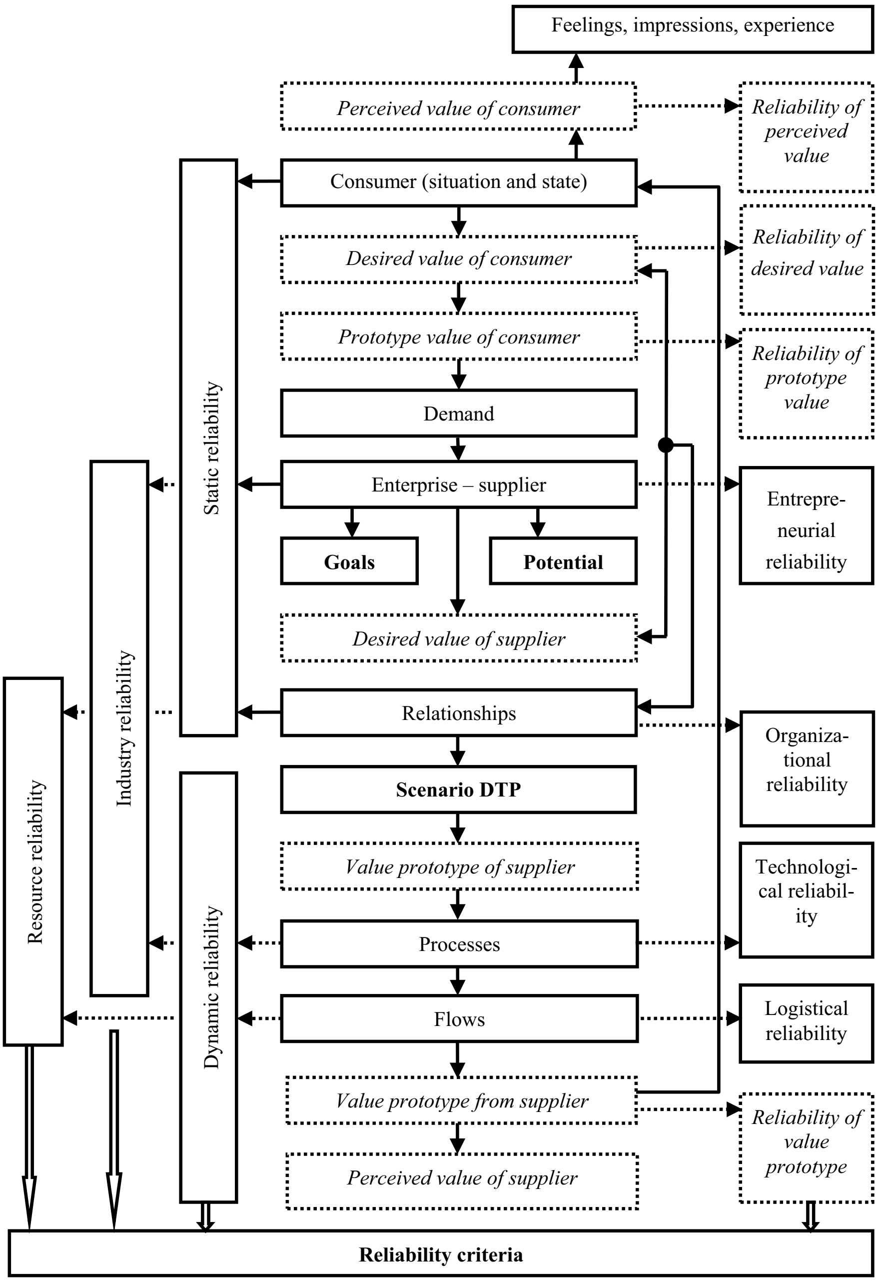

Fig. 4 Variants for determining the reliability indicators of Value Chain Management

Table 2 Options, codes, and criteria for the value of consumers of products and/or services to assess its reliability [15, 18]

Value variants	Code	Authors	Value criteria		
			Scale	Criteria variant	Code
"The amount buyers are willing to pay for what a firm provides"	00	Porter (1985)	1	Loss	0000
			2	Wastage	0001
			3	Bonus	0010
			4	Income	0011
"An experience, and it flows from the person (or institution) that is the recipient of resources"	01	Feller et al. (2006)	1	Delusion	0100
			2	Mistake	0101
			3	Skill	0110
			4	Competence	0111
"Products and services being viewed as a bundle of attributes"	10	Lancaster (1975)	1	Unnecessary	1000
			2	Excess	1001
			3	Attractive	1010
			4	Necessary	1011
"A perception that becomes the reference and evaluation in seeing the at-tributes of products"	11	Woodruff (1997)	1	Irritation	1100
			2	Disappointment	1101
			3	Approval	1110
			4	Delight	1111

value, and, on the other hand, enables the supplier to do the same, focusing, for example, on profit.

As the result of joint activity of consumer and supplier, prerequisites are created for assessing the reliability of the stages of life cycle or objects of value, management objects, as well as their various variants using the system of criteria indicated in Table 2 by four-digit binary codes.

The information above allows one to develop the methodology for assessing the reliability of Value Chain Management, which is the purpose of further research.

5 Discussion

The problem of creating a DTP and a DT of managing objects and components of chains of various types has not yet been solved and not even formalized. There are two main approaches to tackling this problem. The first approach is aimed at developing the potential of already created information tools that allow modeling and assessing the effectiveness of management decisions, such as SCOR reference model [31] and others [3, 16, 27, 29, 32]. The second approach focuses on rethinking the essence and content of DTs of this type and forming their new concepts.

In this study, the theoretical and methodological prerequisites for resolving the mentioned problem are built on the second approach, which, according to the authors, has not yet been properly developed. Therefore, in the future, the discussion is possible on the aspects of creating DTP and DT of the management of objects and components of business chains, such as clarifying the terminology of Value, Demand, and Supply Chain Management, for the development of unified terms of their objects and components; creating the set of relevant and irrelevant (promising) classification attributes and dichotomies to substantiate their content and relationships; determining transformation variants of these objects and components when changing traditional approaches to managing diverse chains; developing typical scenarios for the behavior of chain links in statics, depending on the mode of their functioning; forming the system of indicators of the effectiveness of Chain Management, etc.

6 Conclusion

The following findings obtained by the authors highlight the novelty in the current study: The enlarged structure of DTP of Value Chain Management is substantiated (Fig. 1); the content of the criterion “reliability” of the Chain Management “consumer—focus enterprise—supplier” is clarified (Fig. 4); variants for determining the indicators of reliability of Value Chain Management are determined (Fig. 4); the criteria for the value of consumers of products and (or) services for assessing its reliability have been established (Table 2).

Further studies are expected to clarify some theoretical and methodological aspects of creating DTP and DT of management of objects and components of chains of various types. Among possible avenues for further research are clarifying the structures of these twins and the content of their main blocks; substantiating and defining the content of the approach to developing DTP and DT management of objects and components of chains; formulating proposals to create the methodology of design, formation, use and optimization of DTs of this type; determining the set of qualitative attributes of objects and components of Chain Management and their dichotomies that allow identifying these objects and components; identifying possible variants for their transformation and basic combinations; justifying the set of typical impact scenarios taking into account environmental changes, etc.

Acknowledgements This article was prepared in accordance with the state task of the Ministry for Education and Science of the Russian Federation to the Institute of Economics of the Ural branch of the Russian Academy of Sciences for the year 2023.

References

1. Bailey, K. D. (1994). *Typologies and taxonomies: An introduction to classification techniques.* Sage Publications Inc.
2. Barbie, A., Hasselbring, W., & Pech, N. (2021). Continuous integration testing of embedded software with Digital Twin Prototypes, preprint. https://doi.org/10.36227/techrxiv.14770983
3. Barykin, S. V., Bochkarev, A. A., Kalinina, O. V., & Yadykin, V. K. (2021). Concept for a Supply Chain Digital Twin. *International Journal of Mathematical, Engineering and Management Sciences*, *5*(6), 1498–1515. https://doi.org/10.33889/IJMEMS.2020.5.6.111
4. Blackhurst, J., Cantor, D., & O'Donnell, M. (2012). *Sustainable supply chains: A guide for small- to medium-sized manufacturers.* Iowa State University.
5. Blackwell, R. D., & Blackwell, K. (1999, October 1–9). The century of the consumer converting supply chains into demand chains. *Supply Chain Management Review*, 22–32.
6. Bhandal, R., Meriton, R., Kavanagh, R. E., & Brown, A. (2022). The application of digital twin technology in operations and supply chain management: A bibliometric review. *Supply Chain Management, 27*(2), 182–206. https://doi.org/10.1108/SCM-01-2021-0053
7. Busse, A., Gerlach, B., Lengeling, J. C., Poschmann, P., Werner, J., & Zarnitz, S. (2021). Towards digital twins of multimodal supply chains. *Logistics, 5*(25), 1–12. https://doi.org/10.3390/logistics5020025
8. Carpenter, S. R., Walker, B. H., Anderies, J. M., & Abel, N. (2001). From metaphor to measurement: Resilience of what to what? *Ecosystems, 4*, 765–781.
9. Christopher, M. (2011). *Logistics & Supply Chain Management* (4th ed.). Pearson Education Limited.
10. Clark, W. C., & Harley, A. G. (2020). Sustainability science: Toward a synthesis. *Annual Review of Environment and Resources, 45*, 331–386. https://doi.org/10.1146/annurev-environ-012420-043621
11. Clemens, B., & Douglas, T. J. (2006). Does coercion drive firms to adopt 'voluntary' green initiatives? Relationships among coercion, superior firm resources, and voluntary green initiatives. *Journal of Business Research, 59*, 483–491. https://doi.org/10.1016/j.jbusres.2005.09.016
12. Coyle, J. J., Langley, C. J., Novack, R. A., & Gibson, B. J. (2013). *Supply Chain Management: A logistics perspective.* Mason, OH: South-Western Cengage Learning.
13. De Chernatony, L., Harris, F., & Riley, F. D. (1998). Added value: Its nature, roles and sustainability. *European Journal of Marketing, 34*(1/2), 39–56. https://doi.org/10.1108/03090560010306197
14. Ding, Y. (2019). Brief Analysis about Digital Twin Supply Chain Model and Application. *Industrial Engineering and Innovation Management, 2*, 14–23. https://doi.org/10.23977/ieim.2019.21003
15. Feller, A., Shunk, D., & Callarman, T. (2006). Value Chains Versus Supply Chains. *BPNrends* (March), 1–7.
16. Gerlach, B., Zarnitz, S., Nitsche, B., & Straube, F. (2021). Digital Supply Chain Twins—Conceptual Clarification. *Use Cases and Benefits. Logistics, 5*(86), 1–24. https://doi.org/10.3390/logistics5040086
17. Grieves, M., & Vickers, J. (2017). *Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems.* In F.-J. Kahlen, S. Flumerfelt, & A. Alves (eds.). *Transdisciplinary Perspectives on Complex Systems: New Findings and Approaches.* Springer. Cham, 85–113. https://doi.org/10.1007/978-3-319-38756-7_4
18. Lancaster, K. (1975). Socially optimal product differentiation. *American Economic Review, 65*(9), 567–585.
19. Loanne, S. S., & Webster, C. M. (2014). Consumer-to-consumer value within social networks. *The Marketing Review, 14*(4), 447–462. https://doi.org/10.1362/146934714X14185702841442
20. National University of Singapore (2019). Digital Twinning of Supply Chains: An Orchestration Platform for Supply Chain (Re)Design. *THINK Executive Summit: Journey to Digitalization. Digital Twinning and Optimizing of Supply Chains.* January 16.

21. Oliver, R. K., & Weber, M. D. (1982). Supply-chain management: Logistics catches up with and a strategy. In M. L. Christopher (Ed.), *Logistics: The strategic issues* (pp. 63–75). Chapman & Hall.
22. Pisano, U. (2012). Resilience and sustainable development: Theory of resilience, systems thinking and adaptive governance. *ESDN Quarterly Report No. 26*.
23. Porter, M. E. (1985). *Competitive strategy: Techniques for analyzing industries and competitors.* The Free Press.
24. Potra, S., & Izvercian, M. (2015). Customer value placed under scrutiny: New perspectives for an integrative co-creation approach (pp. 555–560). In *10th European Conference on Innovation and Entrepreneurship, 17-18 September 2015, Genova, Italy.*
25. Singh, M., Fuenmayor, E., Hinchy, E. P., Qiao, Y., Murray, N., & Devine, D. (2021). Digital Twin: Origin to Future. *Applied System Innovation, 4*(2), 36. https://doi.org/10.3390/asi4020036
26. Solow, R. (1993). An almost practical step towards sustainability. *Resources Policy,* September, 162–172.
27. Srai, J. S., Settanni, E., Tsolakis, N., & Aulakh, P. K. (2019). Supply Chain Digital Twins: Opportunities and challenges beyond the hype (pp. 1–6). In *23rd Cambridge International Manufacturing Symposium University of Cambridge*, September 26–27, 2019. https://doi.org/10.17863/CAM.45897
28. Stock, J., & Boyer, S. (2009). Developing a consensus definition of supply chain management: A qualitative study. *International Journal of Physical Distribution & Logistics Management, 39*(8), 690–711. https://doi.org/10.1108/09600030910996323
29. Tyapukhin, A. P. (2019). Sustainability of Resource Supply Systems. *World of transport and transportation, 17*(6), 142–165. https://doi.org/10.30932/1992-3252-2019-17-142-165
30. Tyapukhin, A., & Ermakova, Z. (2022). *Options, Structure, and Digitalization of Value Chain Management Objects.* In: V. Kumar, J. Leng, V. Akberdina, E. Kuzmin. (eds.). *Digital Transformation in Industry*. Lecture Notes in Information Systems and Organisation, *54*. Springer. Cham, 373–386. https://doi.org/10.1007/978-3-030-94617-3_26
31. van der Valka, H., Strobelb, G., Winkelmanna, S., Hunkerc, J., & Tomczyka, M. (2021). Supply Chains in the Era of Digital Twins—A Review. *International Conference on Industry Sciences and Computer Sciences Innovation –iSCSi.* Porto, Portugal.
32. Wang, Z. (2020). Digital Twin Technology. In *Industry 4.0-Impact on Intelligent Logistics and Manufacturing.* London, UK: Intech Open.
33. Wisner, J., Tan, K. C., & Leong, G. K. (2012). *Principles of Supply Chain Management: A Balanced Approach* (3rd ed.). South-Western Cengage Learning.
34. Woodruff, R. B. (1997). Customer value: The next source for competitive advantage. *Journal of the Academy of Marketing Science, 25*(2), 139–153. https://doi.org/10.1177/0092070397253006

Methods of Assessing the Institutional Environment for the Development of Information Logistics

Alexander Baranov

Abstract In the context of global processes of innovative economy formation, the traditional logistic system is losing its relevance. The leading role in the world economy is shifting to information logistic services as a system of new organizational and economic interaction. Meanwhile, at present, there is no single approach to the institutional environment of such practice. The author of the article analyzes methods of the research of information logistics, clarifies the correlation of logistics with information and material flows, saving information and transaction costs, more efficient allocation of time resources; systematizes the evolution of forms and methods of economic integration using information logistics, the differences between the digital ecosystem and information clusters. In the research the indicators of the digital transformation of logistics services that can be used to assess the effectiveness of information logistics at the micro level are supplemented. The paper presents a framework for creation of the method for assessing the formation of the institutional environment for the digital transformation of logistics services on the example of Republic of Belarus.

Keywords Information logistics · Information flows · Information and transaction costs · Digital ecosystems · Clusters

1 Introduction

In a historical retrospective, at the first stage of the genesis, the main problems of using logistics systems in the conditions of an industrial mode of production belonged to the sphere of material flows. Support for the movement of goods from a supplier to a consumer was only the accompanying information. Thus, according to the American management model, logistic is associated not only with the planning, implementation and control of the technical and economical efficiency of transportation of tangible

A. Baranov (✉)
Francisk Scorina Gomel State University, 104, Sovetskaya St, Gomel, Belarus
e-mail: axmbaranov@inbox.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_18

and intangible products, but also with the transfer of additional information between the place of production and the place of consumption.

The research question, theories, and methods of logistics services are sufficiently deeply and versatile reflected in the scientific works of researchers. The problems of strategic management of integrated transport and logistics systems, as well as certain conceptual provisions of logistics theory, were developed by representatives of the leading scientific logistics schools *D. Bowersox, D. Closs* [1], *J. Cooper, K. O'Laughlin, J. Kresge* [2], *J. Mentzer, K. Kahn* [3], *J. Stock* [4], et al. The works of *P. Radanliev, D.C. DeRoure, J.R. Nurse, P. Burnap, E. Anthi, U. Ani, L. Maddox, O. Santos, R.M. Monitalvo* [5], et al. are devoted to the conceptual approaches to the analysis of the development of transport and logistics services. The problems of cluster formation and digital ecosystems are devoted to the work of *Y. Sheffi* [6], *Mc. Kinsey* [7], *F. Meisel, T. Kirschstein, and C. Bierwirth* [8]. The researches of *Y. Wan* [9], *W. Kersten, T. Blecker, C.M. Ringle* [10], *F. Klug* [11], *M. Lisa Ellram* [12], *L.V. Zhuravleva, V.D. Kirilin, P.O. Repnikov, M.A. Usyukin* [13], et al. are devoted to the problems of informatization and digitalization of economics and logistics.

However, the theoretical and methodological provisions of the formation of digital ecosystems and information clusters of digital transformation of logistics have not been fully developed at present. In addition, a mechanism for improving information and materials management processes in logistics systems based on the formation of an appropriate institutional environment has not been developed. It is necessary to solve several problems related to the study of the conceptual and theoretical foundations of saving information and operational costs, more efficient allocation of information and time resources in the logistics system. The methods for using digital tools in managing logistic systems requires justification.

These problems hinder the formation and development of information clusters and digital ecosystems of logistics services, including the optimization and management of operational activities in logistics systems in the context of the development of the information economy.

The author tried to offer his vision to solve these problems by offering the methods for assessing the formation of an institutional environment for the digital transformation of logistics services.

Of course, the research suggests some limitations related to the use of the author's method. There is no enough connection between researchers and practitioners in this field. However, empirical data on logistics in the Republic of Belarus make it possible to note patterns confirming the main hypotheses of the author.

The first part of the article is an introduction that introduces the activity of the topic. The second part gives review of theoretical aspects of the research. The third part—the review of the literature on the topic of the research, the genesis of the views on logistics in the information economy. The fourth part is devoted to the evolution of the methodology for the study of information logistics, digital ecosystems, and information clusters and measuring the depth of integration relationships in logistics intersystem formations of the corporate level. The fifth part is devoted to the formation of a new methodology for researching the institutional environment of information logistics of the Republic of Belarus. The sixth part is a conclusion that summarizes, outlines further prospects for research in this area.

2 Theoretical Aspects

Logistics refers to the overall process of managing material, financial, and information flows. Accordingly, *logistics management* is the sphere of activity of the business entity aimed at organizing and regulating financial, material, and information flows in order to minimize costs along the entire route, as well as general optimization of the enterprise's activities. *Interorganizational logistics* involves the coordination of the actions of the organization, suppliers, consumers, and logistics intermediaries to achieve the goals of the logistics system.

There are *three levels of logistics integration*: The first level—separate logistics functions are performed; the second is internal integration, when logistics functions are combined under a single management within the enterprise, *the third level* is the external integration, when various enterprises integrate their logistics activities in the supply chain; enterprises compete not with each other, but with enterprises operating in other supply chains. The *volume of logistics services* is distinguished—the volume of logistics operations, as a result of which qualitative changes in the material flow (movement and transformation) in the field of trade occur. At the same time, *forwarding services* are services related to the organization of the process of departure and receipt of cargo, as well as the performance of other work related to the transportation of cargo in accordance with the contract of the transport expedition.

Achieving logistics goals requires constant monitoring and influencing the logistics processes *of management of the process of movement of materials and information. Management* in this case is aimed at coordinating the activities of all departments engaged in the production and sale of products. The tool for such a combination *is information support.* Information arises from various logistics activities and accompanies the material flow at all stages of its progress. Information is used when developing and making management decisions in the logistics system. Accordingly, it is necessary *to manage and control information processing flows.*

One of the key trends in the development of logistics in the XXI century is the increasing integration of network counterparties within the framework of various IT platforms that optimize cross-functional business processes, this process refers to the *informatization of logistics.*

Information logistics is the area of organization logistics that solves the problems of organization and integration of information flows for making management decisions in logistics systems. With the help of information logistics and the improvement of planning and management methods based on it, companies in leading industrial countries are currently undergoing a process, the essence of which is the replacement of physical stocks with reliable information.

Information logistics organizes *the flow of data that accompanies the material flow* and is a significant link for the enterprise that connects supply, production, and sales. The task of information logistics is to ensure a *high degree of information content of the management system*, as well as to provide each level of the management hierarchy of the logistics system with the necessary information of the proper quality and in the necessary time.

From the point of information logistics, an information flow is a collection of messages circulating in the logistics system, between the logistics system and the *external environment*, necessary for managing and monitoring logistics operations. Information logistics organizes the data flow that accompanies the material flow and is the essential link for the enterprise that connects supply, production, and sales. It covers the management of all processes of movement and storage of real goods in the enterprise, allowing the timely delivery of these goods in the required quantity, picking, quality from the point of their occurrence to the point of consumption with minimal costs and optimal service.

The sustainability of the commodity circulation chains has become one of the most important parameters of the functioning of supply chains, along with the provided level of service and costs, while if cost reduction is achieved mainly due to local optimization, then sustainability acts as a *criterion for the effectiveness of the entire supply chain.*

The digital transformation of logistics services is the digitalization of cargo transportation, which includes intelligent systems for managing and tracking goods at all stages of transportation, complete automation of document management (electronic commodity and transport documents) in ensuring transportation within the country and in international communication with rapid customs clearance of goods in cross-border communication.

The *digital transport corridor* is used as a market definition of an integration and distribution information and service system for electronic logistics and ensuring effective monitoring and support of transcontinental cargo flows along transit and trade corridors.

The fundamental difference between digital transformation, automation and informatization is not just in increasing the efficiency of existing processes, but in the creation of new opportunities and the construction of new processes of activity. This defines *the potential for digital transformation of logistics.*

The intensity and efficiency of the information and logistics system is an assessment of the success rate of solving logistics problems through the use of an information system.

In the supply network, none of the organizations works autonomously and does not compete alone. The focus company depends on network partners who provide it with parts for assembly, goods for sale, ensure the movement of goods, etc. The logistics strategy of full vertical integration of industries is clearly outdated. The traditional approach is that suppliers specialize in delivering the part of the value proposition that they have succeeded in integrating into a single supply chain. Evidence that increased *depth of integration relationships* (both *organizational and interorganizational*) leads to increased efficiency of the overall supply chain. It has been obtained through the research of *M. Frolich* and *F. Westbrook* [14].

The authors found that strategies for the broadest integration lead to the highest rates of significant improvement in performance. They presented that point in the form of *time savings in logistical integration.* It can be assumed that wider integration reduces the uncertainty of material flow through the supply network, which in turn increases efficiency and reduces the time of operations.

3 Literature Review

The concept of information logistics was updated at the fourth stage of its evolution in the 90 s of the XX century. Its formation led to a continuously growing array of information in the field of production, circulation, and finance, which required appropriate processing, as well as the development of communication tools and computerization of economic activity. The emergence of information logistics can be associated with the change in the technological order in the world economy that has taken place since the 80 s of the XX century, gave impetus to the development of international financial and industrial groups, transnational clusters and corporations; in addition, flexible production systems and technologies began to be used. The formation of TNCs is inherently informational in nature, involving the creation of special logistic organizations.

According to *H. Yi-Hui*, *L. Chieh-Yu* [15], the term «information logistics» can be defined as the optimal management and control of information processing flow in terms of storage time, distribution, and presentation of resources to achieve optimal company results compared to its costs. It can also be considered as a concept of using IT to optimize the logistics process.

Foreign scientists consider information logistics from two positions. On the one hand, some experts refer information logistics to the functional area of information management. On the other hand, information logistics is considered as a company's information resource management system based on logistics principles [16].

These methodological approaches do not contradict each other and can be used to clarify the concept of integrated information logistics. On the one hand, information logistics can be represented as a supporting subsystem of the functional sphere of logistics management or the general theory of logistics. Then its goal is to provide the most complete up-to-date information of logistics systems, reduce transaction costs in this area, and the object of study is information flows that accompany material ones. On the other hand, information logistics becomes a tool that performs the function of providing the entire organization with information, based on the basic principles of logistics (necessity, completeness, accurate calculation, time). Thus, information logistics is becoming a separate scientific area that has significant integration potential, which is able to combine and *strengthen the institutional interaction between the key functional elements* of a virtual enterprise or information cluster, such as obtaining resources, the production process, marketing, obtaining finished products, and its implementation.

From our position, information logistics is associated not only with information and material flows, but also with saving information and transaction costs, more efficient distribution of time resources, so it can be defined as the optimal management of the processes of movement of material and information from the standpoint of storage, distribution, and transportation resources, which contributes to the growth of efficiency and profitability of the subjects of the information economy. Logistics itself is associated with information flows that carry information about the transportation of goods, the movement of resources, etc. However, the integration of IT, blockchain technologies, and smart contracts into the logistics system leads to a sharp reduction in information and transaction costs, which should include the costs of time, anthropogenic resources in order to develop models of optimal collaboration of cluster subjects based on improved efficiency, modeling of vertical, and horizontal informational correlation.

Information logistics in some scientific works was called Internet logistics, and in the works of *Y. Wang, I. Giannoccaro, L. Purvis, A. Iffikhar*—e-logistics [17], it indicates a wide scale of use logistics information systems, which are of particular importance in the context of the transformation of traditional economic activity into an electronic form, which allows quickly, without the use of an intermediary mechanism and distribution centers, redirect material flows directly from the producer to the consumer, saving time resources and implementing the principles of prosumerism, characteristic of the new information economy.

Information flows in information logistics are formed in accordance with material ones. It is assumed that each material flow corresponds to an information. Such a correspondence is not always isomorphic (complete). Often, information and material flows occur in *different time intervals*. Thus, a material flow can arrive at a given place, and documents for it may not yet be delivered here. If the arrival of a material flow is ahead of the arrival of documents on it, then this is considered unpackaged deliveries, accepted by the recipient for safekeeping and only then, after the arrival of documents, the compliance of the arrived materials with these documents is checked. Maybe vice versa: Documents for cargo arrived at their destination, and the material flow is still on the way. If the opposite, then the documents are recorded as a basis for accounting for "stocks on the way" and after the arrival of the cargo are checked with its composition and volume. Preferable is the option of advance of information flows in comparison with movement of material ones. This makes it possible for better preparation for receiving goods. In fact, information flows are not always ahead of the curve. Information flows should be adequate to material ones in terms of the characteristics of these flows. Thus, *information logistics should assume a consistent relationship (which can be reflected as correlation) between material and information flows, the values of which should be analytically dependent on each other* and on the resulting indicators of the end object of information logistics management.

The term "value chains" was developed and introduced by *M. Porter* in 1985 in the book "Competitive Advantage" [18]. It describes *the value chain* as a set of various types of company activities aimed at *development (making new products, using new technologies), production, marketing (growth in the loyalty of consumers), delivery, and maintenance* of its products. Per research unit *M. Porter* takes an individual company in a particular industry. The value chain consists of main (*internal logistics, external logistics*, manufacturing process, marketing, service) and ancillary (material and technical support, technological development, frame management, company infrastructure) activities. Value chain is a series of sequential actions of the company to transform resources into a final product or service. In the general sense, this is a tool aimed at strategic planning, in order to describe in detail the activities of the organization.

However, according to a number of researchers [19, 20], the informatization of logistics activities is not associated exclusively with the use of IT, this process is progressive in parallel with the introduction of new forms of economic integration, such as virtual enterprises, strategic alliances, innovation clusters, etc. In our opinion, information logistics is especially relevant when we organize the activity of transnational information and information-time clusters, the subjects of which are dispersed around the world, and the management of logistics flows moves to the information level.

4 Material and Methods

The logistics principles are generalized experimental data, the laws of it phenomena can be found from the observations of logistics experts. Knowledge of principles by logistics experts makes it easy to compensate the uncertainty of some *institutional environmental factors.* The basic principles of logistics include: consistency, complexity, scientific, specificity, constructiveness, reliability, and variability.

When analyzing and designing logistics systems, methods and techniques of logistics management, the following principles of logistics system management were developed and tested: a systematic approach—manifests itself in considering all elements of the logistics system as interconnected and interacting to achieve a single management goal. However, a distinctive feature here is that the functioning of individual elements is not optimized, but it can be done with the entire logistics system in general; the principle of global optimization—when optimizing the structure or management of the logistics system, it is necessary to agree on local goals for the functioning of system elements in order to achieve a global optimum (*especially in information clusters and digital ecosystems*); the principle of total costs is to take into account the totality of the costs of managing material and related financial and information flows in the logistics chain; the principle of logistic coordination and integration—provides for the achievement of an agreed, integral participation of all links of the logistic system in the management of material, financial and information flows in the process of implementing the goal of the system; the principle of modeling and information support—when analyzing, synthesizing, and optimizing objects and processes in logistics systems and chains, various mathematical, economic-mathematical, graphic, and other models are widely used (at the same time, the non-use of information and technology support is practically excluded); principle of development of the necessary set of subsystems providing the process of logistic management of technical, economic, institutional, legal, organizational, personnel support, etc.; the principle of universal quality management—ensuring the high quality of operation of each element of the logistics system to ensure the overall quality of goods and service provided to end consumers; the principle of humanization of technological solutions—solves the issues of compliance of the logistics system with environmental, ergonomic, social, ethical requirements, etc.; principle of stability and adaptability—consists in stable operation of the logistic system at permissible deviations of parameters and factors of the environment and flexible adaptation at their significant fluctuations.

In a digital environment, the organization of work changes throughout the *value chain.* Software integration, work in the cloud, data analysis must be combined with the design, production, and technical support of complex "physical" equipment. It must be stated that with the appearance of the classic control model is not effective for smart devices.

Automation and robotization cover all mining processes. In modern conditions, companies are being transformed into digital corporations, in which many standard business processes are already automated, hierarchies, and connections within companies and the procedure for interacting with the entire industry ecosystem with competitors, suppliers, and customers are changing. Automation from the operations moves to the control area, and the information system implements this process cheaper, more reliable, more effectively.

The structure of the enterprise management, which causes the appearance of new functional structures: Data Management development department; IT Operations Quality Assurance Department; Client Experience Management are changing. In the digital ecosystem, the IT and R&D division works especially closely together to implement improvements and updates as soon as possible. The effect that the company receives as a result of organizational transformations depends on the art of processing the obtained data. Thus, information becomes an asset that affects business performance [21].

In addition, the more partners in a single network and ecosystem, the smarter it is, machine algorithms allow you to identify patterns, create models and generate recommendations. Ultimately, *the use of digital technology will lead to an increase in labor productivity due to a significant decrease in time spent on production operations, reduction of production costs and power consumption for the manufacture of products, which makes it possible to reduce supply prices.* Qualitative analysis of data, according to estimations of foreign experts, allows to increase performance from 3% to 15% [22].

Digital Ecosystem, according to *I. A. Arenkova, T. A. Lezina, M. K. Tsenzharik, E. G. Chernovoy* [23] unites members of the value network and attracts new participants by providing them with access to technologies and valuable resources. It is controlled by a founding company that owns a digital platform and unique technologies. For example, the leaders of the world economy Microsoft, Apple, WalMart form ecosystems within the created digital platforms, which, as a result, create value for all its participants in the form of new products, technologies, or growth in the loyalty of consumers. The digital ecosystem differs from the traditional idea of clusters and

Table 1 Differences between the digital ecosystem and clusters

Characteristic	Traditional cluster	Informational cluster	Digital ecosystem
Geographic proximity of participants	Important	Not important	Consciously rejected
Role of competition and cooperation	Effectivity is achieved through competition	Competition is more important, but cooperation promotes innovation	Equally important is competition and cooperation
Generation and transfer of knowledge	Limits help to share knowledge and create them cooperatively, but locally communications are an important driver of innovation	Characterized by the exchange of operational information, there is no close relationship at the strategic level. Knowledge is generated, distributed in the network	Focus on involving all innovative actors in the use of technologies for the development of new decisions
The foundation integration	Geographic proximity	Strategy presents the resource base	Digital platform is the technological resource
Degree of independence of participants	Members in a certain degrees are independent	The cluster core is the leader and performs control functions	Leadership formally belongs to the company-founder (keystone)

most closely correlates with the concept of information and information-time cluster formations (Table 1) [24].

As a result of the involving of IT in the processes of information logistics management, prerequisites and tools are formed not only for improving the efficiency of individual economic entities, but also for intersystem associations created with their help in the form of information and information-time clusters, which leads to an increase in the effect of informatization of management by increasing sustainability and flexibility of the created integration structures. An important problem in the evolution of new forms of interaction between firms in the information economy is the *intersystem compatibility* of constituent elements, which is assessed through the prism of *technological and organizational indicators*, that requires the use of new mechanisms and methods of information management based on a closer model of interaction.

At the same time, an unlimited increase in the level of management information capacity, which is characteristic of the digital ecosystem, does not seem to be economically feasible, since there is a limit of the effectiveness of management using IT, which, in turn, is determined by the characteristics of interorganizational logistics interaction.

Let us consider the indicators for assessing the level of logistical integration, the analysis of which allows us to assess the degree of correlations within individual logistical intersystem formations (information and information-time clusters) based on the analysis of material, informational and financial flows connecting participants in the integration formation (Table 2).

Turning to transport logistics, it should be noted that the role of information flows in the management of transport and cargo is evidenced by direct agreements between senders and ports, calendar and contact schedules for the delivery of trains and ships. The goods following the transshipment should be separated from the general loading, tracking should be organized for their movement on the network of railways in order to inform transport hubs in advance about the cargo flows sent to them.

Table 2 Measuring the depth of integration relationships in logistics intersystem formations at the corporate level

Index	Designation reading	Analytical expression	Explication
Analytical indicators of the intensity of mutual connections			
Significance indicator of mutual material flows	*TFT*	$TFT = \frac{FT_a}{FT_s}$,	FT_a—the total freight turnover between the participants of the logistics intersystem formation; FT_s—total freight turnover of participants
Significance indicator of mutual financial flows	*TI*	$TI = \frac{I_a}{I_Z}$,	I_a—total mutual investments of participants; I_z—total investments of participants in the economy
Significance indicator of mutual information flows	*TInf*	$T\,inf = \frac{Inf_a}{Inf_s}$,	Inf_a—the total value of the intensity of the information flow between the participants; Inf_s—the total intensity of information flows of participants
Significance indicator of mutual information resources	*TRInf*	$T\,Rinf = \frac{RInf_a}{RInf_s}$,	$Rinf_a$—volume of the joint database of participants; $Rlnf_s$—the total volume of information resources of participants
Index of openness	*TO*	$TO = \frac{TAz}{Dz}$,	*TAz*—the total cost of transactions between participants; *Dz*—the total income of participants

(continued)

Table 2 (continued)

Index	Designation reading	Analytical expression	Explication
Indicator of the degree of diversification of activities (sectoral analysis)	*GL*	$GL == 1 - \frac{\sum i \sum j\lvert Xij - Mij\rvert}{\sum i \sum j(x_{ij} + \sum jMj)}$	*Xij*—volumes of supplies from participants within the logistics intersystem formation; *Mlj*—volumes of deliveries to participants within the logistics intersystem formation; *i*—kind of activity; *j*—participants of logistics intersystem education

Transport and freight flows directly depend not only on information, but also on *financial flows*, that can be classified by their intended purpose: payment (purchasing, payment for services), investment, fiscal, etc. The most important in the context of the information economy are investment, since they allow to assess the potential for the development of information logistics systems in the long term. *The intensity of the information flow* is an assessment of the success rate of solving logistics problems through the use of an information system.

To estimate the depth of integration of logistic relationships functions within the framework of corporate system is proposed to use a set of indicators, shown in Table 2. Source Components for indicators were based on subcomponents of Digital Transformation Index and Industry Digitization Index by McKinsey (Digital Quotient).

We believe that each type of logistics intersystem formations can be characterized by a range of values indicators and the totality of components will reflect *depth of integration relationships.*

Taking advantage of research *N.A. Gvilia, A.V. Parfenova, T.G. Shulzhenko* [25] it can be noted that the hypothesis of the required level of use of elements of informatization in logistics activities depends on the level of logistics integration within the association. According to a PwC study, which cites in their work *M.M. Kovalev, G.G. Golovenchik* [26], information systems will be used by 90% of logistics companies in the world and that will become the determining factor in the digital transformation of the industry in the next five years.

From our point of view, this index and indicators can be used to determine the intensity and effectiveness of information logistics transformation at the micro level (firms, virtual enterprises, information, and information-time clusters) [27]. For each variable, it is necessary to set a rating from 1 to 10, depending on the share of the target indicator (up to 10%—1 point, 11–20%—2 points, etc.). The rating of a firm or a cluster is determined by the normalized value of the initial data relative to the score scale. Thus, the digital transformation index of logistics services can be compiled both *vertically (supply, demand, potential)* and *horizontally* in terms of indicators, which allows to perform a detailed SWOT analysis and identify areas for further stimulation of the transformation of logistics services.

According to our research [27], information and information-time clusters have the average significance of mutual material flows (*TFT*), the average significance of mutual financial flows (*TI*), the high significance of mutual information flows (*TInf*), a high indicator of the significance of mutual information resources (*TRInf*), a high indicator of openness (*TO*), and a low indicator of the degree of activity diversification (sectoral analysis) (*GL*) [28]. In the economy of the Belarus, a promising form of application of digital logistics is supra-systemic formations, which elements can be the source of the unification and integration of logistics systems of partner countries in EAEU. From our point of view, supersystem formations can have the highest level of depth of interorganizational integration through the use of information clustering technologies, which implies an increase in the index of digital transformation of logistics services [29].

In the Concept of the Development of the Logistics System in the Republic of Belarus until 2030 (Approved by Government Decree № 1024 of December 28, 2017) [30], the following tasks in the field of digitalization have been formulated: the transition to electronic document management technologies along sustainable commodity circulation chains; formation of a single digital platform for logistics systems based on the integration of interaction with international information systems; unification of standards for information exchange of data between participants in the logistics system; development of an electronic exchange trading system in the provision of logistics services.

In compliance with the research of *E.M. Karpenko*, according to the methodology for assessing the development of logistics in the country based on the Logistics Performance Index (*LPI*), the efficiency of the logistics system of the Republic of Belarus is characterized by negative dynamics. So, in accordance with the Logistics Performance Index (*LPI*), this indicator for the Republic of Belarus is 2.54 (110th place in the world). At the same time, the targets of the logistics system of the Belarus should be considered: the growth of the position of the country in the world ranking in terms of the logistics efficiency index to a level of at least 50th place; growth in the volume of logistics and forwarding services, a twofold increase in transit revenues [31].

As a part of the digital agenda of the EAEU, such projects in the field of informatization of logistics as “Digital Road” and “Digital Transport” have already being implemented. According to the Dean of the Faculty of Economics of BSU *A.A. Koroleva*: “It is advisable to expand the connection to cargo transportation through online channels of small and medium-sized businesses. The best examples are the multimodal systems Cargoclix.com, DBSehenker, Cargomatic, UPS, MyDHL, Xeneta, and Inttra, which simplify the process of purchasing logistics services for legal entities” [32]. *A.A. Koroleva* emphasizes that information logistics is a key factor in the growth of the economy of the Republic of Belarus, which can be implemented through the creation of a Eurasian digital transport corridor between China and the EU as part of China's New Silk Road project.

From our position, the information and information-time clusters can become centers of such interaction, and the informatization of logistics systems and cluster mechanisms can significantly improve the economic efficiency of such integration mechanism.

5 Results

Institutionalization of logistics is the process of transformation of its structures from ordinary organizational forms into a full-fledged socio-economic institute. Its consequences are monitored in the formation of *sustainable demand* through the subsystems of the information economy, including e-government, IT sector, science, new opportunities for logistics operators, new forms of financial relations (smart contracts, blockchain technologies), super-complex organizational forms of economic relationship (information clusters).

The creation of new digital partner interaction platforms raises questions about the participation of key institutions *in the supply* by communication environment and building *the potential for its use* in information logistics. But *none of the experts considered the institutional environment* of logistics *with the proposed system of indicators.*

Conceptually, such research will *make it possible to form a set of directions* to ensure the sustainability of the functioning of information logistics space in relation to the impact of external threats and internal adverse factors.

The proposed recommendations are based on the results of an analysis of the trends and features of the development of international supplies in the world digital economy, they can provide the possibility of determining the sequence of actions to stimulate the digital transformation of international cargo transportation in the Republic of Belarus, strengthening existing and gaining new competitive advantages at the international level. All that indicators will make it possible to calculate the index, characterizing the use of digital technologies, and their aggregates along the entire chain of international transport and logistics services, based on offered indicators (*supply, demand, potential*).

It is necessary to refer the specific weight of the organizations in Belarus, using the Internet for interaction with suppliers to strengths of demand—88.3% (that is an important prerequisite of formation of information clusters); specific weight of the organizations using the Internet for interaction with consumers, in the total number of the surveyed organizations—78.6% (that belongs to positive aspects of development of subsystems of information economy and create prerequisites of strengthening of interaction with consumers in cluster structures).

The share of organizations in Belarus that use electronic sale of goods (works, services) or using the system automated exchange messages between organizations

(EDI), in general number of surveyed organizations—30.5%. The specific weight of the organizations conducting electronic procurement of goods (works, services) to the orders obtained by means of special forms—38.8% (that belongs to the average level of relevant indicators, but are much below than indicators of the European countries—50–70%).

The specific weight of the population in Belarus, using the Internet for implementation of interaction with state bodies and the state organizations in total population—23.6% (that is a low indicator, because, for example, in Russia the specific weight of the population, using the Internet for receiving the public and municipal services in total population—77.6% [28]).

Among indicators of the *Supply,* it should be noted investments into startups. In EU countries the corresponding indicator grew in 2021 by 2.9 times to the nearly 49 billion euros. Leaders of the European market, with the greatest number of high-tech startups were Great Britain (32%), Germany (15%), and France (14%) [16]. Taking into account the difference in scales of economies of Belarus and EU countries, this rate in our country is rather high—404.8 million Belarusian rubles.

The share of expenses on research and development in the commercial sector in GDP is rather low in Belarus and doesn't exceed 0.5% of GDP. The volume of budget financing organizational activity and development of material and technical resources on subjects of innovative infrastructure, as well as the dynamics of attraction of venture investments, are also at a low level and need additional measures to increase in financing.

High level of financing of the State program "Digital development of Belarus" in 2021 is comparable in relative sizes to similar programs in Russia and the countries of the European Union; that belongs to the positive aspects.

The rating of Belarus, considering indicators of patent statistics, according to the World organization of intellectual property is at rather low level—the 62nd place from 171. At the same time not only EU countries, but also Ukraine (28th place) and Russia (8th place) considerably are ahead of Belarus.

The index of cluster development corresponds in 2020 to the 60th place, this indicator in Belarus is higher, than in Russia and the CIS countries, but considerably concedes to the corresponding indicators not only the countries of Europe, the USA, Japan, but also to the countries of Southeast Asia.

The Rating of institutional blockchain conditions on which in 2020 Belarus took the 19th place from 141, belongs to considerable advantages, having outstripped almost all CIS countries (except of Russia), developed and developing countries.

In the DESI 2020 Index (in accordance with our calculation results) Belarus took the 17th place that exceeds similar indicators for Portugal, Croatia, Hungary, Slovakia, Poland, Cyprus, Italy, Romania, Greece, and Bulgaria [27].

The rate of development of the electronic government in Belarus in 2022—the 58th place, showed the lowering dynamics, on this indicator Republic of Belarus conceded to the countries of Eastern and Western Europe, Russia, and Ukraine [33].

To determine the Index of Digital Transformation of Transport and Logistics Services of the Republic of Belarus (*Dfti*), we will use the methodology of

T.S. Kuprievich [34] in a modified version, taking into account the *LPI*—the logistics efficiency index; any digital transformations can be constrained by the overall level of efficiency of the country's logistics system. However, *we will offer our own indicators* of digital transformation and combine the application and potential of digital transformation in logistics into the single position (Table 3).

The Index of Digital Transformation of Transport and Logistics Services can be calculated using the geometric mean method (multiplicative method), which implies a more accurate result due to the synergy of partial indicators:

$$Df_{ti} = \sqrt[3]{D_{dt} S_{dt} EP_{dt}} \tag{1}$$

where D*dt* is indicators of demand for networking in logistics activities, associated with IT use initiatives; *Sdt* is indicators of the existing offer of products and services in the IT field, used for the informatization of logistics; *EPdt* is indicators of the use of IT in the field of international logistics and the potential for its development.

Indicators *Ddt,* according to the results of our research, are relative indicators, *Sdt*—absolute, and *EPdt*—are characterized by international ratings, showing the institutional conditions of digital transformation:

$$Df_{ti} = \sqrt[3]{30.2*}748.4 * 58.56 = 111.529676 \tag{2}$$

From our position, in addition, it is necessary to adjust the potential for the digital transformation of logistics, taking into account the current quantitative indicators of the development of logistics services in Belarus (Table 4).

The highest growth rates are demonstrated by the volume of transport forwarding services, which may be due to the large volume of investments in fixed assets in the transport and logistics sector.

Aft—generalized average growth rate of logistics activity indicators in the Republic of Belarus.

$$Aft = \sqrt[n]{(Aft_1 * \ldots * Aft_n)} = \sqrt[3]{(123.8 * 115.98 * 128.32)} = 122.593099 \tag{3}$$

where *Aft* is the generalized average growth rate of indicators of logistics activities in the Republic of Belarus; *Aftn* is average growth rate of 1…*n*-th indicators of logistics activities in the Republic of Belarus.

In general, weak points of Republic of Belarus on indicators of demand are indicators of electronic interaction with suppliers, consumers, and the government organizations. Weak points of supply indicators—volume of budget financing of organizational activity and development, development of venture investment and expenses on research and development.

From our position, the Republic of Belarus need to create supranational information clusters that would cover several regions and unite them with the help of logistics, information, production, scientific and technological ties. Information clusters,

Table 3 Indicators of the formation of the institutional environment for the digital transformation of logistics services in the Republic of Belarus (2018–2021)

Indicators	Demand (*Ddt*)	Supply (*Sdt*)	Potential (EPdt)
IT	The share of organizations that use electronic sale of goods (works, services) or using the system automated exchange messages between organizations (EDI), in general number of surveyed organizations—30.5%	Investment in IT startups—404.8 million of belarusian rubles	Evaluation of performance digital transformation economy of Belarus– 0.588
Science, including e-science and innovation	The share of organizations that spent on innovation in the total number of surveyed organizations –19.7% The share of issued national patent applicants on ICT inventions in general number of national applicants for patents for inventions—2.3%	Share of expenditure on R&D in the commercial sector in GDP—441 million of belarusian rubles	The rating of Belarus according to the World Intellectual Property Organization—393
Information clusters	The share of organizations using the Internet for interaction with suppliers, in the total number of examined organizations—88.3%	The volume of budget financing of organizational activities and the development of the material and technical base for the subjects of the innovation infrastructure of Belarus—46.5137 million of belarusian rubles	Cluster development index—4 (60th place as the component of the Global Competitiveness Index)
Smart contracts, blockchain technology	Investments in blockchain to the volume of investments in fixed assets—0.3%	Dynamics of attracted venture investments in belarusian startups—55.66 million of belarusian rubles	Blockchain institutional conditions rating—8.51 (according to the Global Crypto Adoption Index)

(continued)

Table 3 (continued)

Indicators	Demand (*Ddt*)	Supply (*Sdt*)	Potential (EPdt)
Formal institutions for the functioning of subsystems of information economy	The share of organizations using the Internet for interaction with consumers, in the total number of examined organizations—78.6%	Investment in fixed assets of the ICT sector—723.5 million of belarusian rubles	Digital Economy and Society Index (DESI)—0.498 (according to the results of our calculations)
Logistics operators	The share of organizations electronic procurement of goods (works, services) orders, received through special forms, placed on the website, or on the Extranet, or using the system automated exchange messages between organizations (EDI), in general number of surveyed organizations—38.8%	Investments in fixed capital in transport and logistics sector—2711.9 million of belarusian rubles	Logistics Performance Index (LPI)—2.54
Electronic government (e-government)	The number of citizens, having digital skills in general population—0.69% The proportion of the population,using the Internet for interaction with state authorities management and public organizations in general population—23.6%	Investments in the implementation of the State Program "Digital Development of Belarus 2021"—855.171311 million of belarusian rubles	E-Government Development Ranking—0.8084

Table 4 Indicators of logistics activities in the Republic of Belarus, 2017–2021

Index	2017	2018	2019	2020	2021	Average pace growth,%
The volume of logistics services, million of belarussian rubles	296.7	302.2	438.5	511.2	673.1	123.8
The volume of transport forwarding services, million of belarussian rubles	653.1	727	906.9	1334.8	1735.9	128.32
Number of logistics centers, units	35	44	60	58	61	115.98

digital ecosystems based on information logistics are the determinant of the development of the information economy, which can bring Belarus economy to the level of an international digital platform for interaction between East and West, providing a key role in the global economic system.

6 Conclusion

Despite the applied methodical rigor, this study has some limitations that need to be considered when interpreting its findings and conducting in the future research.

Future studies could investigate if there are any differences in the integration potential that links and proves cooperation between basic institutions and functional areas of information economy actors at the micro-level.

Complementary research may be needed in the sphere of digital ecosystems of organizations in the aspect of IT and R&D interaction departments, which will have the effect of accelerating innovation. The effect that the company receives as a result of organizational transformations depends on the depth of integration connection and the level of digital transformation of logistics services.

Ultimately, information logistics contributes to the growth of labor productivity, increasing the efficiency of modeling horizontal and vertical information connection not only at the micro level, but also at the level of transnational clusters, the level of international economic relations.

Informatization makes it possible to ensure the increase in the efficiency of the main processes and operations of transport and logistics services, in particular, to increase the accuracy of planning and forecasting parameters of information and material flows, to process incoming delivery requests with high speed, to quickly select the most suitable type of vehicles, relative to the characteristics of the product, to determine rational transportation routes, to speed up the fulfillment of delivery orders.

Thus, the relevance of the research is determined by the problems listed above, their significance from the standpoint of conceptual, theoretical, methodological and practical justification, insufficient study of issues, related to the development of digital ecosystems and information clusters and the need to improve information and materials management processes in logistics systems, based on the formation of an appropriate institutional environment. The practical significance of the research results is that the theoretical and methodological provisions, formulated in the work, can be used by organizations in the development of strategic solutions for the implementation and development of digital logistics service ecosystems in order to reasonable reduce total logistics costs and improve the efficiency of flow process management. The use of the results, obtained in the work makes it possible to realize the scientific and applied advantages of logistics as a tool for improving the efficiency of material and information flow management in information clusters and digital ecosystems.

References

1. Bowersox, D., & Closs, D. (1996). *Logistical management—The integrated supply chain process*. McGraw-Hill. Google Scholar.
2. Cooper, J., O'Laughlin, K., & Kresge, J. (1992). The challenge of change: Logistics in the New Europe. *The International Journal of Logistics Management, 3*(2), 1–16. https://doi.org/10.1108/09574099210804831
3. Mentzer, J., & Kahn, K. (1995). A framework of logistics research. *Journal of Business Logistics, 16*(1), 231–249. Google Scholar
4. Stock, J. (1997). Applying theories from other disciplines to logistics. *International Journal of Physical Distribution and Logistics Management, 27*(9/10), 515–539. https://doi.org/10.1108/09600039710188576
5. Radanliev, P., De Roure, D. C., Nurse, J. R., Burnap, P., Anthi, E., Ani, U., Maddox, L., Santos, O., & Montalvo, R. M. (2019). Cyber risk from IoT technologies in the supply chain–discussion on supply chains decision support system for the digital economy (Preprint). https://doi.org/10.13140/RG.2.2.17286.22080
6. Sheffi, Y. (2012). *Logistics clusters—delivering value and driving growth*. The MIT Press.
7. McKinsey,. (2019). *Globalization in transition: The future of trade and value chains*. McKinsey and Company. Google Scholar.
8. Meisel, F., Kirschstein, T., & Bierwirth, C. (2013). Integrated production and intermodal transportation planning in large scale production distribution networks. *Transportation Research Part E: Logistics and Transportation Review, 60*, 62–78. https://doi.org/10.1016/Fj.tre.2013.10.003
9. Wan, Y. (2021). Improving the information flows and business process in global maritime logistics chains considering digitization and digitalization aspects. PhD thesis. University of Bremen. Google Scholar
10. Kersten, W., Blecker, T., & Ringle, C. M. (2020). *Digitalization in Supply Chain Management and Logistics*. Berlin epubli.
11. Klug, F. (2018). Logistikmanagement in der Automobilindustrie. Springer, *Berlin, Heidelberg*. Google Scholar
12. Lisa, M. E. (2021). Environmental sustainability in freight transportation logistics management. *International Encyclopedia of Transportation, 13*(2), 58–63. https://doi.org/10.1016/b978-0-08-102671-7.10220-9
13. Zhuravleva, L.V., Kirilin, V.D., Repnikov, P.O., & Usyukin, M.A. (2020). Integration analysis of "factories of the future" and "industry 4.0" technologies. *Information Technologies in Design and Production, 3*(179), 45–51. Google Scholar
14. Frohlich, M., & Westbrook, R. (2001). Arcs of integration: An international study of supply chain strategies. *Journal of Operations Management, 19*, 185–200. https://doi.org/10.1016/S0272-6963(00)00055-3
15. Yi-Hui, H., & Chieh-Yu, L. (2019). Logistics Service Type, Firm Size and the Reasons for Keeping Green Mindfulness. *Universal Journal of Management, 7*(3), 105–113. https://doi.org/10.13189/ujm.2019.07030
16. Lukinskiy, V.S., Lukinskiy, V.N., Pletneva, N.G (2022). Logistics and Supply Chain Management. *Liters*. (In Russ.). Google Scholar
17. Wang, Y., Iffikhar, A., Purvis, L., & Giannoccaro, I. (2022). The impact of supply chain complexities on supply chain resilience: The mediating effect of big data analytics. *Production Planning and Control, 9*(4), 3–31. https://doi.org/10.1080/09537287.2022.2032450
18. Porter, M. E. (1985). *The Competitive Advantage: Creating and Sustaining Superior Performance*. Free Press.
19. Chang, E., West, M., & Hanzic, M.A. (2006). A digital ecosystem for extended logistics enterprises e-Networks: Increasingly Volatile World, *Proceedings of the 11th International Workshop on Telework. Frederiction*, (pp.32–40). https://static.aminer.org/pdf/PDF/000/386/989/digital_ecosystems_a_next_generation_of_the_collaborative_environment.pdf

20. Shulzhenko, T.G., & Komissarov, M.A. (2018). Methods of business administration in the context of digitalization of logistics management *Bulletin of SPBSEU management faculty, 3*, 321–326. (In Russ.). Google Scholar
21. Selishcheva, T.A. (2021). The impact of the Covid-19 pandemic on the economies of the member countries of the Eurasian Economic Union and the prospects for its recovery. *Proceedings of St. Petersburg State University of Economics,* 3, 36–42. (In Russ.). Google Scholar
22. Samorodova, L.L., Shutko, L.G., & Akunina, Y.S. (2019). Digital ecosystems and the economic complexity of the region as factors of innovative development. *Issues of the innovative economy,* 9, 401–410. (In Russ.). https://doi.org/10.18334/vinec.9.2.40607
23. Arenkova, I.A., Lezinoy, T.A., Tsenzharik, M.K., & Chernovoy, E.G. (2022). Business management in the digital economy: challenges and solutions. *Litres.* (In Russ.). Google Scholar
24. Kayikci, Y. (2018) Sustainability impact of digitization in logistics. *Procedia Manufacturing*, 21, 782–789. https://doi.org/10.1016/j.promfg.2018.02.184
25. Gviliya, N.A., Parfenov, A.V., & Shul'zhenko, T.G. (2019). Management of integrated inter-corporate logistics systems in the context of digital economy *Manager, 1*, 40–51 (In Russ.). https://doi.org/10.29141/2218-5003-2019-10-1-4 (In Russ.).
26. Kovalev, M.M., & Golovenchik, G.G. (2019). Digitalization of the Belarusian economy in modern conditions of globalization *Ed. center of BSU* (In Russ.). Google Scholar
27. Baranov, A.M. (2021). Modeling of outsourcing in the formation of cluster formations. *South Siberian Scientific Bulletin, 6*, 185–192. Google Scholar
28. Gviliya, N.A. (2018). Modern methods for assessing the level of digitalization of integrated inter-corporate logistics systems. *Regional problems of economic transformation, 8*(94), 121–128. (In Russ.). Google Scholar
29. Yandong, He, Fuli, Zhou, Mingyao, Qi, & Xu, Wang (2019). Joint distribution: Service paradigm, key technologies and its application in the context of Chinese express industry. *International Journal of Logistics Research and Applications*, *23*(6), 1–17. https://doi:https://doi.org/10.1080/13675567.2019.1667314
30. On the approval of the Concept for the Development of the Logistics System of the Republic of Belarus for the Period until 2030 (2022). *National Legal Internet Portal of the Republic of Belarus.* (In Russ.). https://pravo.by/document/?guid= 3961&p0=W22238552
31. Karpenko, E.M., & Karpenko, V.M. (2020). Criteria for assessing the effectivity of the functioning of the regional transport and logistics system. *Works of BSTU. Ser. 5, Economics and Management*, *2*(238), 84–90 (In Russ.). Google Scholar
32. Koroleva, A.A. (2019). Economic effects of digital logistics. *Bulletin of the Belarusian State University. Economy, 1*, 68–76. (In Russ.). Google Scholar
33. Belarus in numbers (2022). Minsk: *GU BelISA*. 44 p. (In Russ.). http://belisa.org.by/en/service/periodicals/chp/
34. Kuprevich, T.S. (2019). Methodology for assessing the impact of the digital economy on international cargo transportation. *Proceedings of Francisk Skorina Gomel State University, 5*(116), 143–148. (In Russ.). Google Scholar

Digital Model of a Transport Enterprise: The Role of Intensity and Operating Conditions of Vehicles

Evgeniy Kozin

Abstract This paper presents a digital simulation model of a motor transport enterprise, which is part of a decision support system for enterprise management. The model is built using the Python programming language and implements the concept of a digital twin of a transport enterprise. The model is based on the principle of a queuing system and allows to simulate changes in the technical condition of the vehicle fleet, simulate maintenance and repair of vehicles, carry out resource planning for vehicles, and manage the age structure of the fleet. With the help of the developed model, it is possible to search for solutions for the development of an enterprise within the framework of solving a step-by-step inverse problem of multicriteria optimization of mathematical programming. The user of the system enters the performance indicators of the enterprise and has the opportunity to evaluate the possible parameters of the enterprise when one or more target indicators change. The result of the system operation is a list of recommended values of indicators, following which will allow achieving the goal set by the user related to achieving economic benefits or reducing the costs of the operation of the enterprise. The program is intended for managers and engineering and technical workers of vehicle service enterprises for forecasting activities, forming business plans, or an enterprise development strategy.

Keywords Digital twin · Transport enterprise · Simulation model · Fleet of vehicles

1 Introduction

One of the important and urgent problems for the management of motor transport enterprises now is the presence of a large number of factors that complicate the decision-making process for the management of motor transport enterprises and forecasting their commercial activities. At the same time, the costs of maintenance and repair of vehicle fleet, spare parts, and the maintenance facilities have a large

E. Kozin (✉)
Industrial University of Tyumen, 38 Volodarskogo Street, Tyumen 625000, Russian Federation
e-mail: eskozin@mail.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_19

weight in the cost of road transportation. Surveys conducted among the management of enterprises made it possible to conclude that there is a need to digitalize the processes of collecting and analyzing data and using modeling tools as one of the ways to make managerial decisions.

Quality indicators characterize the ability of the car to meet certain needs when used for its intended purpose. Consequently, the questions of the regularities of changes in the quality of cars have always been in the focus of scientific interests of various researchers. In the theory of technical operation of cars, six types of such patterns are defined: Patterns of changes in the quality of cars by operating time; patterns of random processes of changing the quality of cars; patterns of change in indicators of group behavior of cars by operating time; patterns of influence of operating conditions on the quality of cars; patterns of change in the quality of cars over time; patterns of change in indicators of group behavior of cars over time. The patterns of types 1, 2, 4, and 5 are the most studied. At the same time, within the framework of enterprise management and the current level of information technology development, the application prospects are the least studied patterns of changes in the group behavior of cars (patterns of types 3 and 6), which allow predicting the flow of requirements for maintenance, repairs, logistics, and other areas of activity transport company.

Thus, the scientific problem can be formulated as follows: Within the framework of the modern fleet management paradigm, the patterns of changes in the indicators of the group behavior of cars over time have not been established.

The purpose of this study is to develop a simulation model of a motor transport enterprise, which is based on the patterns of changes in the quality of vehicles. This model is a part of the decision support system together with the recommender system module and the information analysis and visualization module. The work is aimed at establishing patterns that form the flow of requirements for enterprise resource management.

Simulation modeling can be used to evaluate the processes of changing the quality of cars. It allows you to evaluate various options for combinations of factors, to form forecasts about the values of car quality indicators. On the basis of simulation models, it is possible to evaluate and predict the management processes of a motor transport enterprise: From the parameters of the technical operation of cars to the financial and economic indicators of the enterprise's activities related to cars and special vehicles [33]. Such simulation models can be used as part of decision support systems, which have been increasing in importance and application prospects in the last few years. On their basis, it is possible to train models based on artificial neural networks technologies, verifying them on real data from enterprises. Establishing patterns of changes in the quality of cars and their integration into a simulation model will improve the accuracy of modeling and create an effective tool for managing a modern enterprise using information technology.

The scientific novelty of the study is as follows: Development of the concept of a digital twin of a motor transport enterprise, which synthesizes methods for managing the technical operation of vehicles, taking into account the intensity and operating conditions, and the technical capabilities of the development and design tools for software products in the field of working with data; establishing patterns of changes in the indicators of group behavior of cars in terms of operating time and time and, on this basis, increasing the efficiency of managing a motor transport enterprise.

2 Literature Review

Many researchers emphasize the importance of fleet management processes for various types of industry, since transportation plays a key role in the continuity of production processes [7]. At the same time, to ensure the readiness of the fleet, considerable attention should be paid to timely maintenance and repair of equipment [24]. Due to the influence of random factors on the reliability of the fleet, stochastic models can be applied to manage the readiness of the fleet [14, 22]. Such models can take into account the uncertainty of demand for vehicles [23], and also be the basis for generating and processing big data [4, 34], for managing and coordinating the car fleet [3, 28], and for determining the optimal size of the fleet [27].

Simulation models can be used to predict the state of the fleet of vehicles in order to improve the efficiency of its management [15, 25, 26]. The issues of simulation modeling of cars, as well as the processes of changing the quality of cars, are described in sufficient detail in [8, 16, 21]. Models allow you to set the reliability parameters of vehicles [2, 17], plan car maintenance [13]. At the same time, the authors emphasize the prospects of using the patterns of changes in the indicators of the group behavior of cars over time, considering the system "Car – operating conditions" [35]. Simulation models can also be used for strategic planning of enterprises, for example, to justify a car maintenance strategy [5, 9, 29, 31].

One of the modern stages in the evolution of simulation modeling of technological processes is the digital twin [1, 30]. Digital twins are used for forecasting [11], modeling of the work of enterprises [12, 20].

At the same time, the vehicle fleet cannot be considered separately from the parameters of the main production in which it is involved [18]. This may be reflected by seasonal fluctuations in the intensity and operating conditions of vehicles. With regard to modeling the operation of a motor transport enterprise, the concept of a virtual or digital environment for the functioning of an enterprise can be used, within which it is possible to simulate its various states without the risk of errors in experiments on a real enterprise [19].

At the same time, analytical studies have shown the absence of simulation models that describe the operation of motor transport enterprises, taking into account the intensity and operating conditions.

3 Materials and Methods

The study used the basic statements of the theory of technical operation of road transport. An external customer generates a flow of requirements for vehicles, i.e. determines the intensity and conditions of operation of vehicles. The model takes into account two technical states of the vehicle: Operational and faulty. When the car is in working condition, it performs transport work. In this case, there is an increment in the daily operating time (mileage) of the car. For each unit of model time, the operating time is compared with the interval between scheduled maintenance and with the time between failures. The frequency of maintenance is determined by the maintenance and repair system, as well as the recommendations of the manufacturer. The model used a preventive maintenance and repair system. When modeling, the condition was taken into account that the car must be serviced and repaired with a given indicator of the quality of work.

The failure puts the car in an inoperable state, after which it is placed in the repair zone, where the failure is eliminated within a specified time. After the failure is eliminated, the car is transferred to a working state and returns to the line again. The intensity and operating conditions are set as initial parameters using harmonic mathematical models and random variables. The maintenance and repair subsystem is a multichannel queuing system with a queue [6]. The flow of requests to the system is generated by the vehicle operation module. The intensities of the flow of receipt of applications, the flow of service are random variables with user-defined distribution laws.

Technically, the simulation process was implemented using the *Python* programming language in the *IPython* programming environment using the *Jupyter Notebook*. The model is formed using the principles of object-oriented programming, where one car is an object that has attributes (for example, age, manufacturer, and model) and methods (in work or under repair). With each iteration of the model, a given number of such objects is generated, simulating the operation of a fleet of vehicles. According to the results of a large number of iterations of the model, the spread of random values of the variables is averaged and allows to interpret the results. The collection of statistical data on the operation of the model is implemented using the *Numpy* framework and *Pandas*.

The results were visualized using the *Matplotlib* package and *Seaborn*. Modeling of random variables is carried out using simulation within the framework of the theory of operations research and was implemented using the Random library. According to the results of the model, a flow of requirements for spare parts for cars is formed. The optimal order quantity was determined using the economic order quantity (EOQ) or *Wilson* model. This takes into account the cost of maintaining a unit of stock and the execution of one order. The optimal number of car maintenance and repair workshops (or units within one workshop) was determined using a feasibility study [10]. The method involves finding the extremum point of the function, which is the sum of the costs for the operation of units and the losses from waiting for requests in the queue or requests that have left the queue. The resulting simulation model is integrated into the management decision support system, which operates on the basis of a step-by-step inverse problem of multicriteria optimization of mathematical programming. The system can serve as the basis for business planning of the organization's processes.

4 Theory and Calculation

The algorithm of the simulation model of the technical operation of the vehicle fleet is considered in Fig. 1.

The model is based on the intensity generator of vehicle operation for each unit of model time. The operating time generated by the model is compared with the current quality level of the car, also generated by the model and expressed by the value of the probability of failure, taking into account the intensity and operating conditions. If the daily operating time of the vehicle exceeds the threshold value of failure, then the failure counter is activated, and the equipment is transferred to a faulty state.

This takes into account the age of the car, which also affects the quality indicators. The car is in a faulty state during the repair, after which it goes into working condition and is again sent to the line. The model allows at the macro level to carry out enterprise resource planning and evaluate the results of management decisions.

The motor transport enterprise carries out resource planning in time, as a rule, within a calendar year. At the same time, the quality indicators of cars change according to the operating time (mileage). To do this, the model must include patterns of change in operating time over time and quality over operating time. At the same time, the operating conditions also affect the change in the quality indicators of cars.

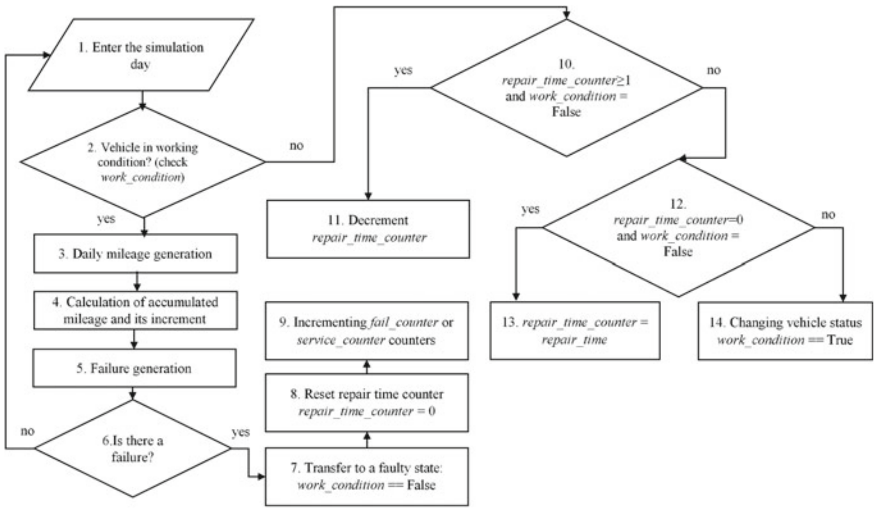

Fig. 1 Algorithm for the simulation model of car operation

In the works of modern researchers, it was revealed that the reliability of cars changes under the influence of natural and climatic factors, road conditions and some other indicators. The model determines several different factors that characterize the operating conditions, as well as the type and parameters of the functions that describe them.

In general, the process of changing the quality of a car over time *T* can be described by a function of the initial quality indicator set by the manufacturer *Yi*, the intensity *L* and operating conditions *X*:

$$Y = f[Yi, L(T); X(T)]. \tag{1}$$

With a nominal quality indicator known in advance, the simultaneous influence of intensity and operating conditions on the quality *Y* of cars for simulation conditions is determined by an additive model that takes into account their equivalent influence and averages their values.

$$Y = (a \cdot 1 + b \cdot \frac{\sum_{i-1}^{n} (X_1 + ...X_n)}{n} / 2), \tag{2}$$

where *a, b* is the coefficients of significance of the factor (weights); *n* is the number of factors characterizing the operating conditions *X*.

However, based on statistical data, the user can make adjustments and set the weights of the formula indicators and even the type of the model itself.

Since the main production, which forms the demand for car operation, often has periods of increase and decrease in activity, the intensity of car operation for the conditions of the model is usually described by harmonic models of the form:

$$Y_i = Y_0 + \sum_{k=1}^{g} A_{Yk} \mathrm{Cos}(m(kT_i - T_{0k})), \tag{3}$$

where Y_0 is the average value of *Y* per cycle; *k* is harmonic number; *g* is the number of harmonics; A_{Yk} is oscillation half-amplitude of the *k*-th harmonic; *m* is interval between T_i and T_{i+1} in degrees; T_{0k} is initial phase of oscillation in degrees.

It should be noted that some operating conditions can also be adequately described by the harmonic models presented above. This may be applicable, for example, to natural and climatic conditions, road infrastructure factors. Other factors characterizing the operating conditions can be described by mathematical models of other types: Linear, quadratic, exponential, power, etc.

For the conditions of modeling the regularities of changes in the quality indicator of a car by operating time, according to the implementation of typical models was adopted. These are models that provide a smooth and monotonic change in the quality index, or a smooth non-monotonous or stepwise change, or the absence of a relationship between quality and operating time.

To take into account the impact of random processes on the change in the quality of cars, a random component was added to the model, which has a user-defined distribution law between the given values. As the initial data for modeling, a fleet of 40 vehicles with a pronounced seasonality in the intensity of operation, described by harmonic models, was chosen. The average age of the fleet was about 10 years, and the average value of the interval between failures was 5,000 km. The service interval is 15,000 km. The duration of maintenance and troubleshooting was about 3 days. Random variables were distributed according to normal or uniform distribution laws. The simulation period was one year.

5 Results and Discussion

A graphical display of the results of modeling the patterns of changes in the quality of cars from the intensity of operation is shown in Fig. 2.

Based on the initial conditions of the presented iteration of the model, the car is not used as intensively in summer as in the rest of the year, while the peak of intensity occurs in winter. This is typical, for example, for special vehicles in the oil and gas sector. The intensity of operation should be understood as the rate of increment of the vehicle's operating time per unit of time, usually a month. With different intensity of operation, the quality indicators of the car also change. Thus, at high intensity, the moments of failure are reached faster, which will affect the overall level of fleet readiness.

The process of changing the quality of a car under the influence of operating conditions, which also change over time, is modeled in a similar way. A graphical representation of the change in the quality indicator of a car over time when it is affected by intensity and operating conditions together (lower part) and separately (top and center) is shown in Fig. 3.

The figure shows a situation where the conditions and intensity of operation have the opposite effect on the quality in the same seasons of the year, which determines

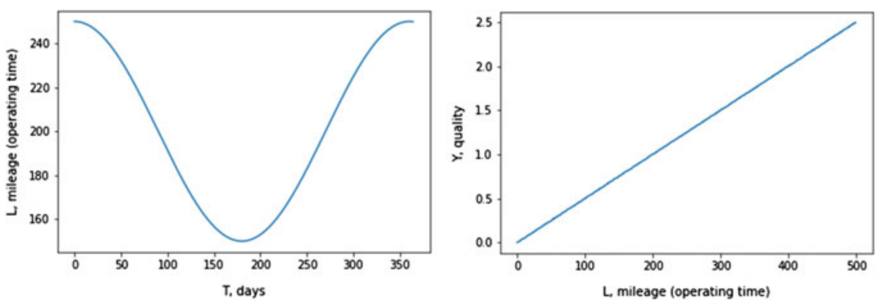

Fig. 2 Modeling the patterns of changes in the operating time of a car over time and the quality of a car by operating time

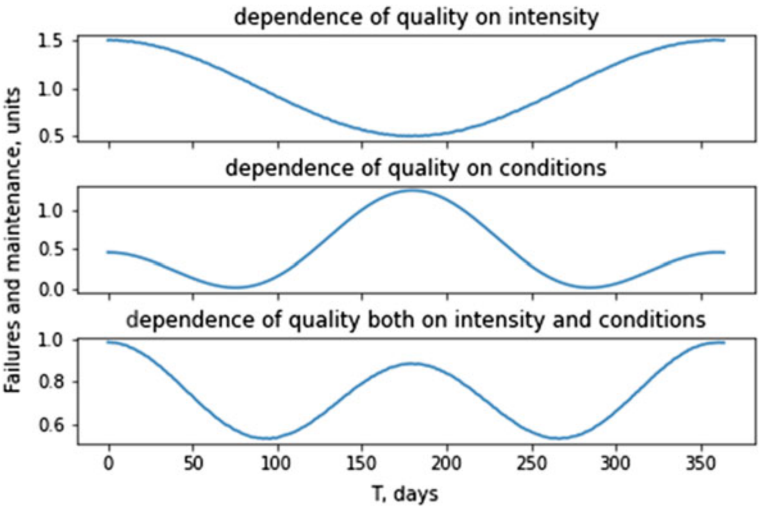

Fig. 3 Modeling patterns of quality changes from operating conditions and from time, subject to the equivalent influence of these indicators

the form of the resulting dependence with several maximum points – in winter and summer. Obviously, the technical service of the enterprise must be ready to ensure the readiness of vehicles in both of these periods.

When performing a given number of iterations, the simulation model for each vehicle allows to analyze the results of its operation by visualizing the accumulated mileage, intensity of operation, the time of occurrence of failures, and putting into maintenance (Fig. 4).

For the car shown in Fig. 4, the intensity of its operation decreases in the summer, while most failures are associated with periods of the most intensive operation. At the time of failure, the car is being repaired, and there is no increase in daily mileage on the graph. The moments of sending the car to the maintenance area upon reaching the planned mileage are distributed relatively evenly throughout the year.

For the management of the enterprise, the distribution of failures of the entire fleet of equipment during the year is interesting. This indicator is the sum of the number of failures of each car in the fleet. Fig. 4 (below) shows the simulation results for failures and maintenance requests for a fleet of 40 vehicles over one calendar year.

Seasonality characteristic for each individual car is also observed in the distribution of the total number of failures – two peaks are clearly visible on the graph: From February to March and from July to September.

These data are an important indicator for planning the work of the enterprise as a whole at the strategic and tactical level: Management of the workshop (production base) for the maintenance and repair of vehicles; planning the supply of spare parts and materials; managing the age structure of the park. These subprocesses are implemented in the simulation model and will be discussed below.

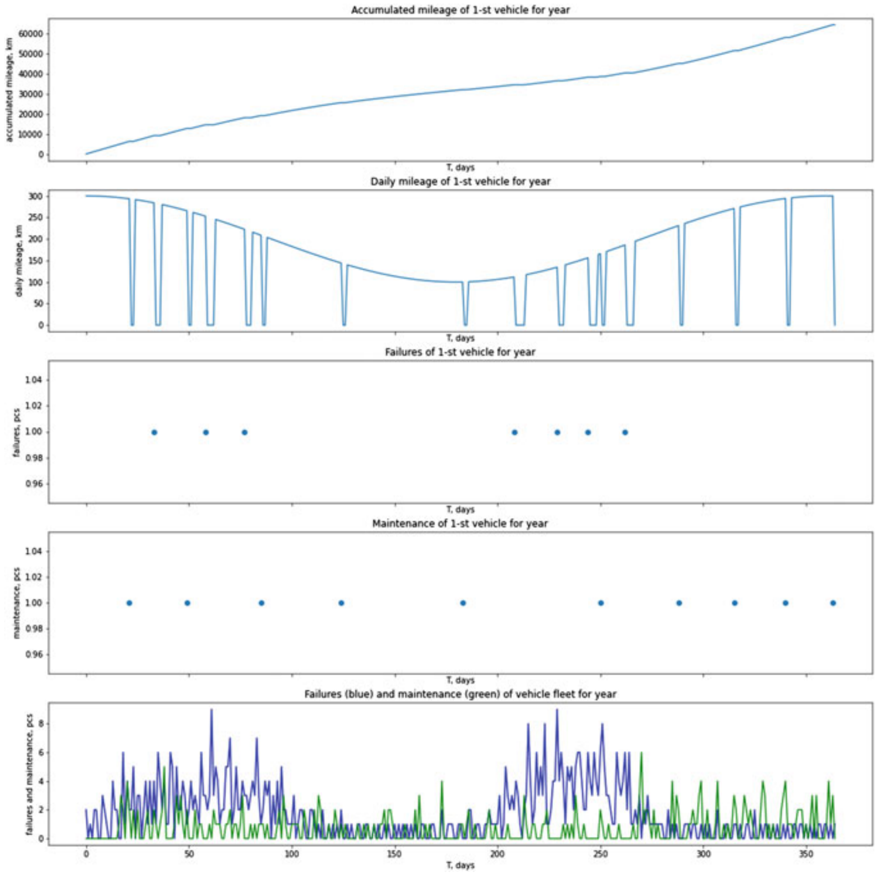

Fig. 4 Simulation of the operation of one car, taking into account the intensity and operating conditions

The production and technical base is a multi-channel queuing system, the channel of which is a workshop (or a single unit) equipped with personnel and equipment for car maintenance and repair [32]. The intensity of receipt of applications is due to the vehicle operation module. According to systems theory, this information enters the input of the system. Each channel has a certain complexity of request processing, which can also be set by the user. Usually it depends on the type of failure, the normative complexity of the work, the equipment of the unit and some random component. The output of the system is the optimal number of units (workshops) that can process the entire flow of incoming requests without queuing and rejecting requests, and also satisfies the established economic criteria for the cost of a unit of time for a workshop and the losses associated with idle requests waiting for service. This method is called techno-economic.

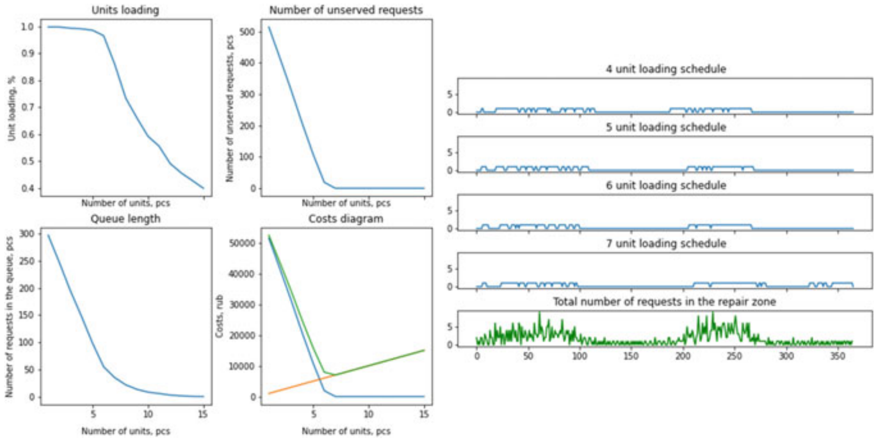

Fig. 5 Determining the load and finding the optimal number of workshops for car repair during the year for a fleet of 40 vehicles

The results of modeling the operation of the production base for the maintenance and repair of vehicles are shown in Fig. 5.

For the given modeling conditions, the optimal will be the presence of 7 units, which corresponds to the minimum point of the total cost curve, which is green in the graph on the left side of Fig. 5.

The model contains an algorithm for leveling the loading of units to avoid overloading the first units and underloading the last ones. This allows you to reduce the load factor of units and use their working time more efficiently. The visualization of the degree of loading of units during the year is shown in Fig. 5 on the right, where 1 is 100% loading.

An important element in ensuring the technical readiness of the fleet of vehicles is the efficient operation of the logistics service of the enterprise. This service determines the optimal order size for spare parts, forms a delivery schedule, taking into account the minimum insurance stock size. At the same time, planning should be linked to the types of vehicle failures and the intensity of their occurrence.

The simulation model was based on an algorithm for modeling the optimal size and frequency of ordering spare parts according to the technical and economic method (EOQ-model or Wilson's formula). The model takes into account the costs of storage and implementation of the order. The simulation results for a fleet of 40 vehicles and the previously determined intensity of the formation of requests for repairs are shown in Fig. 6.

For the conditions of the model, the optimal order size is 70 units, the frequency of deliveries for this order will be 10 times a year. The distribution by type of spare parts for the specified example was not carried out.

The model allows assessing the change in the readiness indicators of the car fleet depending on its average age. To do this, the operation of the fleet for a period of 10–15 years is modeled, after which the average daily mileage of cars, the average

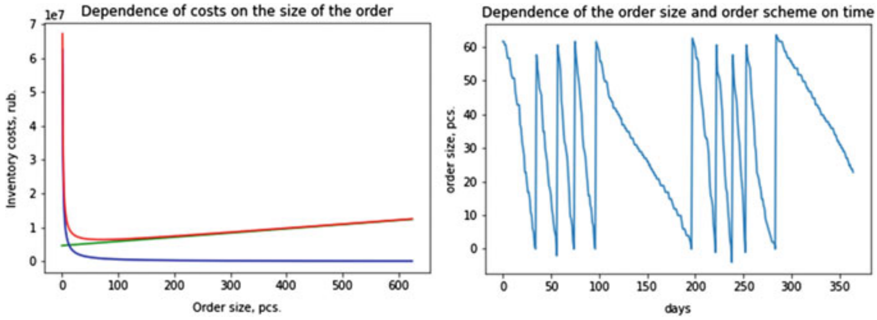

Fig. 6 Modeling the size of the order and the frequency of deliveries of spare parts

annual number of failures, the number of days in operation and a number of other indicators are estimated. For the simulation conditions, an increase in the average age of the park from 10 to 20 years is noticeable. At the same time, the average annual mileage decreases, as the number of vehicle failures caused by the aging of the fleet increases. This also affects the average number of working days per year, which also decreases markedly. The presented module will allow assessing the impact of the age of the fleet of vehicles on the management of other production processes of the enterprise (Fig. 7).

For example, to estimate the increase in the load of the repair area, which, obviously, may entail additional costs for personnel and technological equipment for car repair. In addition, it will allow evaluating various fleet renewal strategies and vehicle service management strategies, for example, involving contractors and abandoning their own repair areas.

When added to the model of economic parameters, it can serve as a tool for planning and evaluating the effectiveness of enterprise services.

The limitations of the model are due to the parameters of the current level of its detailing and allow the formation of forecasts in the framework of the strategic planning of the activities of a motor transport enterprise.

6 Conclusions

Thus, as a result of the research, a simulation model for the operation of the fleet of vehicles was developed. The model is implemented using Python programming tools, it is based on the patterns of changes in the quality of cars of 1–6 types. Algorithmically, the model is a queuing system that can be in several states, passing into each other sequentially with the intensity of the flow of requests λ and the intensity of the flow of services μ. The first module of the system is the simulation of the fleet operation. This module generates a flow of requirements to other systems of

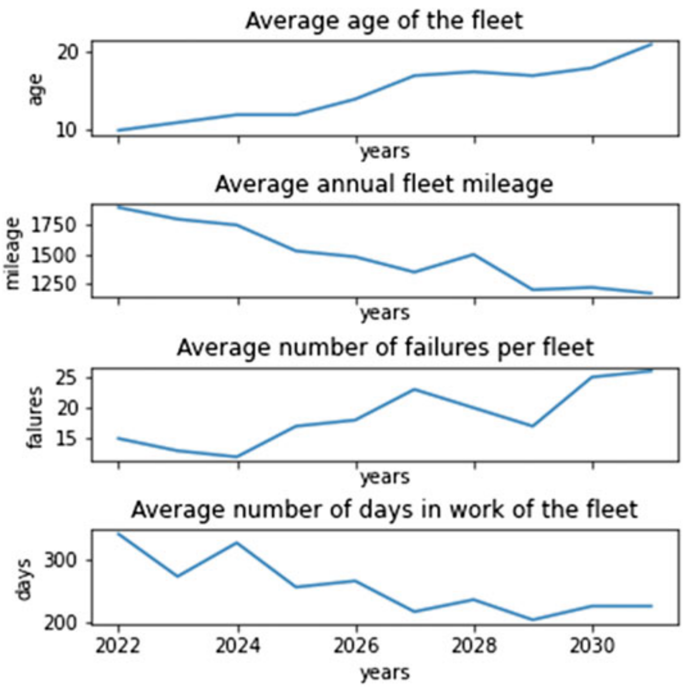

Fig. 7 Modeling the work of the fleet of vehicles for a long period of time

the model, simulating the work of various services of a motor transport enterprise – from the technical service for maintaining vehicles in good condition to the logistics and supply service of the enterprise. At this stage, the model implements modules for determining the optimal number of workshops for servicing and repairing vehicles, determining the optimal stock size and frequency of ordering spare parts, as well as a module for managing the age of the fleet. In the future, processes describing the operation of other enterprise services, as well as financial and economic indicators will be added to the model to provide the possibility of economic optimization of processes based on the use of the objective function.

Further research directions are as follows: Formation of a classification set of features that characterize the management patterns of a modern motor transport enterprise to ensure the generation of options for making managerial decisions in the framework of ensuring the transition "before – became"; expanding the capabilities of the simulation model by adding other areas of activity of the technical service of the motor transport enterprise to it: The financial and economic service, the personnel management service, the process of organizing maintenance and repair of vehicles, expanding the simulated parameters of the production and technical base of the enterprise (technological equipment, premises and their layouts and etc.).

References

1. Aivaliotis, P., Georgoulias, K., & Chryssolouris, G. (2019). The use of Digital Twin for predictive maintenance in manufacturing. *International Journal of Computer Integrated Manufacturing, 32*(11), 1067–1080. https://doi.org/10.1080/0951192X.2019.1686173
2. Andrzejczak, K., Młyńczak, M. (2018). Poisson-distributed failures in the predicting of the cost of corrective maintenance. *Eksploatacja i Niezawodnosc*, *20*(4), 602–609. doi: https://doi.org/10.17531/EIN.2018.4.11.
3. Azad-Farsani, E., Abedini, S., Sardou, I. (2021). Optimal coordination of plug-in hybrid electric vehicles: A stochastic market-based approach. *Journal of Cleaner Production*, *321*. doi:https://doi.org/10.1016/J.JCLEPRO.2021.128990.
4. Bachechi, C., Po, L., Rollo, F. (2022). Big Data Analytics and Visualization in Traffic Monitoring. *Big Data Research*, *27*. doi:https://doi.org/10.1016/J.BDR.2021.100292.
5. Baklouti, A., Schutz, J., Dellagi, S., et al. (2022). Selling or leasing used vehicles considering their energetic type, the potential demand for leasing, and the expected maintenance costs. *Energy Reports, 8*, 1125–1135. https://doi.org/10.1016/J.EGYR.2022.07.074
6. Borucka, A., Niewczas, A., Hasilova, K. (2019). Forecasting the readiness of special vehicles using the semi-Markov model. *Eksploatacja i Niezawodnosc*, *21*(4), 662–669. doi:https://doi.org/10.17531/EIN.2019.4.16.
7. Brunheroto, P. H., Pepino, A. L. G., Deschamps, F., & Rocha Loures, E. F. (2022). Data analytics in fleet operations: A systematic literature review and workflow proposal. *Procedia CIRP, 107*, 1192–1197. https://doi.org/10.1016/J.PROCIR.2022.05.130
8. Carow, K., Cantwell, N., Ivanco, A., et al. (2022). High-fidelity heavy-duty vehicle modeling using sparse telematics data. *SAE Technical Papers*. https://doi.org/10.4271/2022-01-0527
9. Christer, A., Waller, W. (1984). An operational research approach to planned maintenance: Modelling p.M. for a vehicle fleet. *Journal of the Operational Research Society*, *35*(11), 967–984. doi:https://doi.org/10.1057/JORS.1984.193.
10. Dong, W., Liu, S., Yang, X. et al. (2019). Balancing reliability and maintenance cost rate of multi-state components with fault interval omission. *Eksploatacja i Niezawodnosc*, *21*(1), 37–45. doi:https://doi.org/10.17531/EIN.2019.1.5.
11. Eddy, C., Wagner, A., Wagner, J. et al. (2022). Application of a Digital Twin Virtual Engineering Tool for Ground Vehicle Maintenance Forecasting. *SAE Technical Paper Series*, *1*. doi:https://doi.org/10.4271/2022-01-0364.
12. Escriche, Lng. S., Royo, L., Ruperez, Lng. A. et al. (2021). A Digital Twin Based Approach for Simulation and Emulation of an Automotive Paint Workshop. *SAE Technical Papers*. doi:https://doi.org/10.4271/2021-01-0240.
13. García, C., Carrasco, J., Paredes, M., et al. (2022). Algorithm for assignment of maintenance activities through knowledge management. *Ingeniare, 30*(1), 57–68. https://doi.org/10.4067/S0718-33052022000100057
14. Gundegjerde, C., Halvorsen, I., Halvorsen-Weare, E., et al. (2015). A stochastic fleet size and mix model for maintenance operations at offshore wind farms. *Transportation Research Part C: Emerging Technologies, 52*, 74–92. https://doi.org/10.1016/J.TRC.2015.01.005
15. Hijjo, M., Klingler, A. (2021). Modeling and simulation of electric vehicle flexibility to support the local network. *SEST 2021 - 4th International Conference on Smart Energy Systems and Technologies*. doi: https://doi.org/10.1109/SEST50973.2021.9543258.
16. Hsieh, P., & Lu, M. (1990). Reliability estimation and failure prediction of vehicle systems and components. *SAE Technical Papers*. https://doi.org/10.4271/901740
17. Iscioglu, F., Kocak, A. (2019). Dynamic reliability analysis of a multi-state manufacturing system. *Eksploatacja i Niezawodnosc*, *21*(3), 451–459. doi:https://doi.org/10.17531/EIN.2019.3.11.
18. Izdebski M., Jacyna-Gołda, I., Nivette, M. et al. (2022). Selection of a fleet of vehicles for tasks based on the statistical characteristics of their operational parameters. *Eksploatacja i Niezawodnosc*, *24*(3), 407–418. doi: https://doi.org/10.17531/EIN.2022.3.2.

19. Jones, D., Snider, C., Nassehi, A., et al. (2020). Characterising the Digital Twin: A systematic literature review. *CIRP Journal of Manufacturing Science and Technology, 29*, 36–52. https://doi.org/10.1016/J.CIRPJ.2020.02.002
20. Lattanzi, L., Raffaeli, R., Peruzzini, M., et al. (2021). Digital twin for smart manufacturing: A review of concepts towards a practical industrial implementation. *International Journal of Computer Integrated Manufacturing, 34*(6), 567–597. https://doi.org/10.1080/0951192X.2021.1911003
21. Line, J., & Krishnan, G. (2008). Managing and predicting intermittent failures within lone life electronics. *IEEE Aerospace Conference Proceedings*. https://doi.org/10.1109/AERO.2008.4526629
22. List, G. F., Wood, B., Nozick, L. K., et al. (2003). Robust optimization for fleet planning under uncertainty. *Transportation Research Part E: Logistics and Transportation Review, 39*(3), 209–227. https://doi.org/10.1016/S1366-5545(02)00026-1
23. Repko, M. G. J., & Santos, B. F. (2017). Scenario tree airline fleet planning for demand uncertainty. *Journal of Air Transport Management, 65*, 198–208. https://doi.org/10.1016/J.JAIRTRAMAN.2017.06.010
24. Mechlia, M., Schutz, J., Dellagi, S. et al. (2021). Quasi-optimal sizing of a vehicle fleet considering environmental impact, maintenance, and eventual containment measures. *Sustainability (Switzerland)*, *13*(8). doi:https://doi.org/10.3390/SU13084384.
25. Migawa, K. (2012). Availability control for means of transport in decisive semi-markov models of exploitation process. *Archives of Transport, 24*(4), 497–508. https://doi.org/10.2478/V10174-012-0030-4
26. Oliskevych, M., Taran, I., Volkova, T. et al. (2022). Simulation of cargo delivery by road carrier: case study of the transportation company. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, *2*, 118–123. doi:https://doi.org/10.33271/NVNGU/2022-2/118.
27. Presser, D., Cafaro, V., & Cafaro, D. (2022). A stochastic fleet size and mix model for maintenance operations at offshore wind farms. *Computer Aided Chemical Engineering, 51*, 949–954. https://doi.org/10.1016/B978-0-323-95879-0.50159-4
28. Ribas-Xirgo, L. (2022). A state-based multi-agent system model of taxi fleets. *Multimedia Tools and Applications, 81*(3), 3515–3534. https://doi.org/10.1007/S11042-021-11607-3
29. Schutz, J., & Rezg, N. (2013). Maintenance strategy for leased equipment. *Computers and Industrial Engineering, 66*(3), 593–600. https://doi.org/10.1016/J.CIE.2013.05.004
30. Shikata, H., Yamashita, T., Arai, K., et al. (2019). Digital twin environment to integrate vehicle simulation and physical verification. *SEI Technical Review, 88*, 18–21.
31. Stasko, T., & Oliver Gao, H. (2012). Developing green fleet management strategies: Repair/retrofit/replacement decisions under environmental regulation. *Transportation Research Part A: Policy and Practice, 46*(8), 1216–1226. https://doi.org/10.1016/J.TRA.2012.05.012
32. Thomas, O., & Sobanjo, J. (2016). Semi-Markov decision process: A decision tool for transportation infrastructure management systems. *International Conference on Transportation and Development*. https://doi.org/10.1061/9780784479926.036
33. Timbario, T., Timbario, T., Laffen, M. et al. (2011). Methodology for calculating cost-per-mile for current and future vehicle powertrain technologies, with projections to 2024. *SAE Technical Papers*.
34. Walker, D., Ruane, M., Bacardit, J., et al. (2022). Insight from data analytics in a facilities management company. *Quality and Reliability Engineering International, 38*(3), 1416–1440. https://doi.org/10.1002/QRE.2994
35. Zakharov, N. S., Makarova, A. N., & Buzin, V. A. (2020). Basic simulation models of car failure flows. *IOP Conference Series: Earth and Environmental Science, 459*(4), 042084. https://doi.org/10.1088/1755-1315/459/4/042084

Building Intelligent Transport Systems of the Eurasian Economic Union Based on Optimal Management and Forecasting

Alexander Chupin, Petr Afonin, and Dmitry Morkovkin

Abstract The article presents the results of the analysis of existing national intelligent transport systems in the member states of the Eurasian Economic Union (EAEU). Currently, the development of intelligent transport systems (ITSs) is significantly limited by the difficulty of creating the control part of the system, which, except for the simplest cases of linear second-order objects, requires the use of functional converters of many variables or complex computing devices that solve the boundary problem. The authors have developed a scheme illustrating the realization of ITS optimal control based on a number of principles. This scheme shows the principal possibility of constructing ITSs of optimal control of n-order objects in which a set of predictive devices is used as the optimal regulator. World experience shows that one of the most important elements of the economy of states is the transport infrastructure. It largely determines the scale of production and trade. Due to the increasing requirements for the quality of automatic control processes in the transport infrastructure, ITSs are increasingly being used. ITS is the transport management using the information infrastructure. In other words, it is the use of a control system and an extensive class of speed-optimal systems. The purpose of the study is the development of ITSs in the EAEU countries by using the method of optimal management and forecasting. The paper is structured as follows. In Sect. 1, we describe the state of ITSs in the EAEU countries. In Sect. 2, we present a block diagram of the optimal ITS control system with single-coordinate prediction. Section 3 provides a description of various studies. And in Sect. 4, we conclude on the application of the optimal control and forecasting method.

A. Chupin (✉)
RUDN University, 6 Miklukho-Maklaya Str., Moscow, Russian Federation
e-mail: chupin-al@rudn.ru

P. Afonin
Saint Petersburg Electrotechnical University LETI, 5 Professora Popova Str., St. Petersburg, Russian Federation
e-mail: pnafonin@etu.ru

D. Morkovkin
Financial University Under the Government of the Russian Federation, 49 Leningradsky Prospekt, Moscow, Russian Federation
e-mail: morkovkinde@mail.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_20

Keywords Forecast · EAEU · Economic and mathematical modeling · Management · Intelligent transport systems

1 Introduction

The analysis of the existing national intelligent transport systems (ITSs) in the EAEU member countries and the development of coordinated approaches to their interaction will allow implementing a set of measures to justify the optimal cost, design, operation, and development of ITS projects.

Currently, the state policy in the field of information infrastructure in the transport sector in the Republic of Armenia is not built, i.e., the current strategic and program documents are not defined [7]. The Republic of Armenia has already approved the concept of "Smart City", which aims to improve the quality of life through the introduction and development of technological solutions.

As part of the development of transport infrastructure in the Republic of Armenia, a number of measures are being implemented, such as the program "New bus network, integrated system of fares and tickets", negotiations on the possibility of introducing a global navigation satellite system (GLONASS) and the electronic toll collection system "Platon".

In the Republic of Belarus, the state policy in the field of information infrastructure in the transport sector is defined by a number of legislative acts, conceptual and program documents [15].

Also, the Republic of Belarus is carrying out the following activities:

- unifying documents needed for the implementation of transport and logistics activities;
- developing logistics activities through the active use of innovative management technologies and automation;
- enhancing international cooperation in the field of logistics information exchange, sharing of best practices, scientific, technical, and educational cooperation;
- developing infrastructure and information and communication technology (ICT) in the field of logistics.

As early as in 2022, it is expected to form an intelligent transport system, which will be integrated with the transport systems of the EU and the EAEU, uniting road, rail, air, and water transport on the basis of a single information transport space [1, 9].

The Republic of Kazakhstan is actively working on the introduction of information systems in the road transport sector through the implementation of the state program "Digital Kazakhstan" [10].

Thus, in order to systematically integrate vehicles, infrastructure, users and information and communication technologies, certain steps are carried out to create an intelligent transport system, which consists of 11 components, with their phased implementation.

The first two components are a set of technical means that collect data from road users in Kazakhstan and control and monitor road traffic. The remaining road safety components will be introduced in stages.

The development of information systems in the road transport sector will improve the transit potential, form a world-class service infrastructure and networks of trade and logistics centers for multimodal transport, identify the needs for further development of infrastructure.

In the Kyrgyz Republic, the information infrastructure in the transport sector has two automated information systems, namely:

1. The Automated Information System “Electronic Transport Control” (AIS ETC).
2. The Dynamic System of Weight and Dimension Control of Vehicles in Traffic (DSVK).

In order to build an open and transparent state, improve the quality of life of its citizens, and improve conditions for business in the Kyrgyz Republic, a nationwide digital transformation program “Taza Koom” is being launched. It is a key component of the country’s Sustainable Development Strategy—2040, a strategy based on human capital and innovation, in harmony with the environment [11].

The strategy recognizes the importance of developing ICT, which is an integral part of the country’s economic and social development as it seeks to become an information society.

The information infrastructure in the transport sector of the Russian Federation is highly developed compared to the EAEU member countries. The definition of the term “ITS” is stipulated in the legislation of the Russian Federation. Thus, “The Strategy for Road Safety of the Russian Federation for 2018–2024” approved by the Government of the Russian Federation defines the term “ITS” in accordance with the country’s legislative framework and harmonized international standards [3].

Intelligent transport system is a management system that integrates modern information and telematics technologies and is designed for automated search and adoption to implement the most effective scenarios for managing the transport and road complex of the region, a particular vehicle or a group of vehicles to ensure a given population mobility, maximize the use of the road network, improve safety and efficiency of the transport process [4].

The Transport Strategy of the Russian Federation for the period up to 2030 provides a number of measures aimed at developing information infrastructure in the transport sector of the Russian Federation in various areas of security in the field of road transport [20]:

- implementation of intelligent transportation systems on the network of federal highways, where the highest level of traffic flows is observed;
- creation of intelligent transport systems using GLONASS and modern ICT, information standards and unified transport documents, ensuring the implementation of highly efficient commodity transport logistics technologies;

- stimulating the development and implementation of innovative transport and logistics technologies and intelligent transport systems that increase the availability and quality of freight transport;
- stimulating the development and implementation of innovative technologies and intelligent transport systems that increase the availability and quality of passenger transportation;
- integration of intelligent transport systems on the high-speed road network into the nationwide intelligent transport systems in the field of road sector management and organization of goods transportation logistics;
- ensuring traffic safety on the toll road network through the use of technical solutions that reduce the risk of accidents, including the use of road signs (counting variable information signs), markings, fences, modern elements of engineering equipment and road design, automated traffic control systems, and intelligent transportation systems;
- improving the safety of road transport and pedestrians by improving road traffic organization and the introduction of intelligent transport systems that provide management of traffic flows and vehicles, as well as timely (emergency) information and management of actions in incidents, emergencies, and emergencies;
- development and implementation of a new-generation on-board safety systems based on computer technology with elements of artificial intelligence;
- elaboration of the concept of development of intellectual transport systems in order to increase the efficiency of solving problems of transport complex of the Russian Federation. Creation of the regulatory framework (standards) in the development and interaction of intelligent transport systems;
- development of advanced requirements for vehicles equipped with on-board "intelligent" safety systems.

In accordance with the passport of the federal project "System-Wide Measures for the Development of Road Facilities" approved by the minutes of the meeting of the project committee on the national project "Safe and Quality Roads" dated December 20, 2018 No. 4, the following measures are planned to be implemented in the Russian Federation:

- introduction of intelligent transportation systems on public roads, focusing, among other things, on ensuring the movement of unmanned vehicles;
- introduction of intelligent transport systems that provide for automation of road traffic control processes in urban agglomerations;
- implementation of intelligent transport systems focused on the use of energy-saving technologies of road lighting.

Thus, the analysis shows that the development of the information infrastructure of the UTP of international road freight transport in the territory of the EAEU is currently at different levels. At the same time, the overall level of its development in each EAEU state and the degree of harmonization of national information infrastructures among themselves vary [17].

Table 1 Activities aimed at implementing a coordinated (harmonized) transport policy of member states in the field of road transport

Event	Implementation period	Responsible executor (developer of the draft document)	Planned result (document)
Preparation of proposals for the formation of a legal framework for the creation, development, and operation of the national network of intelligent transport systems of member states	2021–2022	Commission, Member states	Analytical report
Development of a draft concept for improving the interaction of the national ITS in the Union	2023	Commission, member states	Draft concept

At the same time, to implement a coordinated transport policy of the EAEU member states, a roadmap has been developed, which prescribes a number of activities (Table 1) [19].

The development of a speed-optimal ITS is now significantly limited by the difficulty of creating the control part of the system, which, except for the simplest cases of linear objects of second order, requires the use of functional transducers of many variables or complex computing devices that solve the boundary problem [5, 13, 16].

In this regard, new ways of constructing optimal control systems have been investigated recently. An analysis of control systems was carried out by [21], who proposed to search for the moment of switching the control action based on a fast-paced view of the family of phase trajectories (future trajectories of the object) under the assumption that this switching will occur at some point in the future. This principle was further developed by [8, 12], who replaced the search for the moment of switching by a sequential analysis of the phase trajectory sections obtained also at a fast rate, assuming that the control action switching occurred at the current moment in time. In this case, the actual switching is performed when the predicted trajectory passes through the origin of coordinates. The characteristics of these works are:

- prediction using big data with repeated solving of a set of future optimal trajectories of the object with checking each trajectory for compliance with the given boundary conditions;
- use of logic for second-order objects in the control system, designed for no more than one switching of the control action.

In this case, it is possible to realize an optimal control system for an $(n - 1)$ order object by having an optimal controller for an n-th order object and a predictive device. Applying the same principle sequentially to objects $(n - 1)$, $(n - 2)$ etc. up to and including the second order, we can construct an optimal system for an object of n-order, the control part of which consists of a set of predictive devices [14].

2 Background

Construction of ITS of optimal control by sequential lowering order and prediction. We consider objects described by a system of differential equations of the form:

$$\begin{aligned} x_1 &= f_1(x_1, u);\\ x_2 &= f_2(x_2, x_1);\\ &\ldots\ldots\ldots\ldots\ldots\ldots\\ x_n &= f_n(x_n, x_{n-1}),\\ u &= u(t) \text{ is control action and } |u(t)| \le 1. \end{aligned} \tag{1}$$

All functions f_i are assumed to be continuous and continuously differentiable with respect to x_i, x_{i-1}, and f_i is continuous with respect to u. It is also assumed that the partial derivatives $\frac{\partial f_i}{\partial x_{i-1}}$ and $\frac{\partial f_1}{\partial u}$ and do not change sign in the whole considered domain of change in the variables.

In addition, some may be x_k subject to restrictions of the type $|x_k| \le \overline{x_k}$ specifying the admissible range of states of the system in the phase space. The problem is to synthesize an ITS of control that provides a speed-optimal transfer of the object (1) from any initial state to an equilibrium state.

When solving this problem, the property of the structure of optimal processes in objects of type (1) is used, which consists in the fact that the trajectory of the optimal process consists of successive sections, at each of which the corresponding control coincides with the optimal control for a system of type (1), but having a smaller order than the initial one.

Figure 1 shows a block diagram illustrating the implementation of the ITS of optimal control based on the principles outlined above. This scheme consists of three main parts: a real object with an optimal (by $(n-1)$-order) regulator, a predictive device (Z), and a logic unit (Y).

The optimal regulator in the object ensures the optimal motion of the $(n-1)$-order object to the value of the coordinate x_{n-1}, set by the logic unit L. The predictor is a model of the object together with the coordinate $(n-1)$-optimal regulator (whose setting corresponds to the given coordinate value x_{n-1}), working at a fast pace and with solution repetition. Obtaining data on the object state at the beginning of each cycle of the solution, the predictor computes what value the coordinate x_n is, if, starting from the given place, the system of order $(n-1)$—to be transferred to the given equilibrium state in minimum time will reach.

The output signal u_Y of the logic block Y is determined depending on the mismatch between the given value of the n x_n—coordinate ass and its predicted value by the relation:

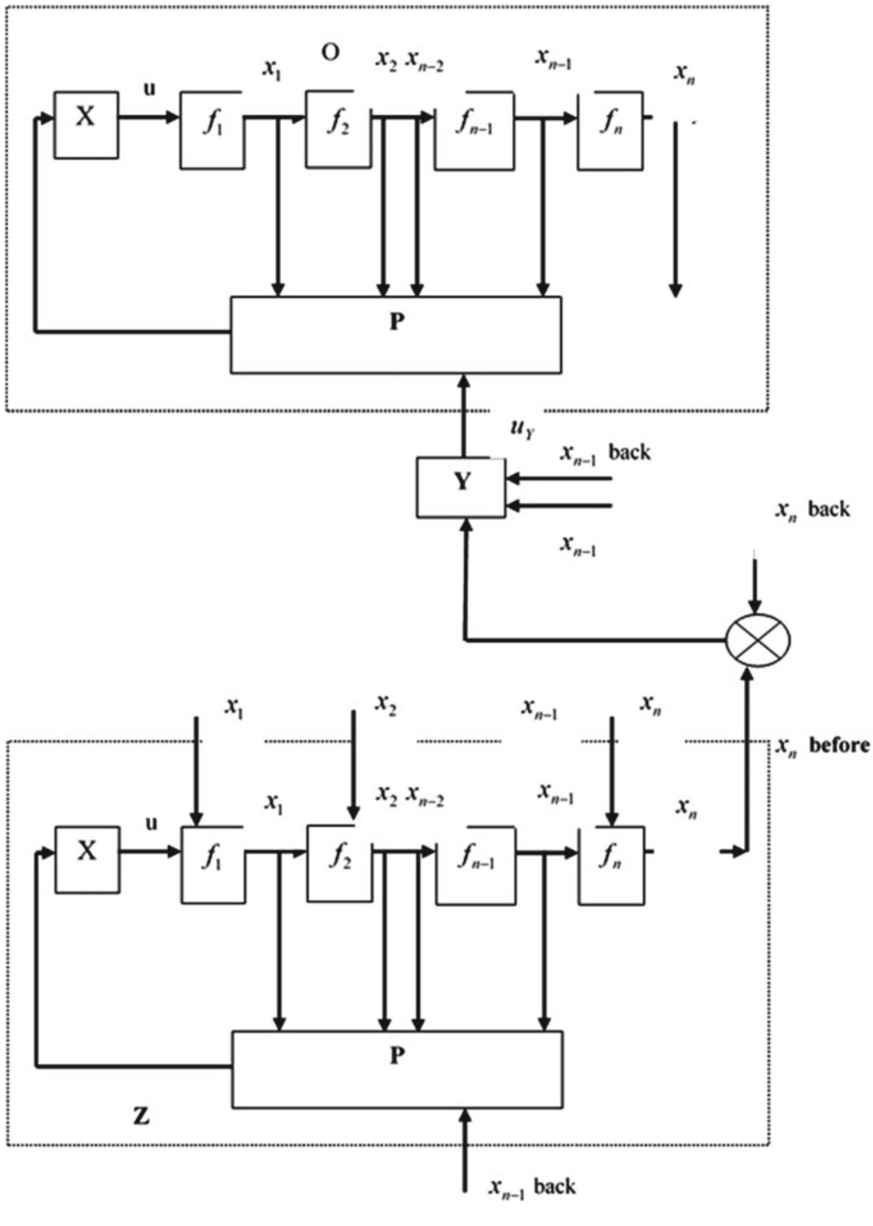

Fig. 1 Block diagram of the ITS of the optimal control system with prediction by one coordinate: O is the object with the optimal regulator; P is the optimal regulator of the $(n - 1)$ is order object; Z is the forecasting device; Y is the logic unit. *Source* Developed by the authors

$$u_Y = \begin{cases} \overline{x_{n-1}}\,\mathrm{sign}\,(x_n\,\mathrm{back} - x_n\,\mathrm{before}) * \mathrm{sign}\,\frac{\partial f_n}{\partial x_{n-1}}\ \mathrm{at}\, x_n\,\mathrm{before} \neq x_n\,\mathrm{back} \\ x_{n-1}\,\mathrm{back\ at}\, x_n\,\mathrm{before} = x_n\mathrm{back}. \end{cases} \quad (2)$$

When a set point $x_n$back is given, there is a mismatch between $x_n$back and $x_n$before, due to which the logical unit Y in accordance with (2) gives the optimal controller a set point for changing the coordinate x_{n-1} (taking into account the sign of the mismatch). The predictor continuously calculates the value of the coordinate.

For further synthesis of the x_{n-1}-order optimal regulator for the object and the prediction device, we can apply the same chain of reasoning which was used for the synthesis of the optimal system of the n-order, i.e., to carry out the transition to the system with the $(n-2)$-order optimal regulator and two prediction devices for coordinates x_n and x_{n-1}. In this case, it is natural that the predictor which produces the future value x_{n-1} of the coordinate and which is part of the device predicting the coordinate x_n must work at a faster rate than it does. Applying the above method $n-3$ sequentially once more, we come to an optimal control system $n-1$ containing a predicting device (Z_1, Z_2, ..., Z_{n-1}) with corresponding logical blocks (Y_1, Y_2, ..., Y_{n-1}) and containing no other optimal regulators. A characteristic feature of such a system is the optimal nature of the computed trajectories in any of the predictive devices that compute the motion of a sequentially shortening number of links at an ever-increasing rate.

The main features of the construction of analog predictive devices. A predictive device is a fast artificial intelligence, working with big data with solution repetition with acceleration processes (with respect to the object). Due to the need to have a high repetition rate of the solution with relatively low accuracy requirements, the use of analog principles for the construction of predictive devices seems most appropriate.

The repetition rate is chosen based on the admissible increment of the predicted value per solution stroke for accuracy reasons. The time scale is chosen on the basis of the repetition rate and the duration of the processes in the object predicted in this device.

3 Discussion

Sysoev et al. [18] discuss the possibility of using heterogeneous sources to calculate the necessary characteristics of the traffic flow, describe the existing approaches to aggregate information obtained from heterogeneous sources, and suggest a conceptual scheme of the module to aggregate heterogeneous data based on BigData and Data Mining methods.

Agarwal et al. [2] consider several parameters like image size and processing time and discuss several approaches of ALPR. The authors presented an improved hybrid fuzzy technique for Malaysian Automatic License Plate Recognition (M-ALPR) system. The benefits include less processing time and reduced program complexity.

According to Khamehchi et al. [6], the dead oil viscosity is a key parameter to numerous reservoir engineering problems such as modeling of (viscously-unstable) flow and transport in hydrocarbon reservoirs, sweep efficiency of enhanced oil recovery scenarios as well as the breakthrough times of the injected fluid. Prediction of this thermos-physical parameter, however, is of challenge due to nonlinear dependence on reservoir conditions as well as the crude oil characteristics. Previous studies have attempted to develop predictive empirical correlations or other intelligent models for dead oil viscosity; however, they often suffer from the lack of generality and required accuracy. In this work, based on a comprehensive databank from diverse geological sources, we develop three intelligent models—upon various schemes including simulated annealing programming, artificial neural network, and decision tree—for estimating dead oil viscosity. The latter may be used further for prediction of saturated and under-saturated oil viscosity as well. Our models function in wide range of temperatures and oil API gravity; hence, they can be employed as unified, general-in-purpose frameworks for universal prediction of dead oil viscosity. We compare the resulting novel frameworks with the pre-existing models available in the literature, and demonstrate the superiority of the decision tree-based model over others in terms of statistical (and graphical) error estimates as well as the (physical) validity of the model. The findings of this study can help for better understanding and more accurate management, simulation, and prediction in different oil fields.

4 Conclusion

The paper shows the principal possibility of constructing ITSs of optimal control of n-th order objects, in which a set of predictive devices is used as the optimal regulator. The synthesis of ITS of optimum control is carried out according to a certain scheme on the basis of the mathematical model of the object. It does not require complex calculations and simplifies the adjustment of the control system. The dissemination of this method to other, more complex, optimal control problems will require further research into the structural properties of optimal processes and the development of very fast and reliable mathematical modeling tools. Our work aims to show how the method of optimal control and forecasting can be used to develop intelligent transport systems of the EAEU member states. The method outlined above does not require a special additional self-adjusting system, the stability of which depends on the order of the equations of the object.

References

1. Abbasi, M., Najafi, A., Rafiee, M., Khosravi, M. R., Menon, V. G., & Muhammad, G. (2021). Efficient flow processing in 5g-envisioned SDN-based internet of vehicles using GPUs. *IEEE Transactions on Intelligent Transportation Systems, 22*(8), 5283–5292.

2. Agarwal, P., Chopra, K., Kashif, M., & Kumari, V. (2018). Implementing ALPR for detection of traffic violations: A step towards sustainability. *Procedia Computer Science, 132*, 738–743. https://doi.org/10.1016/j.procs.2018.05.085
3. Chupin, A. L., Chupina, Z. S., Morozova N. N., Vorotyntseva T. M., & Levinskay, E. V. (2019). Prediction model of the efficacy and the implementation time of transportation intelligent systems. In *IOP Conference Series: Materials Science and Engineering. II International Scientific Practical Conference Breakthrough Technologies and Communications in Industry and City, BTCI 2019* (p. 012006). https://doi.org/10.1088/1757-899X/828/1/012006
4. Evtiukov, S. A., Evtiukov, S. S., & Kurakina, E. V. (2020). Smart transport in road transport infrastructure. In *IOP Conference Series: Materials Science and Engineering* (Vol. *832*, p. 012094). https://doi.org/10.1088/1757-899X/832/1/012094
5. Giuffrida, M., Perotti, S., Tumino, A., & Villois, V. (2021). Developing a prototype platform to manage intelligent communication systems in intermodal transport. *Transportation Research Procedia, 55*, 1320–1327. https://doi.org/10.1016/j.trpro.2021.07.116
6. Khamehchi, E., Mahdiani, M. R., Amooie, M. A., & Hemmati-Sarapardeh, A. (2020). Modeling viscosity of light and intermediate dead oil systems using advanced computational frameworks and artificial neural networks. *Journal of Petroleum Science and Engineering, 193*https://doi.org/10.1016/j.petrol.2020.107388
7. Mammadov, I. B. ogly (2021). The Caspian vector of transport and logistics policy of the EAEU. *Contours of Global Transformations: Politics, Economy, Law, 14*(5), 177–192. https://doi.org/10.23932/2542-0240-2021-14-5-9
8. Mavrin, V., Magdin, K., Shepelev, V., & Danilov, I. (2020). Reduction of environmental impact from road transport using analysis and simulation methods. *Transportation Research Procedia, 50*, 451–457. https://doi.org/10.1016/j.trpro.2020.10.053
9. Temirbekova, A., & Dulambayeva, R. (2022). Development of the transport industry of the EAEU countries in the conditions of the pandemic. *Transportation Research Procedia, 63*, 1389–1395. https://doi.org/10.1016/j.trpro.2022.06.149
10. Ministry of Investment and Development of the Republic of Kazakhstan. http://mid.gov.kz/
11. Ministry of Transport and Roads of the Kyrgyz Republic (MTR). http://www.mtd.gov.kg/
12. Munusamy, M., Adhikari, M. A., Khan, V. G., Menon, S. N., Srirama, L. T., & Alex, M. R. (2021). Edge-centric secure service provisioning in IoT-enabled maritime transportation systems. *IEEE Trans. Intell. Transp. Syst.*, 1–10.https://doi.org/10.1109/TITS.2021.3102957
13. Muratova, E., Kravchenko, E., Sukhoveeva, A., & Andreeva, O. (2021). Information space of the economic management system in the business management system. In *E3S Web Conferences* (Vol. 273, p. 08088). https://doi.org/10.1051/e3sconf/202127308088
14. Pak, A. Y., Chupina, Z. S., Chupin, A. L., Fattyakhetdinova, V. R., & Shobekova, Sh. U. (2020, June 20). Methodological approach to the choice of a set of means for the automation of transport control operations at road checkpoints across the customs border of the EAEU (pp. 151–163). In: *Economic strategies of EEU: problems and innovations. Proceedings of the III All-Russian Scientific-Practical Conference.*
15. Resolution of the Council of Ministers of the Republic of Belarus of 14.10.2022 No. 692 “On amendments to the resolutions of the Council of Ministers of the Republic of Belarus of March 17, 2016. No. 206 and June 15, 2019 No. 395”. https://www.alta.ru/tamdoc/22bl0692/
16. Safiullin, R., Fedotov, V., & Marusin, A. (2020). Method to evaluate performance of measurement equipment in automated vehicle traffic control systems. *Transportation Research Procedia, 50*, 20–27. https://doi.org/10.1016/j.trpro.2020.10.003
17. Seliverstov, S. A, Seliverstov, Y. A., Titov, V. O., Vydrina, E. O, Gulyaevsky, S. E., & Vashchuk, A. E. (2020). Development of the structural scheme of the marine intelligent transport system of the Arctic region. *Marine Intellectual Technologies*, *1–1*(47), 84–98.
18. Sysoev, A., Khabibullina, E., Kadasev, D., & Voronin, N. (2020). Heterogeneous data aggregation schemes to determine traffic flow parameters in regional intelligent transportation systems. *Transportation Research Procedia, 45*, 507–513. https://doi.org/10.1016/j.trpro.2020.03.063
19. The concept of forming the Common Transport Space of the Eurasian Economic Community: approved by the decision of the Interstate Council of the Eurasian Economic Community of January 25, 2008 No. 374. http://www.evrazes.com/docs/view/68

20. Trofimenko, Y., Komkov, V., & Trofimenko, K. (2020). Forecast of energy consumption and greenhouse gas emissions by road transport in Russia up to 2050. *Transportation Research Procedia, 50*, 698–707. https://doi.org/10.1016/j.trpro.2020.10.082
21. Zhou, S., Sui, S., & Tong, S. (2022). Adaptive neural networks optimal control of permanent magnet synchronous motor system with state constraints. *Neurocomputing, 504*, 132–140. https://doi.org/10.1016/j.neucom.2022.06.114

Digital Technologies and Decision Support for Industrial Enterprises

Towards Viable Modelling for Robust Flow Shop Scheduling in Production Environments Under Uncertainty

Luca Fumagalli, Elisa Negri, Laura Cattaneo, Lorenzo Ragazzini, and Marco Macchi

Abstract The current work contributes to stochastic hybrid flow shop scheduling. After a thorough literature analysis, it is firstly evident that works on stochastic flow shop scheduling are still limited in number; moreover, they often rely on simplifying assumptions; eventually, they may lack in a full viability for industrial application of the proposed models or algorithms. Considering these limitations, the present work proposes a scheduling framework based on Discrete Event Simulation and on Genetic Algorithms. The work stems from a previously published work, therefore, contributes by identifying some inconsistencies in the original algorithm in the so called "limit cases". Overall, the paper proposes an alternative fitness function to avoid the generation of such inconsistencies; besides, it considers a realistic probability distribution to describe the stochastic processing times for robust scheduling of a hybrid flow shop. The end purpose is to move towards a viable application of optimization algorithms in industrial environments.

Keywords Scheduling · Uncertainty · Production management · Genetic algorithms

L. Fumagalli (✉) · E. Negri · L. Ragazzini · M. Macchi
Department of Management, Economics and Industrial Engineering, Politecnico Di Milano, Piazza Da Vinci 32, 20133 Milano, Italy
e-mail: luca1.fumagalli@polimi.it

E. Negri
e-mail: elisa.negri@polimi.it

L. Ragazzini
e-mail: lorenzo.ragazzini@polimi.it

M. Macchi
e-mail: marco.macchi@polimi.it

L. Cattaneo
School of Industrial Engineering, Università Carlo Cattaneo-LIUC, C.So Matteotti 22, 21053 Castellanza, Italy
e-mail: lcattaneo@liuc.it

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_21

1 Introduction

Scheduling is a decision-making process that is performed on a regular basis in manufacturing and service companies. It optimizes one or more objectives, by sequencing jobs, allocating jobs to resources, and selecting alternative resources among those capable to perform a job [1]. Due to its importance for industry, many efforts were made on scheduling problems in the past, to minimize the distance between the industrial application and the academic research works, that are often based on simplifying assumptions. Existing literature on scheduling proposes various approaches to scheduling problems, often based on heuristic or meta-heuristic. However, industrial practice rarely implements algorithmic optimization for the production scheduling, which is still often relying on experts' knowledge. Often this is due to the complexity in modelling the scheduling problem in the company, with all its variables and uncertainties, and to the long time it takes to run an optimization algorithm to find the optimal solution. Various works propose meta-heuristic approaches to the solution of scheduling problems and the genetic algorithms (GA) are discussed as a promising approach that is already validated in literature in a number of works. The present work focuses on the hybrid flow shop scheduling problem (HFSSP). This work starts with a thorough literature review of the previous works on GA-based scheduling of manufacturing systems, and the output of this review is a classification of GA applied to the different types of manufacturing systems. Then, the work identifies the research problems and gaps from literature to define the objectives of the present work. In order to specifically set the objectives of the work, a particular focus is provided on the paper by Chaari et al. [2], selected as a representative work potentially capable to guarantee industrial applicability but at the same time being a meaningful case for the need of adaptation so to solve the inconsistencies with respect to the real industrial case. The proposed GA-based and simulation-based scheduling framework is presented and thus implemented in a stochastic HFSSP application case, replicating one of the cases reported also in [2]. The calculations and results are provided, and the discussion and the concluding remarks are finally reported.

2 Background on Stochastic Scheduling Problems for Flow Shops

Flow shops are production system configurations characterized by a unidirectional and linear flow of production lots (all products meet production resources in the same order). Hybrid flow shops (HFS) consist of production stages, each of which may have several production resources working in parallel. In general, FSSP and HFSSP are well-known combinatorial optimization problems which are NP-hard and consequently many of the conducted studies were made utilizing heuristic and meta-heuristic techniques to solve it [3, 4]. Flow shops, as any other production environment in the real world, are subjected to uncertainty. According to Chaari, it is possible to qualify data as Uncertain, Incomplete or Imprecise [5]. Uncertainty means that doubts exist concerning the validity of knowledge or concerning the veracity of a proposition, Incompleteness means knowledge about system features lacks or is partial, Imprecision means problems exist in the knowledge statement.

Considering all the various types of input data, scheduling in the real world needs to consider reactivity, adaptability, and robustness that are of utmost importance in a dynamic environment with its inherent variabilities. In the light of this context, stochastic scheduling problems shall be addressed. Proactive (or robust) scheduling considers the variability sources to obtain schedules which are good also in the presence of disruptions, thus not requiring the generation of new schedules, that means that they can be adapted to external events with just few little changes.

Stochastic FSSP have been addressed by multiple authors. Contribution on the analysis of processing times was then provided by [2, 4, 6–19], while other authors focused on other types of features of the flow shop system like machines or equipment breakdowns [12, 15, 20–24], arrival of jobs, cancellation of jobs, jobs release [23]. The mentioned literature suggests that FSSP with stochastic processing times lacks efficient methods which can provide high-quality solutions both in terms of industrial value of the solutions and reduced computational time. The main gaps found in reviewing the literature are:

1. Gap 1: Most of the existing approaches are valid for small-size instances only.
2. Gap 2: Most of the works are too theoretical at the expenses of the industrial viability of the found solutions, thus lacking a full support to decision-makers. They mainly focus on the mathematical side of the optimization and modelling, even more they apply too severe assumptions that do not reflect the industrial reality.
3. Gap 3: it is worth noticing that most of the authors did not use simulation-based methods which allow to easily handle dependencies among processing times and use a wider range of probability distributions for representing the processing times.

3 Identification of Research Problem and Objectives of the Work

This work aims at contributing to the research on the stochastic proactive (robust) scheduling of flow shops by proposing a progress with respect to the results provided by Chaari [2], in which the authors studied the HFSSP considering different scenarios and modeled it by using sampled values of the processing times which follow a uniform distribution.

The approach proposed by [2] sometimes issues solutions that, although mathematically consistent with the fitness function, are not optimal from an industrial perspective. More specifically, this paper considers “limit cases” as cases when the proposed model is not able to properly identify the schedule that would be chosen by an industrial decision-maker among different alternatives. In fact, the algorithm in the paper is based upon a bi-objective function that minimizes simultaneously the makespan and its standard deviation. In the “limit cases”, the algorithm would prefer a solution with a low standard deviation and a high makespan, whereas from an industrial point of view other solutions with higher standard deviations but lower makespan could be preferred. This translates into the need of an improved fitness function that would better reflect the needs of industrial practitioners. Moreover, the work by Chaari [2] models the processing times as uniformly distributed, which is not realistic with respect to the actual behaviour of production resources. Overall, the approach proposed by Chaari [2] provide problems coherent with Gap 2 generally found in the literature review.

4 Proposed Framework

In order to propose a solution to reduce the mentioned inconsistencies, the objectives of this work are (i) to define a scheduling framework that combines the GA metaheuristic optimization and the production system Discrete Event Simulation (DES); (ii) to use the proposed scheduling framework to overcome the “limit cases” inconsistencies that are emerging from previous research works on the stochastic scheduling of HFS; (iii) to include a more realistic probability distribution to model the processing times.

The proposed scheduling framework is based on a metaheuristic optimization method, namely a GA, which is the central core of the scheduling framework itself, and on the DES simulation of the production system, which adds flexibility to it, leading to more flexible capability for the performance evaluation. In fact, on one hand, the proposed framework can be applied to various production systems by only changing the simulation model since the structure is always the same, as discussed by [25]; on the other hand, if the simulation model properly replicates the real production system, every possible model-based implementation or modification of circumstances is already contemplated whenever the production conditions are identified from field data acquisition. The choice of GA as metaheuristic algorithm is to allow to obtain a solution with a reduced computational time. This is the reason metaheuristic algorithms may be adopted in industrial environments.

Figure 1 depicts the structure of the proposed scheduling framework underlying its dual nature. This framework is in line with previous works [25–27]. The optimization process is iteratively guided by the GA loop which applies its own operators until the optimal solution is reached. At each iteration, the algorithm interacts with the DES simulation model which processes every individual created by the GA. At this point, the simulation is run for a specified number of scenarios to enable the statistical estimations of the system performances.

The performance values are then given back to the optimization domain where the process is repeated until the maximum number of generations, or the convergence criteria is reached.

The framework proposed in Fig. 1 includes the following elements:

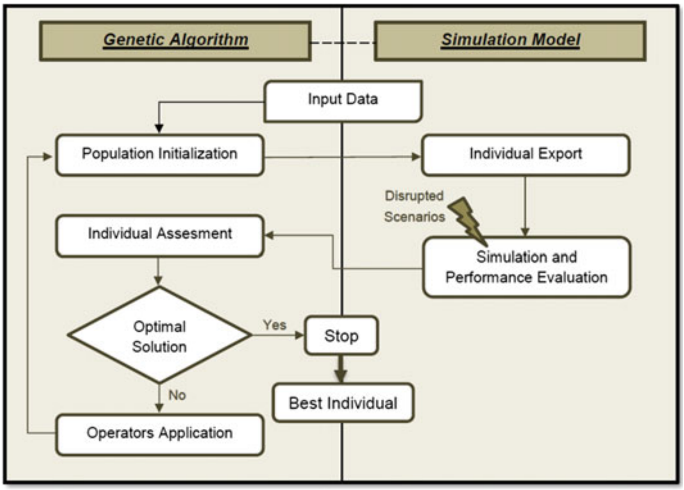

Fig. 1 Proposed scheduling framework

Input data: The problem consists in assigning jobs to stations at each stage knowing that all jobs are known before the processing starts.

DES Simulation and performance evaluation: The simulation model represents the production system on which the list of jobs must be scheduled. The simulation computes performance indicators of the input job sequence on the production system. The stochastic processing times introduced in the model are randomly generated according to a specific probability distribution and for each scheduling alternative a number of repetitions is carried out in order to have information on the average and variability of the computed indicators. Hence, the simulation model transmits the average and standard deviation of the performance indicators associated with each schedule to the GA.

Individual assessment: The assessment of each alternative is carried out through the computation of the fitness function which is an elaboration of the performance indicators values and variability provided by the simulation. The fitness function is highly problem dependent, and it must be customized according to the problem's parameters and constraints. A fitness value is then univocally associated to each individual. Although the scheduling framework is general and not production system type specific, it is here applied to solve HFSSP for a typical multi-stage flow shop, in order to make a progress from the contribution by [2], in which GA was used to create a robust scheduling for the stochastic HFS scheduling problem.

Chaari's investigation considered an initial deterministic scenario and other disrupted scenarios in which the stochasticity is introduced. The work aimed at minimizing the makespan of the initial scenario and the deviation between the makespan of all disrupted scenarios and the one of the initial scenario, in order to obtain a robust solution [2]. Therefore, the framework was adapted to one of the production systems

Table 1 Details of the implemented framework

Detail	Value
Implementation software of GA	MATLAB® (R2020a)
Implementation software of DES simulation	MATLAB/Simulink [30]
Crossover type in GA	Ordered two-point crossover
Selection approach in GA	Roulette Wheel + Fitness scaling technique

reported in [2], in order to be able to compare the main results. The HFS has five different stages, with one production resource in the first stage and two parallel identical production resources in the other stages, with inter-operational buffers between stages with infinite capacity. For more details, please consider [2].

The benchmark problems utilized are the ones suggested by Carlier and Néron [28]. These configurations imply ten jobs and five different stages, and the processing times uniformly lie in the interval between [3, 19]. Besides, also the number of disrupted scenarios N and the degree of uncertainty of the processing times α must be established. Lower bounds (LB) proposed by [29] for the HFS were considered. Details for the implementation of the framework are defined in Table 1.

5 Model Implementation and Experimental Results

After having replicated the results reported in [2] through the proposed framework, a new fitness function is proposed in order to propose a solution to handle the "limit cases" inconsistencies found in the robust solutions, in this way progressing the research on the problem. Finally, a new probability distribution is used to model the processing times in order to offer a more realistic behaviour of the schedules.

The evaluation of the results first uses the same fitness function as the work by Chaari [2].

$$f(x) = \gamma \frac{C_{max I}(x) - \text{LB}}{\text{LB}} + (1-\gamma)\frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(C_{\max_{\varepsilon_i}}(x) - C_{max I}(x))^2}}{\text{DEV\_MAX}(x^*)}$$

This is a bi-objective function that considers in the first term the minimization of the makespan of the initial scenario and in the second term the deviation between the makespan of all disrupted scenarios and the makespan of the initial scenario. The two terms are weighted with a γ coefficient. In details, C_{maxI} is the value of the makespan of the initial scenario I and *LB* is the lower bound of the initial scenario which is generated following the approach used by [29]. DEV_MAX(x^*) can be expressed as follows:

$$\text{DEV\_MAX}(x^*) = \max\left\{\left(C_{max I}\left(x^*\right) - C_{max I_{\min}}\left(x^*\right)\right), \left(C_{max I_{\max}}\left(x^*\right) - C_{max I}\left(x^*\right)\right)\right\}$$

where: (i) x^* is the best solution obtained for the initial scenario I, (ii) $C_{max\,I_{\min}}(x^*)$ is the makespan of the minimal processing time of jobs calculated from the initial scenario ($\text{PT}_{\min} = \text{PT} - \alpha\,\text{PT}$) and (iii) $C_{max\,I_{\max}}(x^*)$ is the makespan of the maximal processing time of job calculated from the initial scenario ($\text{PT}_{\max} = \text{PT} + \alpha\,\text{PT}$). For more details, refer to [2].

The number of considered scenarios is $S = 21$. One of them is the initial scenario I in which the processing times are deterministic, the remaining 20 scenarios are the disrupted scenarios with uniformly distributed processing times ($N = S - 1 = 20$). The choice of using $N = 20$ is in accordance with the values considered by [2] for this particular configuration of the HFS, thus allowing the possibility to compare the solutions found. This value is defined through a convergence test which is able to determine the optimal number of scenarios to be examined. The values used in this research work are: Total Scenarios $S = 21$, Population size = 40, # of Generations = 100, $A = 10\%$. For what concerns the results, the overall algorithm performs well for a significant number of runs. Nevertheless, sometimes the GA with the fitness function proposed by [2] proposes a solution that would not be the choice of an industrial practitioner. In fact, as the fitness function is set, in the "limit cases" it would give more importance to the standard deviation of the makespan, with respect to the makespan itself, which is the first relevant objective from an industrial point of view.

An example of the "limit cases" is shown in Table 2 and Fig. 2, with $\gamma = 0.7$. In fact, the bi-objective function chooses sequence A as optimal; while an industrial practitioner would prefer sequence B, where the makespan is always lower than sequence A. From a mathematical point of view, the fitness function is choosing a solution with a low standard deviation and a high makespan, that makes perfect sense according to the mathematical modelling, but would not be sensible from an industrial decision-making perspective. However, when the values are plotted as in Fig. 2, sequence B would be the choice from a decision-maker in industry, because the value of the makespan is always lower or at maximum a little bit higher than in sequence A. We could say that sequence A is dominated from an industrial viewpoint by sequence B.

In order to avoid falling in the "limit cases", the bi-objective function was converted into a mono-objective function, which considers both the makespan of the initial scenario and the deviation between the disrupted scenarios makespan and the initial scenario one. The main difference lies in the assignment of the weights, in this case the same for both the terms (i.e., a unitary value). Moreover, the normalization was removed with the purpose of finding a way to ensure that all the factors can be comparable in terms of the order of magnitude. The proposed mono-objective function is number.

$$f(x) = C_{max\,I}(x) + \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(C_{\max_{\varepsilon_i}}(x) - C_{max\,I}(x)\right)^2}$$

Table 2 Example of "limit cases" sequences

Sequence	A	B
Initial scenario makespan	132	130
Scenario	Makespan of the N disrupted scenarios	
1	129.8491	130.2064
2	132.9332	131.5229
3	133.6098	129.0564
4	133.1644	128.8059
5	134.3919	130.6297
6	130.1019	128.4979
7	132.9156	132.2244
8	131.5033	125.9583
9	133.2702	130.0923
10	128.4319	130.6501
11	130.6196	128.2441
12	133.7532	128.7908
13	130.4260	131.0432
14	133.9034	127.5773
15	134.5274	130.2257
16	133.9237	130.3034
17	132.5174	132.5597
18	131.6184	132.8778
19	129.8582	136.3195
20	131.7461	132.2973
Standard deviation	1.7765	2.2668

As for the bi-objective function previously reported in Eq., C_{maxI} is the value of the makespan of the initial scenario I and $C_{max_{\varepsilon i}}(x)$ is the makespan of the ε_i-th disrupted scenarios.

With this new approach, the scheduling framework makes a more industrially sound choice also in the "limit cases" situation, and all the results are shown in Table 2. As it is possible to see, the algorithm converges to populations with low fitness values. More important, it is possible to observe that the makespan of the initial scenario remains equal to 130 for all the tests performed. This value, as reported also in [2], corresponds to the value of the LB. This is a key result leading to conclude that the proposed algorithm chooses the best sequence viable for the industrial decision-maker. Indeed, the algorithm gives more importance to the makespan, but without neglecting the contribution of the stochasticity.

Since the model deals with stochastic processing times the trend of the best fitness values (red dots in Fig. 2) will always have a little fluctuation instead of

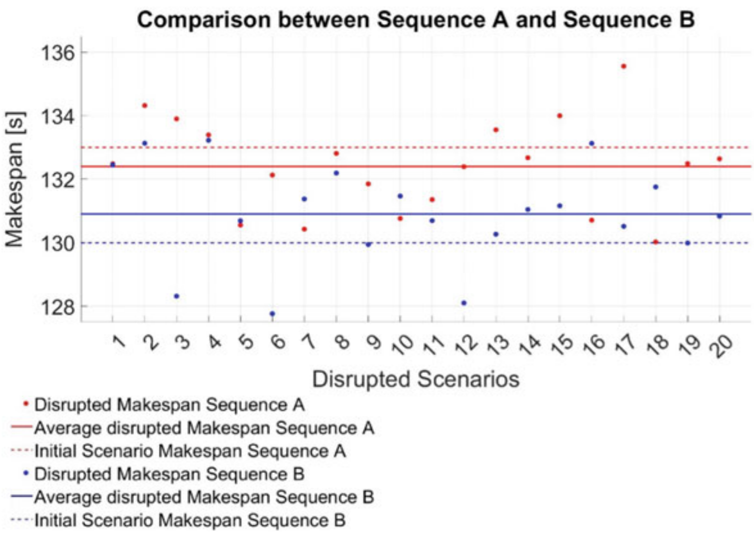

Fig. 2 Case limit example

having a flat plot as in the deterministic case. More tests have been performed also varying the value of α, which is a parameter characterizing the uniform distribution of the processing times. Most of the scientific studies on stochastic FSSP focused on exponential, uniform, and normal distributions for job processing times. None of these realistically describes the real behaviour of stochastic processing times. The lognormal distribution is considered to describe better the reality as it cannot be negative, and it is skewed to the right, so it is more suitable for representing the processing time than the distributions previously seen [3]. The present work thus proposes to improve the results by [2] also by substituting the uniform distribution with a lognormal distribution for processing times. Parameters are reported in Mean = 8,5, Variance = 24,08,334.

It was decided to keep the same processing time values as in the initial scenario of the uniform distribution case. Moreover, the mean and the standard deviation of the lognormal distributions are directly calculated from the uniform distribution values. The proposed scheduling framework, with the lognormal processing times, was tested for 20 runs and the results are shown in Table 3.

The fitness values in the lognormal distribution case vary less than the fitness values of the other case. This finally leads to more robust results of the optimization. This outcome is for the Lognormal case, Expected Value = 131,178, Standard Deviation = 0,185,394; for the Uniform case, Expected Value = 131,3435, Standard Deviation = 0,456,706. The expected value of the fitness values and the relative standard deviation are computed for 20 repetitions.

Table 3 Experimental results

Test	Makespan of the initial scenario	α = 10%	α = 25%	α = 50%	α = 10%, lognormal processing times
1	130	131.6108	133.3900	136.6499	131.3821
2	130	131.4715	133.8294	136.9049	131.1723
3	130	131.5813	134.3792	136.8696	131.2618
4	130	131.9030	134.4928	136.8792	131.4399
5	130	131.4448	133.9902	138.2731	131.2150
6	130	131.6870	133.1917	136.8609	131.4241
7	130	131.6564	134.7450	136.2267	131.1761
8	130	131.6422	134.1367	138.8508	130.9624
9	130	131.6487	133.7472	137.5844	131.3943
10	130	131.2932	134.1369	138.0245	131.3584
11	130	131.8055	134.1038	136.1134	131.2662
12	130	131.4183	133.4338	137.3676	131.3803
13	130	131.4418	133.6576	136.0546	131.2281
14	130	131.5762	138.3476	138.3476	131.0125
15	130	131.7444	137.6935	137.6935	131.4715
16	130	131.6272	137.9646	137.9646	131.1499
17	130	131.8470	139.3843	139.3843	131.3976
18	130	131.6109	137.4690	137.4690	131.3211
19	130	131.3318	136.5000	136.5000	131.8114
20	130	131.5211	139.4398	139.4398	131.1816

6 Conclusions

In the last years, the increasing need for lead time and work in progress reduction and the technology evolution gave a new boost in the research on production scheduling. This phenomenon is enhanced by the increasing operational flexibility and automation level of the industrial plants which could lead to better performances if fully exploited. Besides the market changes brought an increase in order variety, short lead times. These requirements can be met only through proper production scheduling approaches that help companies increasing their competitiveness on the market. Research on scheduling often proposes mathematical optimizations, without a deep thought on the industrial viability of the selected schedules. Having this concern, the paper proposes a GA-based and DES simulation-based scheduling framework for HFSSP with stochastic processing times. The framework was used to propose a progress in the research on stochastic HSSP, and especially with respect to the proposed work by Chaari et al. [2]. In particular, the authors replicated some of the experiments by Chaari and identified certain “limit cases” in which the behavior of the algorithm originally proposed by Chaari chooses solutions that are inconsistent with the expectation of a decision-maker. It chooses an optimal solution, that mathematically corresponds to the minimum fitness value; nevertheless, when considering the variability of the makespan of the different repetitions, it is clear that other solutions would be "industrially preferrable" with respect to the optimal solution found, as a result of a lower average makespan and a higher standard deviation. The paper therefore proposes a new fitness function to avoid falling in the so called "limit cases", reproposing the experimentations done by Chaari with the different parameter values ($\alpha = 10$, 25 and 50). Finally, considering the stochastic processing times not as uniformly distributed but lognormally distributed leads to a more industrially consistent input data modelling.

The results obtained through the proposed scheduling framework were satisfactory, because in almost all runs, the best sequences of the deterministic scenarios are the ones also of the stochastic scenarios. The new structure would enable a more performant management of the stochastic behavior whenever it is integrated with a control system, such as Manufacturing Execution System (MES): a MES would allow taking advantage of the real data, actually acquired from field and describing the progress of production activities; thereafter, the scheduling results would be directly fed into the Production Activity Control on the production system. In the light of this perspective, this work opens various possibilities of future work directions to be explored.

- By integrating simulation inside a metaheuristic technique, the methodology allows adding a higher level of flexibility in terms of modeling parameters of the systems. Hence, the simulation model could be naturally extended to consider a different distribution function for each processing time and even possible dependencies among them.
- Furthermore, future studies could examine the possibility of incorporating a rescheduling strategy in the proposed scheduling framework, thus promotive reactive capabilities to field disturbances.
- Future works could also focus on the minimization of the computational time by hybridizing the GA or by optimizing the functioning of the whole scheduling tool (e.g., a proper tuning of the genetic operators could be applied).
- Furthermore, other types of variability sources such as unexpected releases of high priority jobs or machine breakdowns could be incorporated.

Overall, the ideas developed in this work may be a background for building digital twin modelling approaches where simulation enables predictive capabilities whereas optimization is seamlessly integrated in the control loop of the production activities in the shop floor.

Acknowledgements This research did not receive any grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors express their gratitude to Luca De Felice for his support in the presented work.

References

1. Pinedo, M. L. (2009). Planning and scheduling in manufacturing and services. *Springer*. https://doi.org/10.1007/978-1-4419-0910-7
2. Chaari, T., Chaabane, S., Loukil, T., & Trentesaux, D. (2011). A genetic algorithm for robust hybrid flow shop scheduling. *International Journal of Computer Integrated Manufacturing, 24*(9), 821–833. https://doi.org/10.1080/0951192X.2011.575181
3. Caldeira, R. H., & Gnanavelbabu, A. (2021). A simheuristic approach for the flexible job shop scheduling problem with stochastic processing times. *SIMULATION, 97*(3), 215–236. https://doi.org/10.1177/0037549720968891
4. Gonzalez-Neira, E. M., Montoya-Torres, J. R., & Jimenez, J. F. (2021). A multicriteria simheuristic approach for solving a stochastic permutation flow shop scheduling problem. *Algorithms*, *14*(7), 1–22.https://doi.org/10.3390/a14070210.
5. Chaari, T., Chaabane, S., Aissani, N., & Trentesaux, D. (2014). Scheduling under uncertainty: Survey and research directions. In *2014 International Conference on Advanced Logistics and Transport, ICALT 2014*, 229–234. https://doi.org/10.1109/ICAdLT.2014.6866316
6. Jing, X. L., Pan, Q. K., & Gao, L. (2021). Local search-based metaheuristics for the robust distributed permutation flowshop problem. *Applied Soft Computing, 105*, 107247. https://doi.org/10.1016/j.asoc.2021.107247
7. Wu, C. C., Gupta, J. N. D., Cheng, S. R., Lin, B. M. T., Yip, S. H., & Lin, W. C. (2021). Robust scheduling for a two-stage assembly shop with scenario-dependent processing times. *International Journal of Production Research, 59*(17), 5372–5387. https://doi.org/10.1080/00207543.2020.1778208
8. Khurshid, B., Maqsood, S., Omair, M., Nawaz, R., & Akhtar, R. (2020). Hybrid evolution strategy approach for robust permutation flowshop scheduling. *Advances in Production Engineering and Management*, *15*(2), 204–216. https://doi.org/10.14743/APEM2020.2.359.
9. Abtahi, Z., & Sahraeian, R. (2021). Robust and stable flow shop scheduling problem under uncertain processing times and machines' disruption. *International Journal of Engineering, Transactions A: Basics, 34*(4), 935–947. https://doi.org/10.5829/ije.2021.34.04a.20
10. Liao, W., & Fu, Y. (2020). Min–max regret criterion-based robust model for the permutation flow-shop scheduling problem. *Engineering Optimization, 52*(4), 687–700. https://doi.org/10.1080/0305215X.2019.1607848
11. Sun, H., Jiang, A., Ge, D., Zheng, X., & Gao, F. (2021). A chance constrained programming approach for no-wait flow shop scheduling problem under the interval-valued fuzzy processing time. *Processes*, *9*(5). https://doi.org/10.3390/pr9050789.
12. Alsoufi, G., Zeidan, M. A., Mohammed, L. J., & Salhi, A. (2021). A Robust Expected Makespan for Permutation Flow Shop Scheduling Depending on Machine Failure Rate. *International Journal of Mathematical, Engineering and Management Sciences*, *6*(5), 1345–1360. https://doi.org/10.33889/IJMEMS.2021.6.5.081.
13. Fu, Y., Zhou, M., Guo, X., & Qi, L. (2020). Scheduling dual-objective stochastic hybrid flow shop with deteriorating jobs via Bi-population evolutionary algorithm. *IEEE Transactions on Systems, Man, and Cybernetics: Systems, 50*(12), 5037–5048. https://doi.org/10.1109/TSMC.2019.2907575
14. Jing, X. L., Pan, Q. K., Gao, L., & Wang, L. (2022). An effective iterated greedy algorithm for a robust distributed permutation flowshop problem with carryover sequence-dependent setup time. *IEEE Transactions on Systems, Man, and Cybernetics: Systems, 52*(9), 5783–5794. https://doi.org/10.1109/TSMC.2021.3131849
15. Seif, J., Dehghanimohammadabadi, M., & Yu, A. J. (2020). Integrated preventive maintenance and flow shop scheduling under uncertainty. In *Flexible services and manufacturing journal* (Vol. 32, Issue 4). Springer US. https://doi.org/10.1007/s10696-019-09357-4.
16. Faraji Amiri, M., & Behnamian, J. (2020). Multi-objective green flowshop scheduling problem under uncertainty: Estimation of distribution algorithm. *Journal of Cleaner Production*, *251*, 119734. https://doi.org/10.1016/j.jclepro.2019.119734.

17. Goyal, B., & Kaur, S. (2021). Minimizing waiting time of jobs in flow-shop scheduling: A heuristic approach. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2020.09.797.
18. Zhang, D., Xie, M., Yan, H., & Liu, Q. (2021). Resilience dynamics modeling and control for a reconfigurable electronic assembly line under spatio-temporal disruptions. *Journal of Manufacturing Systems*, *November 2020*. https://doi.org/10.1016/j.jmsy.2021.01.011.
19. Hsu, C. L., Lin, W. C., Duan, L., Liao, J. R., Wu, C. C., & Chen, J. H. (2020). A robust two-machine flow-shop scheduling model with scenario-dependent processing times. *Discrete Dynamics in Nature and Society*, *2020*.https://doi.org/10.1155/2020/3530701
20. Al-Behadili, M., Ouelhadj, D., & Jones, D. (2020). Multi-objective biased randomised iterated greedy for robust permutation flow shop scheduling problem under disturbances. *Journal of the Operational Research Society*, *71*(11), 1847–1859.https://doi.org/10.1080/01605682.2019.1630330.
21. Negri, E., Pandhare, V., Cattaneo, L., Singh, J., Macchi, M., & Lee, J. (2021). Field-synchronized Digital Twin framework for production scheduling with uncertainty. *Journal of Intelligent Manufacturing, 32*(4), 1207–1228. https://doi.org/10.1007/s10845-020-01685-9
22. Villalonga, A., Negri, E., Biscardo, G., Castano, F., Haber, R. E., Fumagalli, L., & Macchi, M. (2021). A decision-making framework for dynamic scheduling of cyber-physical production systems based on digital twins. *Annual Reviews in Control, 51*(April), 357–373. https://doi.org/10.1016/j.arcontrol.2021.04.008
23. Zhang, Z., Tang, Q., & Chica, M. (2021). Maintenance costs and makespan minimization for assembly permutation flow shop scheduling by considering preventive and corrective maintenance. *Journal of Manufacturing Systems, 59*(April), 549–564. https://doi.org/10.1016/j.jmsy.2021.03.020
24. Branda, A., Castellano, D., Guizzi, G., & Popolo, V. (2021). Metaheuristics for the flow shop scheduling problem with maintenance activities integrated. *Computers and Industrial Engineering*, *151*(November 2019), 106989. https://doi.org/10.1016/j.cie.2020.106989.
25. Fumagalli, L., Negri, E., Sottoriva, E., Polenghi, A., Macchi, M. (2018). A novel scheduling framework: Integrating genetic algorithms and discrete event simulation. *International Journal of Management and Decision Making*, *17*(1), 1.https://doi.org/10.1504/ijmdm.2018.10016046.
26. Fumagalli, L., Macchi, M., Negri, E., Polenghi, A., & Sottoriva, E. (2017). Simulation-supported framework for job shop scheduling with genetic algorithm. In *Proceedings of the XXII Summerschool of Industrial Mechanical Plants "Francesco Turco", Palermo (Italy), 13th–15th September 2017* (pp. 1–8).
27. Negri, E., Ardakani, H. D., Cattaneo, L., Singh, J., MacChi, M., & Lee, J. (2019). A digital twin-based scheduling framework including equipment health index and genetic algorithms. *IFAC-PapersOnLine, 52*(10), 43–48. https://doi.org/10.1016/j.ifacol.2019.10.024
28. Carlier, J., & Néron, E. (2000). An exact method for solving the multi-processor flow-shop. *RAIRO Operations Research, 34*(1), 1–25.
29. Santos, D. L., Hunsucker, J. L., & Deal, D. E. (1995). Global lower bounds for flow shops with multiple processors. *European Journal of Operational Research, 80*(1), 112–120. https://doi.org/10.1016/0377-2217(93)E0326-S
30. Fumagalli, L., Polenghi, A., Negri, E., & Roda, I. (2019). Framework for simulation software selection. *Journal of Simulation, 13*(4), 286–303. https://doi.org/10.1080/17477778.2019.1598782

Methods for Evaluating the Cost-Effectiveness of Using AI for Production Automation

Maksim Vlasov and Anna Lapteva

Abstract The analysis of publications revealed a lack of research on assessing economic indicators when introducing artificial intelligence into technological and production processes. In this regard, the authors aim to find and analyze published methods for assessing the economic effectiveness of automation of production processes using AI. It is rather difficult to evaluate the cost-effectiveness of AI introduced into production for the purpose of automation. Artificial intelligence in automated process control systems is a competitor to deductible means that are the basis of such systems. AI allows improving the quality of a number of functions performed by these means, for example, enhancing the quality of regulation. This, in turn, leads to a rise in the quality of products. However, it is challenging to assess in advance how this event will affect the profitability from the sale of these products. The article developed a methodology for assessing the economic effectiveness of the AI introduction.

Keywords Artificial intelligence · Production automation · Robotization

1 Introduction

Today, the most advanced enterprises in the world are based on the Internet and digital platforms [9]. Scientists, social media, industries, and governments are investing a large amount of resources in the development of digital forms of technology, namely artificial intelligence (AI) [8].

M. Vlasov · A. Lapteva (✉)
Ural Federal University, 19 Mira St., Ekaterinburg 620014, Russian Federation
e-mail: av.lapteva@urfu.ru

M. Vlasov
e-mail: mvlassov@mail.ru

M. Vlasov
Institute of Economics of the Ural Branch of the Russian Academy of Sciences, 29 Moskovskaya St., Ekaterinburg 620014, Russian Federation

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_22

AI allows one to improve the quality of processes in which information processing is of paramount importance. Production automation is among such processes. The development of methods for assessing the economic effectiveness of the AI introduction into automated production is an up-to-date process. In addition, the relevance is due to the significant spread and gradual introduction of AI into the production processes of the enterprise. The growth of digitalization, in turn, determines the relevance of the introduction of AI as a tool that increases production productivity and product quality.

AI is defined as "the ability of a machine to mimic intelligent human behavior" or "the ability of an agent to achieve goals in a wide range of environments." AI is widely used in Russian companies as [17]:

- agents (automated support services for banks, medical and telecommunications institutions, chatbots of client services);
- algorithms that optimize the decision-making process used in all areas from industry (recommendation systems for making technological decisions, improving production safety) to retail (logistics tasks, studying the behavior of buyers) and banks (forming individual proposals, improving targeting).

When creating AI, neural networks are widely used. A neural network requires machine learning to function properly. Training is done with prepared large amounts of data.

The leaders in the introduction and use of AI are banks, telecommunications companies, retail, etc. Such implementations are devoted to numerous publications, which provide a significant number of economic effects produced by the AI introduction. Total spending on AI systems in 2023 will amount to $98 billion [23]. AI allows one to improve the decision-making process due to the ability to analyze large amounts of data [1, 24]. To identify the effectiveness of the AI use, models of its operation during production automation are compiled [2, 18]. The economic effect of the introduction of AI in some cases is not immediate [11]. This effect is detected when introducing AI, for example, into medicine [15]. The introduction of AI allows saving on expensive materials, optimizing processes based on big data processing, analyzing equipment resources in order to timely repair it [7]. AI can process big data [26], allows achieving sustainable business development [6], contributes to the creation of decision-making and control systems [4].

There is a scares number of publications on the use of AI for automation of production processes, for example, in automated process control systems (APCS). It is very difficult to find publications analyzing the effectiveness of AI in industrial production automation. It is reported that the main goal of the AI use is to diminish the influence of the human factor on technological processes (TP). This makes it possible to reduce the number of emergency situations due to the fault of a person and the damage from them [27].

In this regard, the authors believe that there is a problem in the economic analysis of the AI use in automation systems of TP. This article provides an overview of methods for analyzing the cost-effectiveness of AI implementation in such processes.

The purpose of the work is to identify a suitable methodology for determining economic indicators when introducing AI into production and an APCS. The analysis of publications revealed that there is lack of research on assessing economic indicators when introducing AI into technological and production processes, insufficient elaboration of the methodological apparatus for supporting each stage of the AI introduction into an APCS.

To achieve the state purpose, the following objectives need to be attained: to analyze the existing methods for assessing the economic effect of AI implementation and modify the methodology that is most suitable for APCS.

The hypothesis of the study is that the introduction of AI leads to an increase in labor productivity in industry.

2 Materials and Methods

The article is based on the analysis of the existing methods for assessing the economic effectiveness of the use of AI for production automation. Thus, the materials are publications evaluating the effectiveness. Theoretical analysis was carried out using generally accepted methods.

2.1 Difficulty Evaluating AI Implementation

Nobel laureate Robert Solow noted that the computer age was everywhere except for the productivity statistics. The expected effectiveness of AI technologies is also often at odds with objective business performance indicators. Production inefficiency often reduces achievements from the AI introduction [19]. The analysis of publications revealed that there is an insufficient number of research on assessing economic indicators when introducing AI into technological and production processes.

Three approaches to explaining Solow's paradox are considered in the literature:

- specificity of effect measurements. Automation of technology has an impact on people's quality of life, but statistical tools for assessing this phenomenon are not able to fully assess it;
- time lag between innovation and effect.

Investment in AI during the R&D stages and the start of implementation does not create additional and high-quality output, which leads to a decrease in overall productivity. In the long term, with the accumulation of innovative potential, the growth in returns from automation factors is reassessed. As a result, the performance dynamics has a J-shape [3].

According to the PricewaterhouseCoopers (PwC) study, global GDP is going to increase by up to 14% (equivalent to $15.7 trillion) by 2030 as a result of the AI accelerated development [12].

GDP increase numbers were obtained by modeling, for which data from three sources were used [11]. First, surveys were conducted by the McKinsey Global Institute (MGI) of about 3,000 corporations in 14 sectors on digital technology. Second, two MGI databases were used. One contained 400 possible uses of AI in various industries and functions. The other MGI database contained an analysis of the automation potential of individual workplaces. Macroeconomic data are taken from the statistics of international organizations.

2.2 Implementation Objects

The introduction of AI into production process automation systems can be considered at various levels.

The impact of process automation on macroeconomic indicators is considered using economic models. In this case, for example, the movements of capital, labor, and gross product are analyzed.

The largest part of AI is introduced in banks.

The introduction of AI in APCS leads to a different methodology for assessing economic efficiency. Powerful servers are used at the upper level of APCS. These servers cannot be utilized to implement AI. Thus, powerful neuroprocessors implementing AI will have to be purchased separately. Automated workstations (AWSs) are located on another level. With the help of AWSs, process operators monitor the state of the TP and, if necessary, issue control commands. Thus, the person is included in the control loop. A number of problems arise here. First, correct and timely perception of input information by the operator. Second, the right decision to correct the process. Such problems can violate the optimal TP course until the process stops in emergency situations. Each operator analyzes its own set of information to make decisions within its functionality. However, in any case, all these decisions are a priori influenced by the human factor, which means that they may be erroneous. And the cost of such mistakes can have huge economic, environmental, and social consequences. Mitigation of these consequences is possible by using AI in the APCS control loop.

Microcontrollers and programmable logic controllers (PLCs) interact directly with the process objects. Programs in PLCs are executed cyclically with a certain frequency. They are developed under the assumption of stable dynamic models of an adjustable object. In modern APCSs, adaptive control systems operating according to a special algorithm are used. Actuators are located on the lower level. All layers are connected by different types of computer networks.

In APCSs, the advisory system of the type monitors all process parameters and formulates recommendations to the process operator who decides whether to follow the advice or not.

There are two ways to introduce AI into APCSs:

- designing APCSs from scratch using AI;

- introducing AI into the existing APCS to improve its efficiency.

For the first option, it is difficult to allocate the costs of implementing only AI, since the list of designed systems is very large. For this reason, further discussions are related to the second implementation option, i.e., with the modernization of the APCS.

In the modernized APCS, the computer complex already includes regulatory bodies, actuators, the necessary sensors, as well as a process model, knowledge bases, and data for the operation of expert systems. In this regard, the cost of AI introduction into the modernized APCS is mainly determined by the costs of AI.

Another implementation object is robotic systems. Robots are specialized machines. For example, there are robots for welding car bodies. Such robots work according to a rigid program, performing cyclic operations. Their advantage is the absence of fatigue and the liberation of human labor. The use of AI in such robots makes sense if their functions are expanded, for example, the use of vision.

The next implementation object is a metallurgical plant. Its task is to produce steel of a certain composition, which is achieved by observing the required technological regime and introducing alloying additives into liquid steel at certain stages of the process. These additives require precise dosing depending on the composition of the alloyed steel and noble ferroalloys.

3 Literature Review

The concept of efficiency is a complex multidimensional indicator [13, 21]. The efficiency of production automation can be considered at various levels of abstraction. Methods for assessing the effectiveness of investments in specific projects use key indicators, such as costs and net income. According to these indicators, other criteria for economic efficiency are found.

Methods differ in cost and revenue items. For example, the AI introduced in a bank generates revenues from the following processes:

(1) salary savings for consulting operators;
(2) optimizing the assessment of individuals' creditworthiness;
(3) improving safety due to identification of persons;
(4) control optimization.

In financial units, the effect can only be calculated for the first process. For the rest three, it is necessary to collect statistics on changes in the results of the bank's activities before and after introducing AI into these processes. No such statistics were found in the publications.

3.1 AI Implementation Models

On the basis of modeling, the work [26] considers the influence of AI as the latest form of a controlling object on the growth process at the macroeconomic level. AI is defined as "the ability of a machine to mimic intelligent human behavior." These definitions cause economic problems. In particular, what happens if AI automates the ever-growing number of tasks previously performed by human? AI, when used in the production of t-bars and services, could potentially affect economic growth and revenue share. But AI can also change the process by which we create new ideas and technologies, helping to solve complex problems and build creativity. What happens if AI can improve on its own and this leads to "singularities," which are characterized by unlimited machine intelligence and unlimited economic growth.

The authors seek to answer these questions by creating appropriate models. The initial automation model is represented by Zeira, in which the production function (economic and mathematical quantitative dependence between the output values (production quantity) and production factors, such as resource costs and technology level) is represented by formula

$$Y = AX_1^{\alpha_1}X_2^{\alpha_2}\cdot\dots\cdot X_n^{\alpha_n},\quad \sum\nolimits_{i=1}^{n}\alpha_i = 1. \tag{1}$$

Here Y is a process coefficient, or total factor productivity, α is elasticity coefficient.

$$X_i = \left\{\begin{matrix} L_i, & if\ \ not\ automated \\ K_i, & if\ automated \end{matrix}\right\} \tag{2}$$

where L is Manual labor, K is captain.

$$Y_t = A_t K_t^{\alpha} L_2^{1-\alpha}, \tag{3}$$

where Y_t is the production function.

Let β_t is the share of goods that were automated on date t. The manufacturing function can be written as

$$Y_t = A_t\left[\beta_t\left(\frac{K_t}{\beta_t}\right)^{\rho} + (1-\beta_t)\left(\frac{L}{1-\beta_t}\right)^{\rho}\right]^{1/\rho}. \tag{4}$$

The ratio of automated and non-automated production, or the ratio of the share of capital to the share of labor, is

$$\frac{\alpha_{Kt}}{\alpha_{Lt}} = \left(\frac{\beta_t}{1-\beta_t}\right)^{1-\rho}\left(\frac{K_t}{L_t}\right)^{\rho}. \tag{5}$$

As seen from the models, if the value of substitution elasticity between goods is less than 1, i.e., $\rho < 0$, the increase in automation enhances the share of capital, and therefore boosts the long-term growth rate due to the multiplicative effect.

3.2 Investment of AI in Sberbank PJSC

Let us look at the following data: the total cost of developing the neural network of Sberbank PJSC to assess the creditworthiness of individuals is 90 million rubles [16]. The costs of implementing this system and training personnel to work with the software amounted to about 600 million rubles. The total costs of introducing AI into the lending division and electricity from additional equipment amounted to 820 million rubles.

The replacement of human labor with machines led to the benefit of the introduction of AI to assess the creditworthiness of individuals. This allowed Sberbank to free up many credit experts, security officers, and managers in the credit department.

It was taken into account that 30% of qualified specialists will continue working in AI. The share of bank employees in the field of private lending was determined based on Sberbank's 260,000 employees, of which 9% were managers [14]. Of these, 35,500 employees issue consumer loans; 25,000 of them can be laid off. In addition, 2,500 managers of these employees remain out of work and are subject to dismissal. With the average salary of 25,000 rubles of an ordinary Sberbank employee and 35,000 rubles of a manager [22], the savings on wages and tax payments will amount to 925 million rubles per year, or 4.6 billion rubles in five years. In addition, with dismissal, it is possible to reduce the occupied area.

Thus, the introduction of AI to assess the creditworthiness of individuals made it possible for Sberbank to save about 4.6 billion rubles over five years, as well as reduce problems with personnel and improve the quality of assessment.

The introduction of AI into APCS decreases the likelihood of emergencies, raises the quality of regulation, improves management decision-making, and reduces a number of employees. Except for the last event, all the others are of a qualitative nature. There are no statistics on these processes. However, a methodology was published to determine the economic effectiveness of the AI introduction in APCS.

Thus, the total costs of developing a neural network in this technique are not disclosed, but savings from the AI introduction are considered in detail.

3.3 Procedure Described by Vlasov

The introduction of intelligent APCS is associated with high financial costs. The procedure describes the algorithm for introducing AI into APCS. This algorithm allowed distinguishing the required procedures and the corresponding expense items [25]. Total costs will be calculated by formula

$$\text{Tc} = \text{Dw} + \text{Pe} + PSP + \text{Iw} + A + \text{Ml} \tag{6}$$

where Dw is design works; Pe is purchase of equipment; PSP is purchase of software product; Iw is installation works; A is adjustment; Ml is machine learning. Expense items do not fully reflect costs. In particular, the costs of electricity, buildings, operating costs, maintenance of equipment, depreciation costs are not taken into account.

The algorithm contains decision statements after execution, which can be returned to previous procedures, which will increase costs. However, in the proposed formula, this increase in costs is not considered.

These expenses are compensated for the payback period during the operation of the system by increasing the price of the output product. The introduction of intelligent APCS allows one to reduce the staff of process operators, but will require the recruitment of specialists in the operation of AI. The introduction of intelligent APCS leads to a decrease in emergency downtime. Improving the quality of products results in an increase in the price of products. The optimization of the technological progress allows producing products with less energy and resources.

Thus, the introduction of AI in APCS will lead to the following savings per year:

$$\begin{aligned} S &= \text{Ro} \cdot \text{Spo} + \text{Ed} \cdot \text{Cd} + \text{Sr} \cdot \text{Cs} \\ &+ \text{Api} \cdot -\text{Ns} \cdot \text{Sas} - (\text{Dw} + \text{Ps} + \text{Iw} + A + \text{Pe})/\text{Pp}, \end{aligned} \tag{7}$$

where Ro is the number of reduced process operators; Spo is annual salary of reduced process operators; Ed is emergency downtime per year; Cd is cost per unit downtime; Sr is savings on material and energy resources; Cs is cost of saved resources per year; Ns is the number of AI specialists accepted; Sas is annual salary of the AI specialists; Api is the added price from product quality improvement; Pp is payback period; Dw is design works of the system; Pe is purchase of equipment; Ps is purchase of software product; Iw is installation works; A is adjustment; Ml is machine learning.

In this procedure, there are no estimates of the economic efficiency of APCS with AI due to a decrease in emergency situations caused by the exclusion of the human factor and an increase in the product quality owing to increased accuracy of process control.

In addition, electricity costs did not fall into formula (1) as almost fully consumed by neurocomputers working around the clock.

The methodology details the items of expenses and income. The basic principles of determining the economic efficiency of the AI implementation in APCS boil down to assessing costs and financial gains received as in a similar process of increasing production efficiency.

3.4 Method Described by Dolganova

The method was developed to assess the economic effectiveness of the control system of the multifunctional robotic complex (MRC) based on AI [5]. The designed MRC identifies the location, nature and types of destruction, the place and nature of fires, rubble and destruction caused by man-made and other disasters, etc.

The MRC is designed to move around the studied area and perform useful work while examining technogenic formations in conditions of harmful environmental influences. In the process of operation, it can be lost due to man-made disasters. It consumes energy resources while moving.

Obviously, this technique is limited to determine the cost-effectiveness of introducing AI into APCS. However, we try to compare it with the procedure discussed in the previous section.

The mathematical expectation of M_s losses associated with the presence of uncompensated harm from aggressive technogenic formations and a decrease in benefits from benign technogenic objects can be estimated by formula

$$M_s = \sum_i P_i^N \cdot C_i^N - \sum_j P_j^g \cdot C_j^g \tag{8}$$

where i is index of the negative event; j is index of the positive event; P_i^N is posterior probability of occurrence of the i-negative event provided that the MRC management structure presented in Fig. 1 is used; P_j^g is posterior probability of occurrence of the j-positive event provided that the MRC structure without AI is used; C_i^N is penalty for occurrence of the i-negative event; C_j^g is the prize for occurrence of the j-positive event.

Formulas are given to estimate losses associated with possible loss or damage to the MRC, with increased fuel or electricity consumption. These formulas are useful for evaluating a MRC designed to eliminate the consequences of disasters. To automate production within the framework of APCS, such estimates do not make sense.

An estimate of K_1 reduction of losses was introduced due to the improvement in the decision-making result based on the MRC computer using AI

$$K_1 = \left(\sum_i P_i^N \cdot C_i^N - \sum_j P_j^g \cdot C_j^g\right) - \left(\sum_i P_i^{N*} \cdot C_i^{N*} - \sum_j P_j^{g*} \cdot C_j^{g*}\right) \to max. \tag{9}$$

The (*) sign marks the values of indicators for the autonomous MRC.

Additionally, the entered estimates K_2 and K_3 determine reductions in loss or damage to the MRC. For APCS, these estimates are zero. They should be replaced with estimates of reducing losses from equipment downtime due to incorrect actions of process operators.

3.5 Cost-Effectiveness of Robotization (Procedure)

The introduction of robots with AI to automate production processes allows using the same robots to produce various objects, since their restructuring is carried out by launching another program in the microcontroller (it must be pre-loaded there).

The payback period of a robot without AI in years is determined by formula [20]

$$T = \frac{C}{R - z} \tag{10}$$

where C is cost of the robot; R is annual labor savings; z is robot maintenance costs.

3.6 Cost-Effectiveness of the AI Implementation in Steel Smelting

To obtain the required steel grade at the end of melting, ferroalloys of the required element are introduced into the steel. Insufficient or excessive amount of ferroalloy will result in faulty product. Fixing it will take a lot of time, labor, and raw materials. In addition, some ferroalloys are very expensive, which, if introduced in an amount greater than needed, lead to unnecessary costs.

Another problem with the steel smelting process is the complexity of the operator's task of determining the required amount of ferroalloy for the current smelting. AI in such a situation can act as an adviser. To do this, one needs to train it on a big data database.

Thus, the AI introduction into steelmaking makes it possible to save resources and ensure optimal process management by providing advice to the process operator [7].

3.7 Efficiency of APCS

Automation of various industries has a lot in common. For example, the introduction of an APCS defines the following items of costs for the computer equipment operation: computers power consumption; basic and additional wages of production staff; social security; depreciation of fixed assets, computing equipment, building; current repair of technical facilities; overhead costs.

Annual profit growth (annual savings) of P^A is calculated using formula [10]

$$P^A = P_1\left(\frac{A_2 - A_1}{A_1}\right) + P_2\left(\frac{A_1 - A_2}{100}\right), \tag{11}$$

where A_1, A_2 is annual volume of products sold before and after the APCS implementation, respectively, thousand rubles; C_1, C_2 is costs per one ruble of the products sold before and after the APCS implementation, respectively, kopeks.

4 Proposed Method

Vlasov and Lapteva [25] list some of the items of expenses and income.

Expenses R are calculated using formula

$$R = \sum_i Sr_i \tag{12}$$

where Sr_i is the i-th expense item.

Revenues for the year D are determined by formula

$$D = \sum_j Sd_j \tag{13}$$

where Sd_j is the i-th revenue item.

Table 1 shows 31 expense items depending on the specific automation object.

Table 2 presents 16 income items depending on the specific automation object.

Table 3 provides advantages and disadvantages of the analyzed methods when determining the economic effectiveness of the AI being introduced into automated production.

5 Results

Based on a few publications on using AI to automate various TP, we can state that it is possible to assess its cost-effectiveness at different levels and in different types of production.

At the level of macroeconomics [26], the effects of ratios of the volumes of automated and non-automated processes were investigated and it was shown that the increase in automation enhanced the share of capital. Automation and capital are seen as a generalized abstract phenomenon. Such a conclusion has a fairly general meaning. For a specific case of using AI for automation, this technique is of no interest.

The economic effect of using AI in the banking system is achieved by reducing the staff and space occupied by them. In addition, AI allows improving the quality of service and increasing security [16]. The reduction of staff numbers and the improvement of product quality take place during the introduction of AI in robotic industries.

Table 1 Expense items for the AI introduction

i	Expense items
1	Cost of equipment used to implement AI
2	AI training, implementation and debugging
3	Salary, including production staff
4	Additional salary of production staff
5	Social security
6	Other administrative and management expenses
7	Materials
8	Maintenance and current repair of buildings and inventory
9	Depreciation of fixed assets (AI equipment)
10	Wear and tear of low-value and life-limited items
11	Occupational health and safety expenses
12	Training costs
13	Invention and technical improvements
14	Electric power for production needs
15	Maintenance and current repair of machines
16	Amortization of AI, other counting machines, and equipment
17	Specific consumption of raw materials for the production of one ruble of products under the AI
18	Including raw materials and materials
19	Fuel and energy for process needs
20	Basic wages and social security for production workers
21	Production preparation and development costs
22	Equipment maintenance and operation costs
23	Other production costs before and after the AI implementation
24	Non-production costs before and after the AI implementation
25	Pre-production costs for AI design development
26	Capital investments for the creation of AI, including the residual cost of eliminated equipment and the cost of released equipment, structures that will be used in AI
27	AI operation costs
28	Basic and additional salary of the service staff of the information computing center with social insurance contributions
29	Nominal annual fund of AI operation at three-shift loading
30	Time for scheduled preventive maintenance and other planned downtime (15% of the nominal annual AI work)
31	Installed power of peripheral equipment

Table 2 Income items from the AI implementation

j	Income items (for the year)
1	Profit growth under AI operating
2	Increase in profit due to growth in the volume of products sold
3	Profit gains due to lower production costs
4	Profit gains due to reduced equipment downtime
5	Loss from faulty products before and after the AI implementation
6	Cutting raw materials costs after the AI implementation
7	Number of workers released
8	Cost savings
9	Salary savings (with social security contributions)
10	Savings on the wage fund formed by reducing the loss of working time under AI operating
11	Conditional savings resulting from outstripping productivity growth compared to wage growth
12	Savings from reduced overhead (35% of overhead excluding AI):
13	Reducing scrap losses after the AI implementation
14	Reduced costs due to elimination of the human factor
15	Profit gains due to process optimization
16	Profit increase due to the optimal use of equipment

Table 3 Comparison of the methods for determining the cost-effectiveness of the AI implementation

Methods	Basic performance		
	Advantages	Shortcomings	Scope
On models	–	–	Country, world
Sberbank	Calculations in numbers by income items	Spending items not disclosed	Banks
APCS with AI	A specific list of cost elements	Factors not considered: • improving the quality of goods; • influences of the human factor	APCS
Robot Ministry of Emergency Situations with AI	–	Negative and positive events are abstract and not specified	Robotics
Robotization without AI	–	Few factors considered	Robotics
Automated Enterprise Management System (AEMS)	–	Items of expenses for computing equipment (similar to AI) are considered in detail	–

Items of expenses and income during automation of production while implementing AI are little different from such items during the implementation of AEMS and APCS (AI is a type of computer technology).

An accurate assessment of the economic efficiency of introducing AI into APCS is difficult, since AI mainly contributes to reducing the human factor for TP and improving product quality. The economic results of these events can only be estimated with some probability if the probabilistic characteristics of these events are known.

By the economic efficiency of APCS R we mean the ratio of the financial assessment of P expected changes in the activity of the facility to the estimate of the expected costs C for the creation of APCS:

$$R = P/C \tag{14}$$

6 Conclusion

To assess the cost-effectiveness of the AI implementation in APCS, the most suitable method is described by Vlasov and Lapteva [25]. It is closely adapted to the production processes controlled by the AEMS.

The theoretical significance of the study consists in the toolkit proposed by the authors for the quantitative assessment of the processes of introducing AI into the activities of industrial enterprises in order to increase the efficiency of TP, which can become the basis for further research on the analysis of the processes of using AI in automated systems.

The practical value of the study lies in the possibility of using the results obtained by managers of high and mid-level industrial enterprises when planning activities to introduce AI into TP of automated systems.

References

1. Acemoglu, D., & Restrepo, P. (2018). *Artificial intelligence, automation and work*. https://www.nber.org/system/files/working_papers/w24196/w24196.pdf
2. Aghion, Ph., Jones, B.F., & Jones, C.I. (2019). Artificial intelligence and economic growth. https://web.stanford.edu/~chadj/AJJ-AIandGrowth.pdf
3. Autor, D., Dorn, D., Katz, L., Patterson, C., & Reenen, J. V. (2017). The fall of the labor share and the rise of superstar firms. *NBER Working Paper*, 23396. https://www.nber.org/papers/w23396.pdf
4. Belyakova, G. Y., Belyakov, S. A., Fokina, D. A., & Shpak, A. S. (2021). Artificial intelligence instruments as the basis for the development of the machine-building enterprises export potential. *Studies in Systems, Decision and Control, 117–124*,. https://doi.org/10.1007/978-3-030-56433-9_14
5. Dolgova, E. B., Kurushin, D. S., Fayzrakhmanov, R. A., & Vasilyeva, E. E. (2018). Estimation of economic efficiency in application of artificial intelligence system in autonomous robotic

complex control system. *PNRPU Sociology and Economics Bulletin, 3*, 253–265. https://doi.org/10.15593/2224-9354/2018.3.20
6. Gupta, B. B., Gaurav, A., Panigrahi, P. K., & Arya, V. (2023). Analysis of artificial intelligence-based technologies and approaches on sustainable entrepreneurship. *Technological Forecasting and Social Change, 186*, 122152. https://doi.org/10.1016/j.techfore.2022.122152
7. Habr. (2020). How we introduced artificial intelligence at the metallurgical plant. https://habr.com/ru/company/datana/blog/506194/
8. Han, H., Shiwakoti, R. K., Jarvis, R., Mordi, C., & Botchie, D. (2023). Accounting and auditing with blockchain technology and Artificial Intelligence: A literature review. *International Journal of Accounting Information Systems, 48*, 100598. https://doi.org/10.1016/j.accinf.2022.100598
9. Iansiti, M., & Lakhani, K. R. (2017). Managing our hub economy: Strategy, ethics, and network competition in the age of digital superpowers. *Harvard Business Review*, September–October.
10. Itteach. (n.d.). *Economic efficiency of ASUE*. https://itteach.ru/avtomatizirovannie-sistemi-upravleniya/ekonomicheskaya-effektivnost-asup#toc1
11. ITU Trends. (2018). *Assessing the economic impact of artificial intelligence*. Issue Paper No.1, September 2018. https://www.itu.int/dms_pub/itu-s/opb/gen/S-GEN-ISSUEPAPER-2018-1-PDF-E.pdf
12. Ivanovsky, B. (2021). Economic effects of the implementation of «artificial intelligence» technologies. *Social Novelties and Social Sciences, 2*, 8–25. https://doi.org/10.31249/snsn/2021.02.01
13. Kovalev, V. (2005). *Financial analysis: Methods and procedures*. Finance and statistics.
14. Lavrushin, O., Afanasyeva, O., & Kornienko, S. (2015). *Banking: Co-temporary lending system*. KnoRus.
15. Mital, S., & Nguyen, H. V. (2022). Cost-effectiveness of using artificial intelligence versus polygenic risk score to guide breast cancer screening. *BMC Cancer, 22*(1), 501. https://doi.org/10.1186/s12885-022-09613-1
16. Nosov, A. (2018). Assessment of the economic effect of the implementation of a neural network to assess the creditworthiness of individuals. *Science through the Prism of Time, 9*, 39–41.
17. RAEC. (2019). *Digital economics from theory to practice. How Russian business uses artificial intelligence*. https://www.sostav.ru/app/public/files/raek.pdf
18. RAND. (n.d.). *Evaluating the Effectiveness of Artificial Intelligence SYSTEMS in Artificial Analysis*. https://www.rand.org/content/dam/rand/pubs/research_reports/ RRA400/RRA464–1/RAND_RRA464–1.pdf
19. Rasskazov, V. E. (2020). Financial and economic consequences of distribution of artificial intelligence as a general-purpose technology. *Finance: Theory and Practice*, *24*(2),120–132. https://doi.org/10.26794/2587-5671-2020-24-2-120-132
20. Roboticslib. (n.d.). Cost-effectiveness of robotization. http://roboticslib.ru/books/item/f00/s00/z0000026/st032.shtml
21. Savitskaya, G. (2005). *Economic analysis: Textbook* (11th ed.). New knowledge.
22. Sberbank. (2018). Annual reports of Sberbank. http://www.sberbank.com/ru/investor-relations/reports-and-publications/annual-reports
23. Spotlight. (2019). *Artificial intelligence*. Using artificial intelligence the state of multiple industries. https://www.energy.gov/sites/prod/files/2019/10/f67/2019-09-30_Spotlight-Artificial_Intelligence_0.pdf
24. Szczepański, M. (2019). *Economic impacts of artificial intelligence (AI)*. https://www.europarl.europa.eu/RegData/etudes/BRIE/2019/637967/EPRS_BRI(2019)637967_EN.pdf
25. Vlasov, M., Lapteva, A. (2022). Economic Indicators of the Algorithm for Introducing Artificial Intelligence into the Automated Process Control System. In: Kumar, V., Leng, J., Akberdina, V., Kuzmin, E. (eds) Digital Transformation in Industry. Lecture Notes in Information Systems and Organisation, vol 54. Springer, Cham. https://doi.org/10.1007/978-3-030-94617-3_28
26. Zatonatska, T., Dluhopolskyi, O., Artyukh, T., & Tymchenko, K. (2022). Forecasting the behavior of target segments to activate advertising tools: Case of mobile operator Vodafone Ukraine. *ECONOMICS, 10*(1), 87–104. https://doi.org/10.2478/eoik-2022-0005

27. Zhumanalieva, L. et al. (2022). Methodology for evaluating the effectiveness of digital solutions. https://qazindustry.gov.kz/docs/Proekt_metodiki_otsenki_effektivnosti.pdf

Stakeholder Management in Technological Projects and the Opportunity of Artificial Intelligence. A Case Study

Manuel Otero-Mateo, Alberto Cerezo-Narváez, Andrés Pastor-Fernández, Margarita Castilla-Barea, and Magdalena Ramírez-Peña

Abstract Successful project management entails meeting the project objectives, completing the project scope, and achieving the set deliverables, fulfilling stakeholder requirements. Thus, the more complex and varied the expectations of the stakeholders, the greater the need for engaging them in the decision-making process. In this sense, the application of artificial intelligence can help in this integration. First, the paper presents a framework to identifying the internal and external factors associated with stakeholders. Later the relationship is discussed between the identified Critical Success Factors (CSF) and the decision-making process serving as support artificial intelligence. The CSFs identified have been obtained through 315 questionnaires administered to various stakeholders who had taken part in 45 technological projects implemented in a manufacturing company over a 10-year period. The CSFs identified may help to gain a better understanding of dimensions such as top management support, personnel/teamwork and technical task ability, aspects which should not be overlooked, and where the use of artificial intelligence can help to maximize impact and support digital transformation in industry.

Keywords Stakeholders · Critical success factor · Artificial intelligence · Digital transformation

M. Otero-Mateo · A. Cerezo-Narváez · A. Pastor-Fernández · M. Ramírez-Peña
University of Cadiz, Universidad de Cádiz Avenue 10, 11519 Puerto Real, Spain
e-mail: manuel.otero@uca.es

A. Cerezo-Narváez
e-mail: alberto.cerezo@uca.es

A. Pastor-Fernández
e-mail: andres.pastor@uca.es

M. Ramírez-Peña
e-mail: magdalena.ramirez@uca.es

M. Castilla-Barea (✉)
University of Cadiz, Av. de la Universidad num. 4, 11406 Jerez, Spain
e-mail: margarita.castilla@uca.es

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_23

1 Introduction

The first step is to perform a chronological overview in an international context. Project management entails a decision-making process aimed at achieving project success in which stakeholder management is a fundamental area of knowledge. Standard ISO 9000: 2015 [1] defines “stakeholder” or “interested party” as the person or organization that can impact, experience change, or feel affected by another activity or decision. The term “quality” has also been adopted in standard ISO 9000:2005 [1] as the degree to which a set of inherent characteristics (distinguishing features) of an object (anything perceivable or conceivable) fulfills requirements (need or expectation that is stated, generally implied or obligatory).

According to the PMBOK® Guide 7th edition, published by Project Management Institute [2], quality is a *project management principle*, and quality is defined as the degree to which a set of inherent characteristics of a product, service, or result fulfills the requirements. Quality includes the ability to satisfy the customer’s stated or implied needs. The product, service, or result of a project (referred to here as deliverables) is measured for the quality of both the conformance to acceptance criteria and fitness for use.

The Individual Competence Baseline for Project Management, published by International Project Management Association [3], also defines “quality” as the degree to which a set of inherent characteristics fulfills requirements, both implicit and explicit in the project, their needs and achieve benefits. Stakeholder management is implicit in the various inherent responsibilities and characteristics of a project. The ideal situation, therefore, for project organization is that all the people, teams, and suppliers involved in project management are each competent to perform assigned tasks and assume their responsibilities.

The notion of quality involves a leadership structure (power, urgency and legitimacy) which is strongly influenced by stakeholder theory [4], a concept developed by Freeman in his work on business management in 1983 [5], and which soon became oriented to the discipline of Project Management and currently creating synergies with other trends as strategic management (SM) [6], reflecting the humanization of stakeholders, not only from an economic point of view, but also in an analysis of their intrinsic needs and expectations, in a globalized and changing world faced by any organization.

Reaching new goals and responding quickly to stakeholder needs and expectations can no longer be achieved through traditional methods. Integration, cultural change, and the implementation of Agile methodology may be the answer for managing the hybrid organization [7], supported by IT tools that allow digital transformation in industry.

In this sense, the study developed by Keding [8] proposes the use of Artificial Intelligence (AI) to automate strategic management tasks, from two perspectives. The first one, condition-oriented view for the use of AI in strategic management, and the second outcome-oriented view, the consequences of AI in strategic management from a global perspective, for all stakeholders (internal and external).

For all these reasons, the mission of the empirical study described in this document is to relate the critical success factors, their relationship with stakeholders and the impact on the organization, and finally discuss the decision-making process and the use of AI to support the digital transformation of the organization. To this end, a series of technological renovation projects carried out on the production line of a tobacco factory located in Spain, the head company of which owns 51 factories worldwide and employs approximately 30,000 people are studied. Supplying both the domestic and the foreign markets, the factory analyzed a range of production lines depending on the end product: semi-finished (cut tobacco) or finished (ready for consumption).

2 Thematic Overviews of the Key Aspects in the Industrial Sector

2.1 Stakeholders Management

Stakeholder management is an increasingly important aspect of technological projects, and should therefore be approached in a methodical fashion, using existing tools already familiar to the profession of project manager [9, 10]. Stakeholder identification is considered a problem of classification and there are many different classification models. For example, in Mitchell [11], the degree of influence is measured through three dimensions: power, legitimacy, and urgency. ISO 21500—Project, program, and portfolio management—Context and concepts [12] also suggests identifying stakeholders (individuals, groups, or organizations) affected by or who affect the project and recording all relevant information regarding their needs and expectations.

The Stakeholder Circle® methodology developed by Bourne in 2010 is another approach to analyze stakeholder influence, which is still relevant today, reinventing itself with the COVID-19 pandemic [13]. This method classifies stakeholders according to their influence on the project, their engagement with the work assigned, and the influence of this work on other people, with the possibility that someone may not be the right person for the tasks assigned.

As can be seen, a stakeholder identification model should reflect a management approach rather than the traditional perspective of stakeholders, and it should be possible to apply it to practical aspects of a specific situation in a technological project, in changing environments.

Project Management Institute (PMI) ascribes a leading role to stakeholders, and in line with ISO 21500 [12], the latest edition of the PMBOK® Guide 7th edition [2], defines stakeholder management as an area of knowledge; identification, planning, management, and monitoring of stakeholders are considered essential tasks in order to meet the needs (organization, project, and stakeholders) and to resolve any associated problems that may arise. Stakeholder management can enhance the probability of the project staying on course, improve the ability of people to work synergistically, and limit disruption during project planning and implementation.

International Project Management Association (IPMA) regards interested parties management, and more specifically the competence known as Stakeholders, as one of the 14 practice competencies that a project manager should possess. In addition, it highlights not only the need to analyze internal and external networks and manage communications but also to have a stakeholder management plan and to manage their expectations and satisfaction—this being the most global and integrative approach toward projects and business activities, according to the ICB—IPMA Competence Baseline version 4.0 [3].

The IPMA indicates that project managers should identify all the stakeholders, since to a greater or lesser extent these can have a direct or indirect impact on a project. Indeed, "project success" is nothing other than "the various stakeholders' assessment of the project outcomes." Therefore, the project management objective is not only to produce project deliverables on time and within the budget, but also to satisfy all the stakeholders implicated.

Recently renew published international standard, ISO 21500, Project, program and portfolio management—Context and concepts [12], provides guidance on those project management concepts and processes which influence project outcomes. The standard indicates that project organization represents a temporary structure, which should have well-defined limits that are communicated to all project stakeholders, which should be suitably managed.

Tasks of the project manager should include identifying all the stakeholders and their different needs and expectations and ranking them in order of importance. However, this harmonization of interests is a broad and abstract concept. It is possible to apply design-based thinking method in business management, involving stakeholders in defining the problem [13]. The authors warn that the application of this method is not the only way for the development of an organization. The implementation of Lean Thinking or Agile Methodology [14] can also be taken as the complement for harmonizing different stakeholder needs/expectations, and decision-making process.

In engineering projects, Project Manager should also be identified as a stakeholder and with his team project, they play a key role in technological projects, establishing interoperability between pre-existing and new technologies and often bearing the brunt of tensions between the different stakeholders. The project manager is the key to success and must be agile in the decision-making process.

2.2 Technological Projects

Stakeholder engagement not only implies an increase in the probability of successful completion of the project—providing a strategic management perspective aimed at acquiring knowledge, adapting the project to users, and reducing conflict [15]. But the stakeholder engagement also has ethical implications: stakeholder participation can promote a social process which includes aspects related to corporate social responsibility, raising awareness, and changing attitudes and behaviors that may adversely affect the daily work of the company staff.

Globalization and the COVID-19 also have a great impact. The need to approach world projects and the availability of skilled, low-cost labor elsewhere have encouraged many companies to implement their projects in a virtual environment in a convulsive period with sanitary restrictions. Several authors have stood out the communication for its importance, when projects are carried out in a virtual environment with a different work culture, taking teamwork to a higher level [16, 17].

Stakeholder engagement and project manager's role in technological projects has been displayed. It is important to identify the moment/stage and how the stakeholder participated in the project [10, 18]. The active participation of members of an organization in identifying and engaging stakeholders in project decision-making can lead to the commitment necessary to ensure application of the criteria defined stakeholders involved and help achieve project success [19]. Project managers should be aware of the key role they play in managing stakeholders and understanding their needs, a change of governance with a 360-degree vision through a collaborative model [20].

With respect to the launch of new products and market success, aspects of great importance for technological projects, other authors have suggested that empirical research should focus not only on customer barriers, but also on all other stakeholders involved in the process (distributors, suppliers, and competitors) [21].

In the case of multiple projects, adequate definition of project scope by all parties involved is not sufficient. Other key factors for success are involved, such as staff experience (project manager and teamwork) and good communication, especially if resources have to be shared across different projects. Joint management is another type of business which allows risks reduces conflict among the various stakeholders and increases productivity levels [22, 23].

It is necessary to use new languages or extensions capable of representing the dynamism, interoperability, and multiple technologies of smart factories, and where Artificial Intelligence has a relevant role [24].

2.3 Artificial Intelligence (AI)

According to Schwab [25], Artificial Intelligence (AI) has made impressive advances, driven by the exponential increase in computing power and the availability of vast amounts of information. Some examples of AI use: algorithms to develop new drugs, consumer trends in society, or monitoring of industrial systems (case that concerns us).

The evolution of the labor market has also been analyzed by Schwab [25], the impact of Big Data in decision-making, so that companies and governments provide services and support in real time. Leveraging Big Data can automate and replace processes that today are performed manually, mainly the so-called white-collar workers (office, administration, and management tasks). Of course, this decision-making directly affects the labor market.

In the study by Frey and Osborne [26], the possibility that certain jobs could be absorbed by Artificial Intelligence and robotics, which could be automated, was

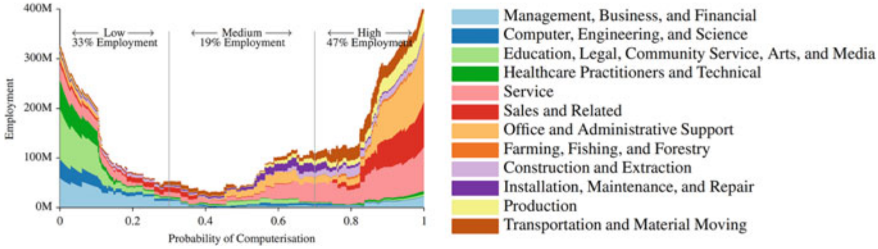

Fig. 1 Employment affected by automation. *Source* Frey and Osborne [26]

analyzed, obtaining a high impact rate. The results obtained predict that up to 47% of U.S. jobs in 2010 were prone to be automated in the next years (Fig. 1).

According to Schwab [25], the forecast is that processors will reach the same computing power as the human brain by 2025. At a top management level, Artificial Intelligence is already having a major impact, even forming part of the top management teams of organizations for decision-making. The clearest example is the AI called VITAL (Validating Investment Tool for Advancing Life Sciences), as indicated by different publications [27, 28]. Deep Knowledge Ventures has implemented AI to predict market trends that are invisible to human understanding, anticipating what is going to happen in terms of trading much further in advance than a group of human experts.

Technological projects that include artificial intelligence (case study) have made it possible to improve production control, integrating regulation, predictive models, and self-adjustment (flow, capacity, and raw material supply). In this context, it is important to highlight that the projects implemented have a direct impact on the reduction of plant operators, as well as white-collar workers, e.g., plant supervisors or quality control personnel.

3 Methodology and Case Study

3.1 *Methodology Applied for Analysis CSFs*

To overcome barriers to successful project management, stakeholder, and the impact of AI, it is important to detect critical success factors. According to Herath and Chong [29], critical success factors (CSFs) are those elements that are necessary for an organization to achieve success. Along the same lines, defined CSFs as those areas in which an organization must obtain satisfactory outcomes in order to achieve its mission, through digitization [30]. This theory can be applied to the detect CSFs in specific projects and in business digitalization, as has been done in other studies [31–33], the results of which have here been compiled and are shown in Table 1, included in the appendix with the corresponding references.

Table 1 Summary of projects. *Source* authors

ID Project	A	B	C	D	TOTAL
Type of Project	Operational improvement	New product development	Quality improvement	Technology transfer	
Average number of personnel involved	15 persons	30 persons	12 persons	10 persons	830 persons
Frequency	15	10	15	5	45
Percent	33,3	22,2	33,3	11,1	100,0
Cumulative Percent	33,3	55,6	88,9	100,0	
Initial time average project (T_initial)	3,8 months	7,6 months	4,2 months	5 months	PERIOD A
Final time average project (T_final)	7,6 months	14,3 months	10,7 months	11 months	
Time deviation	200%	185%	253%	220%	
Initial cost average project (C_initial)	34.000 €	172.000 €	34.000 €	10.000 €	
Final cost average project (C_final)	51.700 €	213.300 €	44.000 €	23.000 €	
Budget deviation	152%	124%	129%	230%	
Initial time average project (T_initial)	8,5 months	9,2 months	5,7 months	4,3 months	PERIOD B
Final time average project (T_final)	9,7 months	15,5 months	6,4 months	5,7 months	
Time deviation	113%	167%	112%	130%	
Initial cost average project (C_initial)	82.700 €	157.000 €	55.900 €	20.600 €	
Final cost average project (C_final)	51.300 €	170.500 €	57.600 €	21.000 €	
Budget deviation	62%	108%	103%	102%	

The questionnaires designed through the information extracted from Table 2, where the most significant CSFs, through this review, we have been drafted the questionnaires, and subsequently validated by experts using the DELPHI method.

This study attempts to detect the CSFs associated with different stakeholders in different technological projects (that integrate AI). Analysis based on 315 questionnaires administered to various stakeholders who had participated in 45 projects implemented in a manufacturing company, in a time interval of 10 years.

The questionnaires were completed by different key stakeholders. Thus, they were not limited solely to the opinions of clients/users and the organization in question, but also examined the direct or indirect impact of all other stakeholders. Among them are the project manager, project team members, sponsors, influential people, and the project management department itself. Participants scored each of the questionnaire items from Likert scale (1 = 'strongly disagree' to 5 = 'strongly agree').

An initial key aspect was to ensure selection of a statistically significant sample. This was achieved by calculating the number of questionnaires in order to estimate their mean overall satisfaction on a scale from 1 to 5 (Likert scale) with a 95% confidence interval, where the mean calculated for the sample would not differ by more than 0.25 points from the mean for the total stakeholder population [59], obtaining a minimum of 246 questionnaires.

Based on figures on a prior literature review, for the present study 45 projects were examined with 7 stakeholders per project, obtaining a total of 315 completed questionnaires. Consequently, the sample studied was statistically significant according to established quality indices.

The first methodological step was to define the scope, which entailed identifying all stakeholders with participation in the case study. For this, it was adopted the approach suggested in ISO 21500 [12], using the *Project Charter* and the *Project Organization Chart* in order to identify stakeholders and generate the resulting *Stakeholder Register*. The second stage comprised data collection. To this end, the indicators most frequently used in the technological projects implemented during the study period (scope, budget, project deliverables, and deviation) were grouped together. The questionnaires were then drawn up, incorporating the CSFs identified in the literature review, administered, and collected. Lastly, the research hypotheses on the relationship between the various CSFs were posited and analyzed using statistical tools, and conclusions were drawn.

The results obtained were divided into two groups: one comprised the factors associated with the stakeholders, and the other concerned the project success (dependent factor) and two groups of independent factors (Technical decisions supported through AI) and (Top management decisions supported through AI).

3.2 Case Study

The first contact of the European continent with tobacco was with the discovery of America. The Spanish Crown had the monopoly. Powdered tobacco from Cuba and

Table 2 State of the art (Success Factors)

Success factors from the literature	[34]	[35]	[36]	[37]	[38]	[39]	[40]	[41]
Corporate understanding				X			X	X
Common understanding with stakeholders on success criteria				X	X			
Executive commitment			X	X		X		X
Organizational adaptability		X						X
Communication			X		X	X		
Project manager selection criteria		X		X		X	X	X
Project manager leadership/empowerment	X	X			X	X		X
Environment			X				X	
Commitment to planning and control	X	X		X	X	X		X
Project mission and common goal and direction			X	X		X		
Top management support		X	X	X		X		
Client consultation and acceptance						X		X
Monitor performance and feedback	X	X	X	X	X	X		
Personnel and teamwork		X	X	X		X		X
Technical task ability	X	X	X			X	X	X
Trouble shooting and risk management				X		X	X	
Project ownership			X					
Urgency of project							X	
Duration and size of project							X	

(continued)

Table 2 (continued)

Success factors from the literature	[42]	[43]	[44]	[45]	[46]	[47]	[48]	[49]	[50]
Corporate understanding	X						X	X	X
Common understanding with stakeholders on success criteria					X		X	X	
Executive commitment	X							X	
Organizational adaptability						X	X		
Communication		X				X	X	X	X
Project manager selection criteria	X			X					X
Project manager leadership/empowerment	X			X	X				
Environment					X		X	X	
Commitment to planning and control		X		X			X		X
Project mission and common goal and direction		X	X				X		X
Top management support	X							X	
Client consultation and acceptance						X		X	X
Monitor performance and feedback			X	X					X
Personnel and teamwork	X		X	X	X		X	X	
Technical task ability					X				X
Trouble shooting and risk management			X		X				
Project ownership			X	X			X		
Urgency of project	X								X
Duration and size of project	X	X	X			X			

(continued)

Table 2 (continued)

Success factors from the literature	[51]	[52]	[53]	[54]	[55]	[56]	[57]	[58]
Corporate understanding			X	X		X	X	X
Common understanding with stakeholders on success criteria						X	X	X
Executive commitment	X			X				X
Organizational adaptability			X	X		X		
Communication								X
Project manager selection criteria	X			X	X		X	
Project manager leadership/empowerment					X	X		X
Environment		X	X	X	X	X		X
Commitment to planning and control	X		X		X			
Project mission and common goal and direction				X	X			
Top management support	X		X	X	X	X	X	
Client consultation and acceptance				X				X
Monitor performance and feedback			X				X	X
Personnel and teamwork	X	X	X	X	X	X		X
Technical task ability	X	X	X	X		X		
Trouble shooting and risk management		X		X				
Project ownership	X				X			
Urgency of project	X	X			X			
Duration and size of project	X	X			X			

Santo Domingo was important. At the beginning of the sixteenth century, the first tobacco manufacturing industries were established in the city of Seville, the first industries in Europe.

With an artisanal manufacturing, the tobacco industry had to reinvent itself, becoming a private company in 1998. The Spanish tobacco company was selected because it was initially a public company that was later privatized. Starting from high number of personnel to undergoing a technological renovation based on private capital. It is a clear example of automation and the application of artificial intelligence, allowing the drastic reduction of personnel.

Case study focused on technological projects directly related to tobacco product manufacture carried out under conditions of strict control as regards specific treatment parameters (temperature, humidity, toasting, and flavoring). Moreover, programmable logic controllers (PLCs) were used due to the large production volume in question (approximately 3,500 t/year–31,000 t/year, depending on the production process and the end product).

At 62%, the budget deviation in the period B (last five years) was significant in Type A—Operational Improvement projects, and this was mainly due to strategic management changes. The projects show a turning point with integration at the European level (other national tobacco companies).

There was also a time deviation of 167% in the period B (last five years) in Type B—New Product Development projects as a result of an overlap between different projects sharing the same resources. Since these were technological projects which in some cases required highly specialized personnel (PLC programming, calibration of communication network systems, etc.), the alternative of contracting new staff was not an option. Consequently, project implementation took longer than initial time estimates.

Technology was a key component of all of the projects selected for the present study, although the goals varied (operational improvement, new product development, quality improvement, or technology transfer).

The main characteristics and parameters of these projects have been grouped according to type in Table 1, in order to facilitate a clearer understanding of the scope of the present study.

In this study, various stakeholders who to a greater or lesser extent could influence the decisions taken in the projects were identified. Generally, external stakeholders are more difficult to identify and manage than internal ones. To identify stakeholders, the model was developed by Mitchell [11]. Figure 2 shows an example of an Operational Improvement project (ID Project A—Table 1) included in the present study.

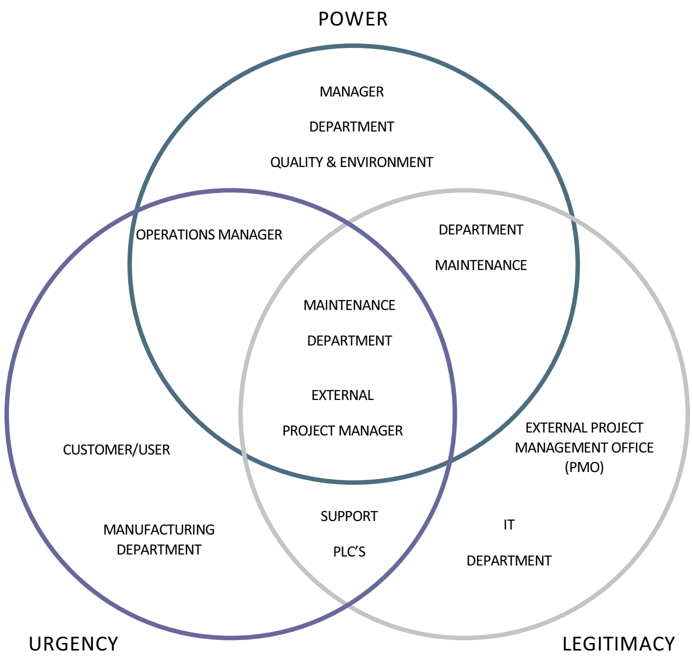

Fig. 2 Stakeholder typology for Type A projects. *Source* authors

4 Results

Questionnaire data were analyzed using the SPSS software package for statistical analysis as follows. Factor analysis was performed to reduce large sets of items to a smaller number of dimensions (based on questionnaire items), and the factors obtained were ranked according to mean and deviation values. A theoretical network was established based on the results obtained from factor analysis, hypotheses were posited, reliability analyses of the results were conducted (Kaiser–Meyer–Olkin measure, Bartlett's Test of Sphericity, and Cronbach's alpha), hypotheses were tested using linear regression models, the interrelationship graph was revised, and mean results obtained according to the statistically significant factors in this study.

4.1 Statistical Analysis

Factor analysis was structured on the dependent variables (Tables 3 and 4), and independent variables (Table 4). The varimax rotation method was used to determine the components.

Stakeholder (dependent variable) consists of two dimensions (Table 2), Factor 1 and Factor 2. Factor 1, which was analyzed according to stakeholder actions and influence on the project (named Stakeholder Actions and Influence), comprised 7 items (Q04, Q08, Q11, Q13, Q21, Q30, Q35), while Factor 2, which was analyzed according to stakeholder identification and communication (named Stakeholder Identification and Communication), comprised 3 items (Q01, Q02, Q15).

Project Success (dependent variable) consists of two dimensions (Table 3). Factor 1, which was analyzed according to inherent characteristics of the project (named Project Scope, Deliverables, and Expectations), comprised 5 items (Q06, Q19, Q26, Q31, Q36), while Factor 2, which was analyzed according to the project-stakeholder relationship (named Project and Relationships), comprised 3 items (Q03, Q23, Q25).

Factor analysis was also performed on 4 independent variables (Table 4).

Independent Factor 1, **Technical decisions supported through AI**, which included Commitment to Planning & Control; Personnel/Teamwork; Technical Task Ability, comprised 8 items (Q07, Q12, Q05, Q34, Q33, Q32, Q17, Q09) and range of factors 0,963 to 0.605.

Table 3 Factorial result for the dependent variable Stakeholder

Items	Factors	
	1	2
Q08—The project has directly led to improve or more effective decision-making or performance for the stakeholders	0.893	0.099
Q11—The different stakeholders were given the opportunity to provide input early in the project development stage	0.888	0.251
Q04—The stakeholders knew who to contact when problems or questions arise	0.868	0.124
Q30—The stakeholders understood their role on the project	0.86	0.399
Q35—The influence of different stakeholder on the project	0.792	0.474
Q21—The value of the project has been discussed with the different stakeholders	0.746	0.543
Q13—The limitations of the project have been discussed with the clients (what the project is not designed to do)	0.602	−0.29
Q02—The project leader possessed adequate information about the external stakeholder network	−0.148	0.93
Q01—The project leader possessed adequate information about the internal stakeholder network	0.284	0.787
Q15—The different stakeholders were kept informed of the project's progress	0.494	0.674
Eigenvalue	2.59	3.68
Percentage of Variance	59.76	17.86

Table 4 Factorial result for the dependent variable Success

Items	Factors	
	1	2
Q36—The Project has completely fulfilled my expectations	0.954	0.204
Q31—The project has completed on time	0.947	0.142
Q19—I am satisfied with the process by which the project was implemented	0.944	0.136
Q06—Given the problem for which it was developed, the project seems to do the best job of solving that problem	0.791	0.387
Q26—The project has completed according to the budget allocated	0.756	0.443
Q03—The project has no or minimal technical start-up problems because it was readily accepted by its intended users	0.001	0.907
Q25—The results of the project represent a definite improvement in performance over the way clients used	0.472	0.765
Q23—The project has made a positive impact on those who have participated	0.634	0.670
Eigenvalue	3.530	3.410
Percentage of Variance	69.396	15.112

Independent Factor 2, **Communication**, comprised 4 items (Q24, Q20, Q28, Q29) and range of factors 0.936 to 0.594.

Independent Factor 3, **Top management decisions supported through AI**, which included Top Management Support; Project Mission/Common Goal/Direction, comprised 4 items (Q14, Q16, Q22, Q18) and range of factors 0.959 to 0.644.

Independent Factor 4, **Monitor Performance and Feedback** comprised 2 items (Q27, Q10) and range of factors 0.760 to 0.597.

According to the factor analysis, the factors obtained are displayed in Table 5, allowing to obtain the theoretical framework include in Fig. 4. The model was also validated through Kaiser–Meyer–Olkin measure, Bartlett's Test of Sphericity, and Cronbach's alpha.

4.2 New Theoretical Framework

According to the regression analysis obtained (dependent and independent variables), a new theoretical framework was obtained, represented in Fig. 3, shown below the final discussion and conclusions.

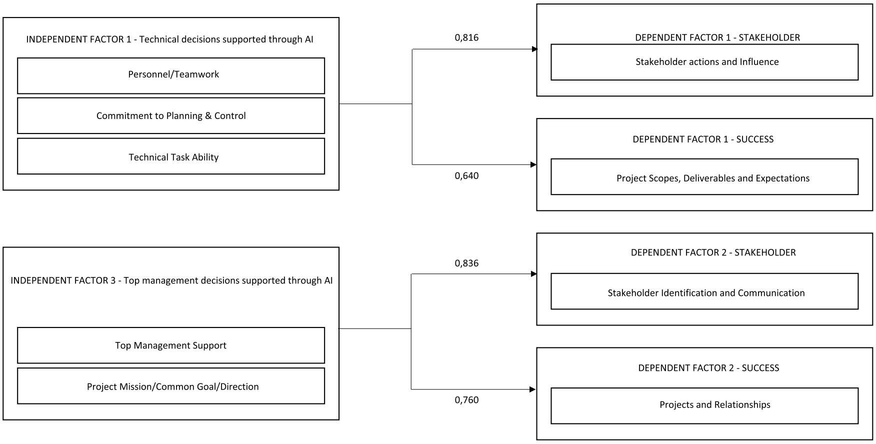

Fig. 3 Final theoretical framework based on the factor analysis. *Source* authors

5 Discussion

The present study has provided a more structured view of CSFs (Fig. 4), not only from the perspective of success, which has been thoroughly analyzed in the literature review (Table 2). Incorporating in this study the stakeholder management (action, influence, identification, and communication), where the figure of the project manager stands out.

The CSFs identified in this study can help to better understand dimensions such as top management support, personnel/teamwork, and technical task ability, aspects that should not be overlooked as they affect the decision-making process.

The model obtained indicates the importance of the project manager figure to manage technical projects both effectively and efficiently, taking an integrated approach which goes beyond achieving profit, budget, risk, and opportunity targets to consider behavioral and contextual competencies that facilitate the relationship between the organization, the team, and the work environment [8, 15, 16].

Results show the importance of Artificial Intelligence as a support top management support and establishing a well-defined project mission, as shown by independent factor 3 with a Standard Beta of 0.836. As regards the implementation of largely internal projects, we encountered large obstacles due to the company's functional organization—a widespread structure among service and industry companies—which rendered it difficult to identify project managers and their teams. This explains why fast and efficient data analysis (trends, historical, and predictive models) aids to the top management support. Artificial Intelligence is already having a major impact, even forming part of the top management teams of organizations for decision-making [25, 27, 28].

To end, the model raised by Mitchell [11] and applied in this study presents some limitations; while it may be useful in stable contexts, in the study described here, which dealt with technological projects, the impact of stakeholders varied in the project execution due to uncertainty factors, where the AI can reduce such uncertainty in process decision-making.

6 Conclusions

The know-how and experience of staff responsible for project tasks has become an influential factor in project success in changing environments [16, 17, 22, 23]. Furthermore, a clear understanding of the basic differences and similarities between projects can help project managers divide, allocate, and manage resources more efficiently [8]; better outcomes were reported in the questionnaires when the project concerned involved technical personnel with experience not only in production systems, in this instance tobacco handling and treatment, but also in aspects related to the IA system. In project management, we currently find tools that integrate artificial intelligence and help the project manager and his team in making technical decisions (e.g., ClickUp, Monday.com, Asana, Teamwork, Basecamp, Wrike, …). A command of technology proved to be a key aspect in the present study, where engineers play a key role, optimizing time through IA [8, 16, 30].

We conclude with the definition of two future lines of research for its development: (1) The use of Artificial Intelligence as an opportunity for companies to support decision-making. (2) The need to advance in the development of digital competences related to Artificial Intelligence, to obtain its maximum potential.

Acknowledgements This work is a deliverable of project financed Ref. PID2019-108669RB-100/AEI/https://doi.org/10.13039/501100011033 and Group PAIDI TEP-95. Also, the authors thank the review and technical work done by Salvador Fernando Capuz-Rizo in the Universitat Politècnica de València (UPV) that has provided the basis for this study.

Appendix

See Fig. 4 and Tables 3, 4, 5, 6

Table 5 Factorial result for independent variables

Items	Factors			
	1	2	3	4
Q07—Problems that arised were solved completely	0.963	0.127	−0.026	0.073
Q12—The appropriate technology (equipment, training programs, etc.) has been selected for project	0.934	0.099	0.187	0.193
Q05—The people implementing the project understood it	0.791	0.307	0.137	0.099
Q34—Adequate technical and /or managerial training was available for members of the project team	0.769	0.457	−0.091	0.270
Q33—The personnel on the project team understood how their performance will be evaluated	0.664	0.223	0.464	0.185
Q32—There was a detailed plan for the completion of the project	0.646	0.507	0.231	0.326
Q17—The technology that is being used to support the project worked well	0.642	0.394	0.200	0.201
Q09—The project leader has the ability to motivate team members and maintain a cohesive project team	0.605	0.579	0.213	0.438
Q24—The lessons learned are documented for used in the future	0.134	0.936	0.279	0.084
Q20—Individuals/groups supplying input have received feedback on the acceptance or rejection of input	0.543	0.632	0.273	0.236
Q28—The results of project reviews were regularly shared with all project personnel	0.587	0.596	0.193	0.417
Q29—Regular meetings to monitor project progress and improve the feedback to the project team	0.564	0.594	0.188	0.384
Q14—The goals of the project were in line with the general goals of the organization	0.191	0.063	0.959	0.109
Q16—Upper management shared responsibilities with project team for ensuring the project's success	−0.081	0.321	0.869	0.087
Q22—I agreed with upper management on the degree of my authority and responsibility for the project	0.064	0.187	0.847	0.205
Q18—The basic goals of the project were made clear to the project team	0.316	0.242	0.644	0.203
Q27—All important aspects of the project were monitored	0.330	0.310	0.421	0.760
Q10—The results of planning meetings were published and distributed to applicable personnel	0.456	0.576	0.208	0.597
Eigenvalue	3.074	2.517	3.735	2.385
Percentage of Variance	67.636	14.848	6.098	3.196

Table 6 Ranking of the independent and dependent variables

Items	Mean	Deviation	Rank
Variable Independent 3—Top Management Support & Project mission /common goal / direction	3,60	0,14	1
Variable Independent 1—Commitment to planning & control, Personnel / teamwork & Technical task ability	2,82	0,27	2
Variable Independent 2—Communication	2,10	0,39	3
Variable Independent 4—Monitor performance and feedback	2,02	0,32	4
Variable dependent Stakeholder—Stakeholder actions and influence	3,55	0,18	1
Variable dependent Success—Project scopes, deliverables, and expectations	3,40	0,08	2
Variable dependent Success—Project and Stakeholders	3,04	0,43	3
Variable dependent Stakeholder—Stakeholder identification and communication	2,17	0,31	4

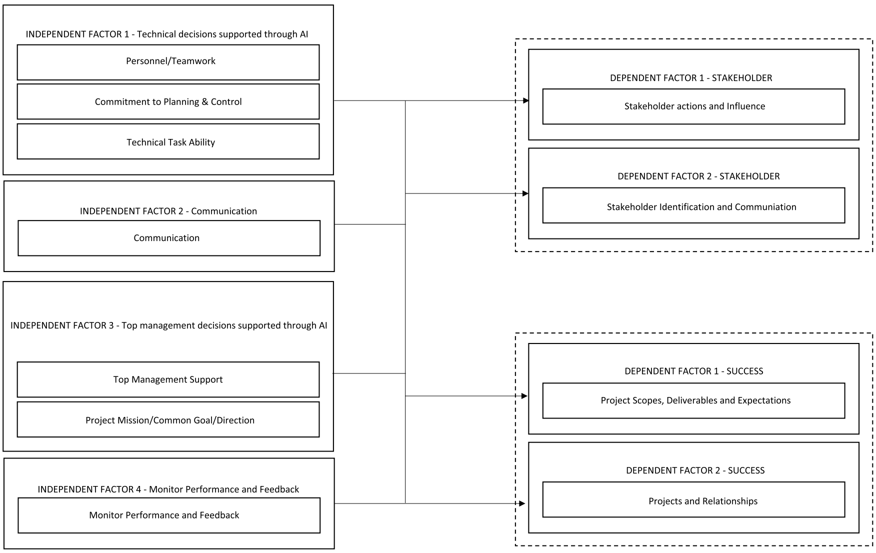

Fig. 4 Theoretical framework. *Source* authors

References

1. International Organization for Standardization. (2015). *9000:2015 - Quality management systems — Fundamentals and vocabulary*. https://www.iso.org/standard/45481.html
2. Project Management Institute. (2021). *The standard for project management and A guide to the project management body of knowledge (PMBOK® Guide) Seventh Edition*. Project Management Institute, Inc.

3. International Project Management Association. (2018). *IPMA Reference Guide ICB4 in an Agile World*. International Project Management Association (IPMA).
4. Gigliotti, M., & Runfola, A. (2022). A stakeholder perspective on managing tensions in hybrid organizations: Analyzing fair trade for a sustainable development. *Business Strategy and the Environment, 1–18*,. https://doi.org/10.1002/bse.3071
5. Freeman, R. E. (1984). *Strategic Management: A Stakeholder Approach.* Pitman Press.
6. Freeman, R. E., Phillips, R., & Sisodia, R. (2020). Tensions in Stakeholder Theory. *Business & Society, 59*(2), 213–231. https://doi.org/10.1177/0007650318773750
7. Zasa, F. P., Patrucco, A., & Pellizzoni, E. (2021). Managing the Hybrid Organization: How Can Agile and Traditional Project Management Coexist? *Research-Technology Management, 64*(1), 54–63. https://doi.org/10.1080/08956308.2021.1843331
8. Keding, C. (2021). Understanding the interplay of artificial intelligence and strategic management: Four decades of research in review. *Management Review Quarterly, 71*, 91–134. https://doi.org/10.1007/s11301-020-00181-x
9. Krchova, H., & Hoesova, K. S. (2020, November 05–06). *Generational differences in project management competencies self-assessment* [Paper presentation]. 13th International Scientific Conference on Reproduction of Human Capital - Mutual Links and Connection (RELIK), Prague, Czech Republic. https://relik.vse.cz/2020/download/pdf/318-Krchova-Hana-paper.pdf
10. Vanickova, R. (2021). The Influence of the Human Factor on the Success of the Localization Project of the Automated Technological Line for Wood Production. *TEM journal-technology education management informatics, 10*(1), 5–12. https://doi.org/10.18421/TEM101-01
11. Mitchell, R. K., Agle, B. R., & Wood, D. J. (1997). Toward a Theory of Stakeholder Identification and Salience: Defining the Principle of Who and what really Counts. *Academy of Management Review, 22*(4), 853–886. https://doi.org/10.2307/259247
12. International Organization for Standardization. (2021). *21500:2021 - Project, programme and portfolio management - Context and concepts.* https://www.iso.org/standard/75704.html
13. Bourne, L. (2022). Rethinking Communication: Project Management in the time of COVID. *PM World Journal*, *11*(9), 1–13. https://pmworldlibrary.net/wp-content/uploads/2022/09/pmwj121-Sep2022-Bourne-Rethinking-communication-pm-in-time-of-covid.pdf
14. Žostautiené, D., Susniené, D., & Mekiene, D. (2020). Design-Based Thinking Method in Business Management. *Modern Management Systems*, *15*(3), 39–50. https://doi.org/10.37055/nsz/132940
15. Kurnia, S., Kotusev, S., Shanks, G., Dilnutt, R., & Milton, S. (2021). Stakeholder engagement in enterprise architecture practice: What inhibitors are there? *Information and software technology, 134*, 106536. https://doi.org/10.1016/j.infsof.2021.106536
16. Hensen, B., & Klamma, R. (2021). VIAProMa: An Agile Project Management Framework for Mixed Reality. *Augmented reality, virtual reality, and computer graphics, 12980*, 254–272. https://doi.org/10.1007/978-3-030-87595-4_19
17. Taylor, S., Hoang, T., Aranda, G., Mulvany, G. T., & Greuter, S. (2021). Immersive Collaborative VR Application Design: A Case Study of Agile Virtual Design Over Distance. *International journal of gaming and computer-mediated simulations, 13*(4), 1–14. https://doi.org/10.4018/IJGCMS.291538
18. Panarotto, M., Isaksson, O., Habbassi, I., & Cornu, N. (2022). Value-Based Development Connecting Engineering and Business: A Case on Electric Space Propulsion. *IEEE Transactions on engineering management, 69*(4), 1650–1663. https://doi.org/10.1109/TEM.2020.3029677
19. Maqbool, R., & Amaechi, I. E. (2022). A systematic managerial perspective on the environmentally sustainable construction practices of UK. *Environmental science and pollution research, 29*(42), 64132–64149. https://doi.org/10.1007/s11356-022-20255-5
20. Aaltonen, K., & Turkulainen, V. (2022). Institutionalization of a collaborative governance model to deliver large, inter-organizational projects. *International Journal of operations & production management, 42*(8), 1294–1328. https://doi.org/10.1108/IJOPM-11-2021-0741
21. Castiglione, C., & Fiore, E. (2022). Sustainable production networks: A design methodology based on the cooperation among stakeholders. *Journal of cleaner production, 362*, 132308. https://doi.org/10.1016/j.jclepro.2022.132308

22. Thilakarathne, N., Rathnasinghe, A. P., Kulatunga, U., Thurairajah, N., & Weerasinghe, L. (2022). An investigation of the conflict management strategies in international construction joint ventures of Sri Lanka. *Journal of financial management of property and construction.* https://doi.org/10.1108/JFMPC-03-2022-0018
23. Sodangi, M. (2022). Towards attaining efficient joint ventures in international construction: The case of Saudi Arabia. *Engineering construction and architectural management*. https://doi.org/10.1108/ECAM-07-2021-0647
24. Sott., M. K., Furstenau, L. B., Kipper, L. M., Rodrigues, Y. P. R., Lopez-Robles, J. R., Giraldo, F. D., & Cobo, M. J. (2021). Process modeling for smart factories: Using science mapping to understand the strategic themes, main challenges and future trends. *Business Process Management Journal, 27*(5), 1391–14717. https://doi.org/10.1108/BPMJ-05-2020-0181
25. Schwab, K. (2017). *The Fourth Industrial Revolution.* Penguin Books.
26. Frey, C. B., & Osborne, M. A. (2017). The future of employment: How susceptible are jobs to computerisation? *Technological Forecasting and Social Change, 114*, 254–280. https://doi.org/10.1016/j.techfore.2016.08.019
27. Journal Credencial. (2016, December 23). *My boss is a robot*. Journal Credencial. https://bit.ly/3g7sAjT
28. Nikkei. (2017, May 10). *Artificial intelligence gets a seat in the boardroom.* Journal Nikkei. https://asia.nikkei.com/Business/Artificial-intelligence-gets-a-seat-in-the-boardroom
29. Herath, S., & Chong, S. C. (2021). Key Components and Critical Success Factors for Project Management Success: A Literature Review. *Operations and supply chain management-an international journal*, *14*(4), 431–443. https://doi.org/10.31387/oscm0470314
30. Leyh, C., Koeppel, K., Neuschl, S., & Pentrack, M. (2022). Analysis of Critical Success Factors for Successfully Conducting Digitalization Projects. *Information technology for management: Business and social issues, 442*, 3–25. https://doi.org/10.1007/978-3-030-98997-2_1
31. Klotz, S., Westner, M., & Strahringer, S. (2022). Critical Success Factors of Business-managed IT: It Takes Two to Tango. *Information systems management, 39*(3), 220–240. https://doi.org/10.1080/10580530.2021.1938300
32. Ali, M., Li, Z., Durrani, D. K., Shah, A. M., & Khuram, W. (2021). Goal clarity as a link between humble leadership and project success: The interactive effects of organizational culture. *Baltic journal of management, 16*(3), 407–423. https://doi.org/10.1108/BJM-09-2020-0341
33. Zhang, Q. W., Yang, S., Liao, P. C., & Chen, W. X. (2020). Influence Mechanisms of Factors on Project Management Capability. *Journal of management in engineering, 36*(5), 04020045. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000812
34. Sayles, L. R., & Chandler, M. K. (1971). *Managing Large Systems: Organizations for the Future*. Routledge.
35. Martin, C. C. (1976). *Project Management*. Amaco.
36. Cleland, D. I., & King, W. R. (1983). *Systems Analysis and Project Management*, (1st ed.). McGraw Hill.
37. Baker, B. N., Murphy, D. C., & Fisher, D. (2008). Factors Affecting Project Success. In D. I. Cleland & W. R. King (Eds.), *Project Management Handbook* (2nd ed., pp. 902–919). Van Nostrand Reinhold.
38. Locke, D. (1984). *Project Management*. St Martins Press.
39. Pinto, J. K. (1986). *Project implementation: A determination of its critical success factors, moderators, and their relative importance across the project life cycle.* University Microfilms.
40. Morris, P. W., & Hough, G. H. (1987). *The Anatomy of Major Projects.* John Wiley and Sons.
41. Kerzner, H. (1987). In search of excellence in project-management. *Journal of Systems Management, 38*(2), 30–39.
42. Wateridge, J. (1995). IT projects: A basis for success. *International Journal of Project Management, 13*(3), 169–172. https://doi.org/10.1016/0263-7863(95)00020-Q.
43. Clarke, A. (1999). A practical use of key success factors to improve the effectiveness of project management. *International Journal of Project Management, 17*(3), 139–145. https://doi.org/10.1016/S0263-7863(98)00031-3.

44. Cooke-Davies, T. (2002). The “real” success factors on projects. *International Journal of Project Management, 20*(3), 185–190. https://doi.org/10.1016/S0263-7863(01)00067-9.
45. Turner, R. J., & Müller, R. (2005). The project manager’s leadership style as a success factor on projects: A literature review. *Project Management Journal, 36*(2), 49–61.
46. Karlsen, J. T. (2008). Forming relationships with stakeholders in engineering projects. *European Journal of Industrial Engineering, 2*(1), 35–49. https://doi.org/10.1504/EJIE.2008.016328.
47. Yang, J., Shen, G. Q., Ho, M., Drew, D. S., & Chan, A. P. C. (2009). Exploring critical success factors for stakeholder management in construction projects. *Journal of Civil Engineering and Management, 15*(4), 337–348. https://doi.org/10.3846/1392-3730.2009.15.337-348.
48. Drinkwaard, W., Kirkels, A., & Romijn, H. (2010). A learning-based approach to understanding success in rural electrification: Insights from Micro Hydro projects in Bolivia. *Energy for Sustainable Development, 14*(3), 232–237. https://doi.org/10.1016/j.esd.2010.07.006.
49. Adamala, S., & Cidrin, L. (2012). Key success factors in business intelligence. *Journal of Intelligence Studies in Business, 1*(1). https://doi.org/10.37380/jisib.v1i1.19.
50. Mas-Machuca, M., & Costa, C. M. (2012). Exploring critical success factors of knowledge management projects in the consulting sector. *Total Quality Management & Business Excellence, 23*(11–12), 1297–1313. https://doi.org/10.1080/14783363.2011.637778.
51. Garg, P., & Garg, A. (2014). Factors influencing ERP implementation in retail sector: An empirical study from India. *Journal of Enterprise Information Management, 27*(4), 424–448. https://doi.org/10.1108/JEIM-06-2012-0028.
52. Yim, R.L., Castaneda, J. M., Doolen, T. L., Tumer, I. Y., & Malak, R. (2015). Exploring the relationship between rework projects and risk indicators. *Project Management Journal, 46*(4), 63–75. https://doi.org/10.1002/pmj.21509.
53. Villamarín García, J. M., & Díaz Pinzón, B. H. (2017). Key success factors to business intelligence solution implementation. *Journal of Intelligence Studies in Business, 7*(1). https://doi.org/10.37380/jisib.v7i1.215.
54. Martens, C. D. P., Franklin, J. M., Mauro, L. M., Silva, F. Q. P. D. E., & De Freitas, H. M. R. (2018). Linking entrepreneurial orientation to project success. *International Journal of Project Management, 36*(2), 255–266. https://doi.org/10.1016/j.ijproman.2017.10.005.
55. Barth, C., & Koch, S. (2019). Critical success factors in ERP upgrade projects. *Industrial management & data systems, 119*(3), 656–675. https://doi.org/10.1108/IMDS-01-2018-0016.
56. Zhang, Q., Yang, S., Liao, P. C., & Chen, W. (2020). Influence mechanisms of factors on project management capability. *Journal of Management in Engineering, 36*(5). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000812.
57. Ali, M., Li, Z., Durrani, D. K., Shah, A. M., & Khuram, W. (2021). Goal clarity as a link between humble leadership and project success: The interactive effects of organizational culture. *Baltic Journal of Management, 16*(3), 407–423. https://doi.org/10.1108/BJM-09-2020-0341.
58. Klotz, S., Westner, M., & Strahringer, S. (2022). Critical success factors of business-managed IT: it takes two to tango. *Information Systems Management, 39*(3), 220–240. http://doi.org/10.1080/10580530.2021.1938300.
59. Cohen, J. (1988). Statistical Power Analysis for the Behavioral Sciences. *Percentual and motor skills, 67*(3), 1007–1007.
60. Schuh, G., Guetzlaff, A., & Schollemann, A. (2022). Reduction of planning efforts for decision making under uncertainty in global production network design. *CIRP Annals-manufacturing technology, 71*(1), 385–388. https://doi.org/10.1016/j.cirp.2022.04.028
61. Pinto, J. K., and Slevin, D. P. (1989). Critical success factors in R-and-D projects. *Research-Technology Management, 32*(1), 31–35. https://doi.org/10.1080/08956308.1989.11670572.

The Relationship Between Objectives and Stages of Agile Implementation in Organizations

Andrei Plotnikov, Kürşat Demiryürek, and Hadi Amiri

Abstract The paper analyzes application of Agile in software development, revealing that Agile initially referred to software development, then in the context of agile began to be applied to the management of any processes in different fields and areas of knowledge. In this way, there was a shift. Therefore, "agile development methodology" and "agile management" may have different meanings. The survey results serve as the material for the study. These materials are interesting as they have the relevance of respondents to Agile. In addition, respondents answered the questions without additional incentives and could interrupt the survey at any time. 1,501 people have participated in the present survey. Purpose of the study: an exploration of the relationship between objectives and stages of agile implementation in organizations based on the opinions of developers. Within the present study, Pearson's rank correlation coefficient was used to calculate the interdependence between the variable "How many years has your company been applying Agile practices?" and the variable "Number of goals." To figure out the interdependence between respondents' answers to the question "what stage of Agile implementation is your company at?" and the variable "Number of goals" that the respondent associates with Agile, the Spearman rank correlation coefficient was used. The results showed that the number of Agile implementation goals depends on the level of Agile competencies in the organization: then higher the level of Agile competencies in the organization, then more goals the organization has. The results of the study enrich the knowledge of goal-setting in Agile. In addition, it can stimulate to consider the problem from a new point of view - the study of the evolution of goals from implementing Agile.

Keywords Agile · Product management · Project management · Digital transformation

A. Plotnikov (✉) · K. Demiryürek · H. Amiri
Ondokuz Mayıs University, Körfez, 19 Mayis Unv., 55270 Atakum/Sumsun, Turkey
e-mail: andreiplotnikovwork@gmail.com

K. Demiryürek
e-mail: kursatd@omu.edu.tr

H. Amiri
e-mail: hadi.amiri.2010@gmail.com

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_24

1 Introduction

Information technology (IT) has evolved astonishingly over the last 20–25 years. The improved IT environment has greatly enhanced an organization's ability to integrate various mediums and has expanded the choice of delivery vehicles for the organization. The rapid growth of information technology has made reasonably priced technology available with a tremendous potential to improve communication efficiency and effectiveness within and between organizations in support of agile business practices. Technology exists for any medium or combination of mediums (multimedia) suitable for conveying information in a rich, meaningful, and easily understood format [11].

The proliferation of IT has brought many changes to the organizational environment. Organizations can enlarge their operations into the global domain as they use technology.

Digital technology is transforming the services and business models of organizations and changing the structure of the economy and society. Organizations are becoming virtual, and there is a trend toward remote working. IT companies are gaining more weight in the GDP structure. The needs of society are becoming dependent on electronic devices: smart watches, smart homes, heart rate monitors, etc. These changes are taking place through the use of information technology. We can assume that digital transformation can be interpreted in different ways, as there are many approaches to the definition. First, it depends on the area of scientific interest in digital transformation studies. Secondly, it depends on the object of study. A sociologist, for example, will have a different view of digital transformation from a programmer. Digital transformation exists in Industry 4.0—the Internet of Things concept. This concept assumes that every physical object has integrated technology. The technology allows the physical object to interact with other entities. A key driver of the fourth industrial revolution is integrating cyber-physical systems into manufacturing processes.

Agile is an approach to digital transformation and optimization of internal software development processes. The essence of agile is the creation of product value, created in an unpredictable environment and rapid changes in the context of digital transformation. Thus, almost any company is now forced to become an IT company in one way or another. Simplifying processes, increasing velocity, and focusing on the customer will benefit any company, regardless of the industry. The limiting parameter for the transformation may be the company's size, the current level of culture in the organization, and its compliance with the basic principles of agile. The principles of agile are declared in the Agile Manifesto [2]. The Agile Manifesto is a document describing the values and principles of agile software development, proposed in February 2001 at a meeting of programmers.

The transition to agile approaches or NeoClassical Theory of Management is not due to continuous process optimization trend because of the general desire of managers to make these changes but to the variability of the environment and the increasing complexity of the systems and software to be produced. Thus, the understanding concerning the future result between developers and customers is different from each other. The solution to this problem and bringing to a common ground is business analysis, which acts as a bridge between customers and developers. Business intelligence has resulted, in part, in terms of reference—a document that outlines the requirements for the final software product. A further increase in the complexity of understanding processes and the development of the customer-centricity category called for the developer community to change its approach to constructing plans and the execution of tasks. Each new task appears as a result of reflection on the results of the previous task.

Agile development approaches in distributed teams have specific problems related to cultural differences, behavioral aspects, and different geographical distributions of employees. It generates another factor—different time zones so that all team members may have different activities simultaneously. Consequently, trust within teams, the basis for employee interaction, becomes very important.

Agile is a group of approaches. By approaches, we can mean both methodologies, models and methods. In this paper, we will not discuss what a methodology is and what a method is. It is only essential to understand that Agile is not classical management and not classical project management. If Agile is not classical management, it contains characteristics that are different from classical management. Agile contrasts itself with the predictive Waterfall model. The name "Waterfall" speaks to the essence of this model. Processes move from top to bottom, giving us the understanding that we cannot go back to previous tasks. Accordingly, we see rigidity in the Waterfall model. "Waterfall" refers to determinism. Determinism defines a causal relationship of events as a result of the completion of previous events. Agile refers to indeterminism. Indeterminism denies the objectivity of causality because subsequent events may involve more significant factors unknown at the event's time. The software development industry shifts from determinism to agile development approaches. A feature of agile approaches is the active participation of stakeholders throughout the development process [17]. Whereas deterministic approaches, based on classical theories to control, involve them in the initial stages, such as initiation or planning, as well as in the implementation of absolute control. Deterministic approaches predetermine the state of future objects based on resulting changes and initial plans, compliance with which is a principle of predictive models.

The Agile approach emerged because of a changing marketplace. Customers began to value rapid speed to market for products and began to be more flexible in formulating product requirements as the system's complexity increased. Flexibility started to manifest in an awareness among customers that software requirements may need to be completed or may be fragmented.

Purpose of the study: we will explore the relationship between objectives and stages of agile implementation in organizations based on the opinions of developers.

2 Literature Review

There are few comprehensive studies on Agile with a large field sample. There are only anecdotal case studies, and their number steadily increases yearly, which confirms the high interest in Agile among researchers. Moreover, there are studies in computer science: that implement Agile UX (User Experience) in the context of software startups [6], and the software team's evolution to self-organized collaboration practices, agile planning practices, and involved customer concentration depended on the customer's trust in the software team and flexible, collaborative routines [7]. Agile as social science: applying Agile principles to students' group work in project management [10]. There are papers in the business and management section: Researchers found that digital transformational leadership and organizational agility positively impact digital transformation, and digital transformational leadership impacts organizational agility [4], and researchers are exploring a lean and agile strategy for the supply chain in the construction industry based on an Agile approach [14]. Moreover, the focus of the examples mentioned above of articles is more related to the business and management section, as most of the papers need technical novelty.

Initially, agile methodologies were related to the information technology sector. Then in the context of agility, they began to be applied to the management of any processes in various fields and areas of knowledge. It is how it happened. Therefore, the articles "agile development methodology" and "agile management" refer to different objects and contents. Instead of technical novelty, a novelty in teamwork and productivity and velocity, relationships with customers, and others, is proposed. By the way, a lot of the work in the business and management section is related to something other than information technology, the domain of Agile, but to general organizational agility.

Goal setting in Agile can be seen in the context of critical roles in different Agile frameworks such as Scrum (the framework that allows developers to create value for the user through adaptive solutions to complex tasks), Kanban (development framework that implements the "just-in-time" principle), and others.

For example, consider the Scrum framework: the product owner prioritizes backlog. Prioritization balances arguments at the work planning stage and shows attention to changing conditions. Consequently, the value of the software is increased [16]. Scrum Master is responsible for the productivity and velocity of the team [12]. Self-organizing development teams in Agile instead of the structure in traditional management are collectively responsible for the sprint execution process, which includes task planning, performing, managing the tasks, following daily stand-ups, and communicating with the Scrum teams [8]. Therefore, team performance depends on maturity [9]. In addition, developer teams stimulate the technical perfection of the product to occur, at the expense of which quality is increased [3]. Product quality is a priority for both the customer and the developers; production speed is also crucial, so risk management should be consistent with these aspects [15]. The idea can be further developed by adding artifacts: burndown chart, sprint backlog, and product backlog [5]. The purpose of the above artifacts contains the goals of agile.

Further, we will consider the approach to goals in the example of a paper [13], which considers the move to Agile because of the desire to eliminate the hierarchical management structure. Leveling out the hierarchy cannot be the primary goal, so another more economic goal is to improve team results and enable working remotely. So here we see that the researcher can claim one goal, but it will hide another goal.

If we summarize the literature review on goal-setting in Agile, there can be many goals in different fields. Goals can be focused on the artifacts of Agile approaches. Objectives can be oriented toward Agile principles as well as Agile values. Therefore, the research topic is broad, and we are grateful for the opportunity to participate in this research.

3 Materials and Methods

The research materials are the data provided by ScrumTrek LLC—the results of the 2019 survey. This data is interesting because of the relevance of the respondents to Agile. In addition, the respondents answered the questions without additional incentives and could interrupt the survey at any time. This data has no shelf life, as it hides various patterns, the discovery of which will enrich Agile theory.

A total of 1,501 people from different cities (primarily Russian) took part in the survey. Respondents answered questions about the organization where they work. Thus, the results of the survey allow us to analyze the characteristics of the use of Agile in the following groups of organizations: IT (605 people, 40%), finance (341, 23%), telecommunications (64, 4%), and non-IT spheres (491, 33%). The survey report is available online at the link in the literature [1].

Participants in the survey came from various roles within their organizations, from senior managers and business owners to developers.

The distribution of employees by primary activity (role) varies across companies in different industries. The highest representation of middle managers is in telecoms, while top managers and company owners are in non-IT. Thus, the highest percentage of Scrum masters and Agile coaches is recorded in the financial sector organizations (26%), the maximum representation of project managers—in telecommunications and IT.

To calculate the interdependence between the variable "How many years has your company been applying Agile practices?" and the variable "Number of goals," the Pearson rank correlation coefficient was used, a parametric method used to examine the relationship between phenomena statistically. This method was used because, in this pair, both variables are quantitative and have a normal distribution (the normality of the distribution of the respective attributes is indicated by the asymptotic significance value, which for both variables takes a value less than 0.05. See Table 1).

Table 1 Kolmogorov–Smirnov one-sample test (testing variables for normality of distribution)

		Number of goals	How many years has your company been implementing Agile practices?
N		1501	1303
	Mean	2.64	3.19
Normal parameters [a,b]	standard deviation	2.412	2.590
Difference between Two Extremes	Module	0.214	0.177
	Positive	0.214	0.177
	Negative	-0.137	−0.113
Kolmogorov–Smirnov Z statistics		3.736	7.736
Asympt. value (two-sided)		0.000	0.000
a. Comparison with a normal distribution			
b. Estimated from the data			

Note The correlation tables use the following indications of the significance of correlations:
**—Correlation is significant at the 0.01 level (bilateral)
*—Correlation is significant at the 0.05 level (bilateral)

The Spearman rank correlation coefficient was used to calculate the interdependence between the respondents' answers to the question "What stage of Agile is your company at?" and the variable "Number of goals" that the respondent associates with Agile—this is a non-parametric method suitable for studying the relationship. This method was used based on the fact that, in this pair, one of the variables under study (the variable "At what stage of Agile implementation is your company in?") is ranked (not quantitative). Spearman's correlation calculation is used to assess the strength of the relationship between such variables.

When the correlation coefficient is used, the closeness of the relationship between the variables is conventionally estimated, considering values of the coefficient equal to. 0.3And less—The Indicators of the Weak Closeness of the Connection

Values more than 0.4 but less than 0.7—indicators of the moderate closeness of connection, and values of 0.7 and more—indicators of the high closeness of connection.

4 Results

The top 5 goals for which organizations implement Agile are as follows:

1. Improving the way they manage changing priorities (49% of employees of companies using Agile consider this goal to be relevant to their organization);
2. Improving product quality (46%);
3. Speeding up product delivery and time to market (45%);

Table 2 Goal alignment with Agile Manifesto principles

Goal	Agile Manifesto principle
Better ways of managing changing priorities (49%)	*Principle 1*
Improving the quality of products (46%)	*Principles: 2, 7, 9, 11*
Faster delivery and speed to market of products (45%)	*Principles: 1, 3, 8*
Improved project management transparency (43%)	*Principles: 4, 6*
Better alignment between business and IT and increased productivity (41%)	*Principles: 3, 4, 6, 7, 12*

4. Improved transparency of project management (43%);
5. Ensuring coordinated work of business and IT and increasing productivity (41% each).

Thus, more than a half of respondents associate the need for Agile with the need for companies to manage the company coherently and openly in a transformational environment while improving product quality and accelerating processes. The overall ranking of Agile goals as perceived by organizations' employees is shown in Table 3.

Next, let us determine the alignment of the goals with the Manifesto principles, see Table 2.

As we can see, the goals align with the Manifesto principles, which are logical and expected. "Ensure alignment of business and IT, and increase productivity" is the goal most consistent with the Manifesto and is in line with 5 of the 12 Agile Manifesto principles.

Logically, the set of Agile implementation goals depends on the level of Agile competence in an organization: the higher the level of Agile competence in an organization, the higher the proportion of its employees naming each Agile goal as relevant. See Fig. 1.

A weak trend is revealed: the more extended and more in-depth experience of Agile application an organization has, the more goals its employees associated with Agile. It is evidenced by the results of the correlation analysis between the respondents' answers to the "How many years has your company been applying Agile practices?" question and the number of organizational goals associated with Agile. This number is calculated based on respondents' answers to the multiple choice question, "What are your company's goals for implementing Agile?" (correlation coefficient $r = 0.106$ is weak and significant at the 0.01 level). Also, between the respondents' answers to the "What stage of Agile implementation is your company at?" question and the number of organizational goals that the respondent associates with Agile (correlation coefficient $r = 0.549$ is medium and significant at the 0.01 level), see Table 4.

This result should be interpreted as follows: the greater the value of the first variable, the greater the value of the second. However, based on this relationship alone, we cannot argue that the benefits of Agile implementation depend on the implementation stage. We can only argue that the indicators' dynamics are consistent over time. As Agile implementation deepens in organizations, the volume of benefits increases with a significant degree of probability.

Table 3 "What are the goals of implementing Agile in your company?"

No	Goal	%
1	Better manage to change priorities	49
2	Improve product quality	46
3	Speed up product delivery/market entry	45
4	Improve transparency of project management	43
5	Ensure alignment between business and IT	41
6	Increase productivity	41
7	Increase motivation of teams	35
8	Improve the predictability of delivery	25
9	Better manage distributed teams	23
10	Reduce project risks	21
11	Improve engineering culture	20
12	Facilitate product support	18
13	Reduce project costs	17
14	Other objectives	4
15	I don't know	2

The results of the correlation analysis suggest that the stage of Agile implementation has the most significant impact on the number of benefits such as

– management of changing priorities;
– acceleration of product delivery/market penetration;
– facilitation of product support;
– management of distributed teams;
– Ensuring alignment between business and IT.

5 Conclusion

Overall, it can be said that the goals of the Agile transition are in line with the Agile Manifesto [2], which was anticipated in advance because it makes no sense to expect goals from Agile that other companies have not tested.

Regarding an inevitable weak trend: the more experience Agile practices have, the more goals are pursued. This fact is likely due to the amount of experimentation during the experience of Agile approaches. The more practice, the higher the chance of benefiting from that practice. The number of goals achieves the increase in chance. If one of several goals is achieved, this one good result offsets the other unachieved goals.

The results of the study enrich the knowledge of goal-setting in Agile. In addition, it can stimulate to consider the problem from a new point of view—the study of the evolution of goals from implementing Agile. In addition, the following studies can

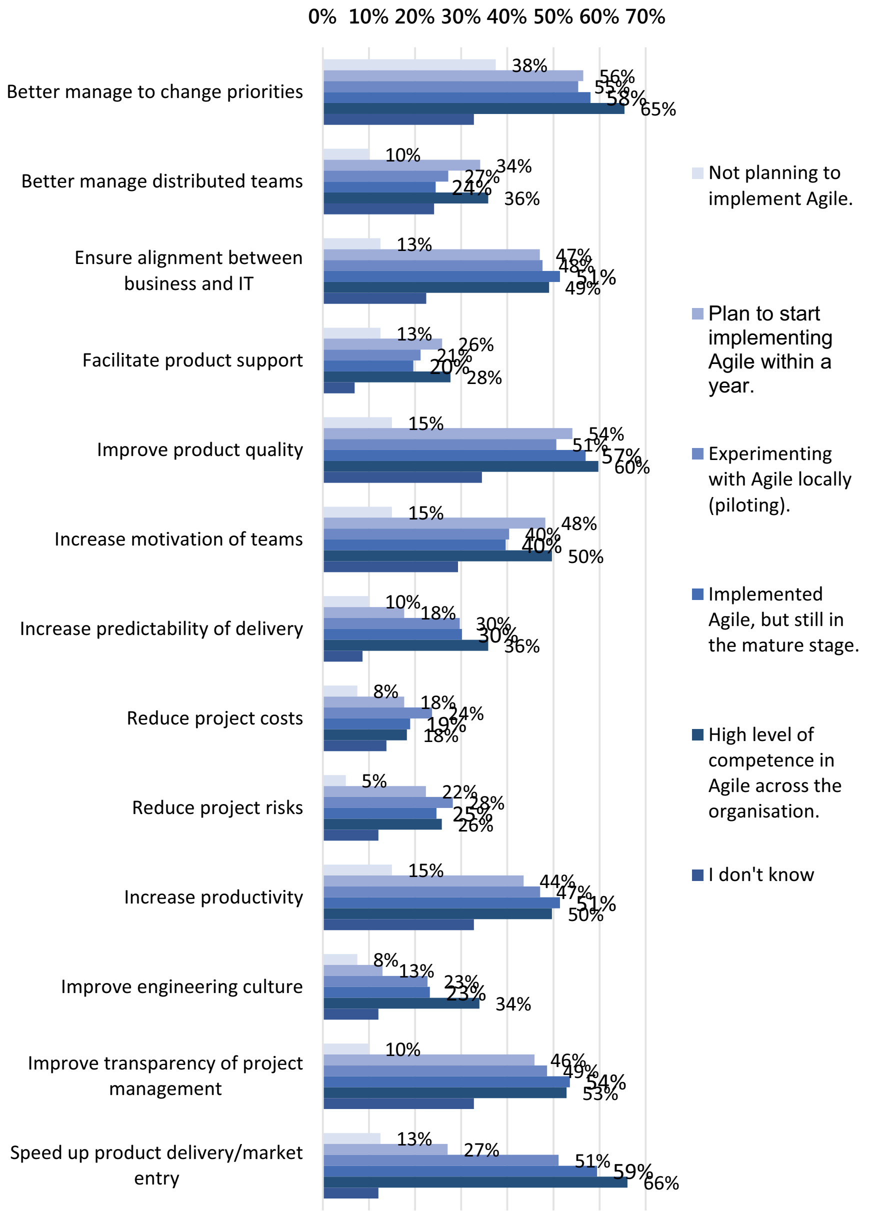

Fig. 1 "What are the objectives for implementing Agile in your company?", depending on the level of Agile competencies in the organization

Table 4 Results of the correlation analysis

		Number of goals
How many years has your company been implementing Agile practices?	Correlation coefficient	0.106**
	two-sided p-value	0.000
	N	1303
What stage of Agile implementation is your company at?	Correlation coefficient	0.549**
	two-sided p-value	0.000
	N	1443

determine the impact of goal-setting trends in organizations. Perhaps the content of goals is independent of Agile maturity but on trends.

In practice, the acquired knowledge can be applied to compose courses and training, focusing on the respondents' demand according to the Agile implementation goals.

Acknowledgements We thank ScrumTrek LLC (www.scrumtrek.ru): IT-Product Manager *Aleksei Evdokimov*, Agile-coach and Agile Transformation Expert *Sergei Rogachev* for the data. The study was supported by The Scientific & Technological Research Council Of Turkey (TUBITAK), The Department Of Science Fellowships & Grant Programs (BIDEB), 2221—Fellowship Program For Visiting Scientists And Scientists On Sabbatical Leave (2022/3).

References

1. Agile in Russia 2019. Annual Research Report: https://scrumtrek.ru/userfiles/reports/AgileSurvey19.pdf
2. Agile Manifesto https://agilemanifesto.org
3. Alami, A., Krancher, O., & Paasivaara, M. (2022). The journey to technical excellence in agile software development. *Information and Software Technology, 106959*,. https://doi.org/10.1016/j.infsof.2022.106959
4. AlNuaimi, B. K., Singh, S. K., Ren, S., Budhwar, P., & Vorobyev, D. (2022). Mastering digital transformation: The nexus between leadership, agility, and digital strategy. *Journal of Business Research, 145*, 636–648. https://doi.org/10.1016/j.jbusres.2022.03.038
5. Butt, S. A., Khalid, A., Ercan, T., Ariza-Colpas, P. P., Melisa, A. C., Piñeres-Espitia, G., & Ortega, R. M. (2022). A software-based cost estimation technique in scrum using a developer's expertise. *Advances in Engineering Software, 171*, 103159. https://doi.org/10.1016/j.advengsoft.2022.103159
6. Choma, J., Guerra, E. M., Alvaro, A., Pereira, R., & Zaina, L. (2022). Influences of UX factors in the Agile UX context of software startups. *Information and Software Technology, 152*, 107041. https://doi.org/10.1016/j.infsof.2022.107041
7. Ciriello, R. F., Glud, J. A., & Hansen-Schwartz, K. H. (2022). Becoming agile together: Customer influence on agile adoption within commissioned software teams. *Information & Management, 59*(4), 103645. https://doi.org/10.1016/j.im.2022.103645
8. Hinterhuber, A. (2022). Digital transformation, the Holy Grail, and the disruption of business models: An interview with Michael Nilles. *Business Horizons, 65*(3), 261–265. https://doi.org/10.1016/j.bushor.2021.02.042

9. Kadenic, M. D., Koumaditis, K., & Junker-Jensen, L. (2023). Mastering scrum with a focus on team maturity and key components of scrum. *Information and Software Technology, 153*, 107079. https://doi.org/10.1016/j.infsof.2022.107079
10. Marder, B., Ferguson, P., Marchant, C., Brennan, M., Hedler, C., Rossi, M., & Doig, R. (2021). 'Going agile': Exploring the use of project management tools in fostering psychological safety in group work within management discipline courses. *The International Journal of Management Education, 19*(3), 100519. https://doi.org/10.1016/j.ijme.2021.100519
11. McGaughey, R. E. (2001). *Application of Multimedia in Agile Manufacturing*. Elsevier.
12. Morandini, M., Coleti, T. A., Oliveira, E., Jr., & Corrêa, P. L. P. (2021). Considerations about the efficiency and sufficiency of the utilization of the Scrum methodology: A survey for analyzing results for development teams. *Computer Science Review, 39*, 100314. https://doi.org/10.1016/j.cosrev.2020.100314
13. Reunamäki, R., & Fey, C. F. (2022). Remote agile: Problems, solutions, and pitfalls to avoid. *Business Horizons*. https://doi.org/10.1016/j.bushor.2022.10.003
14. Sadeghi, S., Akbarpour, A., & Abbasianjahromi, H. (2022). Provide a Lean and Agile Strategy for an Antifragile Sustainable Supply Chain in the Construction Industry (residential complex). *Cleaner Logistics and Supply Chain, 5*, 100079. https://doi.org/10.1016/j.clscn.2022.100079
15. Silvius, A. G., Kampinga, M., Paniagua, S., & Mooi, H. (2017). Considering sustainability in project management decision making; An investigation using Q-methodology. *International Journal of Project Management, 35*(6), 1133–1150. https://doi.org/10.1016/j.ijproman.2017.01.011
16. Sverrisdottir, H. S., Ingason, H. T., & Jonasson, H. I. (2014). The role of the product owner in scrum-comparison between theory and practices. *Procedia-Social and Behavioral Sciences, 119*, 257–267. https://doi.org/10.1016/j.sbspro.2014.03.030
17. Tyagi, S., Sibal, R., & Suri, B. (2022). Empirically developed framework for building trust in distributed agile teams. *Information and Software Technology, 145*, 106828. https://doi.org/10.1016/j.infsof.2022.106828

Hierarchical Multi-agent Model for the Management of a Regional Industrial Network Complex

Andrey F. Shorikov

Abstract The paper considers the description of the dynamics and optimization of the regional network industrial complex in the presence of risks (disturbances) and information uncertainty. For their formalization, the economic-mathematical model in the form of a two-level multi-agent hierarchical intelligent semantic network is proposed. It describes the formalization of the problems of parameter identification, structurally balanced interaction, the prognosis of development and optimization of a guaranteed (minimax approach) result of managing the state of objects and processes of the regional industrial network complex in the presence of risks (disturbances) and information uncertainty within the proposed two-level multi-agent hierarchical intelligent semantic network. The paper presents the methodology for solving the tasks under consideration. The economic-mathematical model of the regional network industrial complex proposed in the article makes it possible to develop algorithms for optimizing the processes under study, which can serve as the basis for creating intelligent management decision support systems.

Keywords Multi-agent hierarchical control · Intelligent semantic network · Regional industrial · Network complex

1 Introduction

The network interaction of industrial enterprises in a particular region is determined by a number of factors and, above all, by the need for close information interaction in the implementation of regional projects, optimization of decision-making process management, increasing the speed of managerial decision-making, full use of regional logistics capabilities, etc. This interaction of enterprises is complicated by the presence of multifactors in its description, information uncertainty, and perturbations (risks).

A. F. Shorikov (✉)
Institute of Economics of the Ural Branch of the Russian Academy of Sciences, 29 Moskovkaya St, Ekaterinburg 620014, Russian Federation
e-mail: shorikov.af@uiec.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_25

When solving various tasks of optimizing the interaction management of regional industrial enterprises, there is a need to model the dynamics of the objects under consideration and related processes in order to achieve acceptable or the best (optimal) values of the selected criteria for the quality of their implementation. The basis for solving such problems is economic-mathematical modeling and digitalization of object interaction in the implementation of processes in such systems (see, for example, the studies [1, 2, 4, 6, 8, 9, 12, 14, 16, 19, 23–25, 28–30, 34, 37, 40, 42, 43, 47, 50], etc.).

The multi-agent toolkit, network modeling, and minimax approach are used here in for the formalized description of the dynamics and optimization of the functioning of regional network industrial complex objects in the presence of risks (disturbances) and information uncertainty in order to optimize the guaranteed results of the management processes under study. The results obtained in the work are based on the research [3, 20, 21, 39–42, 45] and are closely related to the research [1, 2, 4, 14, 18, 19, 24, 25, 36, 43].

2 Literature Review

The level of development of industrial production in the region determines its economic potential and socio-economic condition. The region's industrial enterprises have a key influence on all other economic activities in the region, create the majority of jobs, have a major impact on the development of inter-regional relations, develop inter-sectoral links, and are the main taxpayers. The regional industrial network complex is a complex object of management, influenced by various factors. In this regard, there are various tasks of regional network industrial complex management, which require research in the field of economic and mathematical modeling and solving optimization problems.

There is a different understanding of the regional industrial complex as an object of research and management in scientific literature. In the scientific works [5, 11, 12, 16], etc., the object composition of the industry is described as a set of enterprises with production capabilities and manufacturing industrial products or providing production services. Various aspects of the functioning of regional network industrial complexes have been studied in the papers [1–3, 7, 15, 17, 27, 28, 33, 35, 38], etc.

The main object of the study of regional network industrial complexes is a production enterprise. When solving various problems of management optimization at production enterprises, there is a need to model the dynamics of the objects under consideration in order to predict the acceptable values of the main parameters describing their state in a particular time period. Based on the model of particular production enterprise dynamics, it becomes possible to investigate the problems of optimizing the management of the relevant processes with the purpose of achieving the acceptable or the best (optimum) values of the selected quality criteria of their implementation.

The issues of management optimizing for the processes related to the functioning of production enterprises are actively investigated in the framework of various approaches. For example, the paper [29] describes the methodology for optimizing the process of enterprise production management based on the linear mathematical programming model. Based on the developed methodology, the authors created a software product for the automation of managerial decision-making, the description of which is also given in the work. The article [50] considers the management of medical enterprise activity in order to optimize corporate social responsibility. In this work, the formalization of the initial problem in the form of a non-linear mathematical programming model is proposed. The model formed is linearized, and on its basis, the authors have developed an iterative heuristic algorithm that makes it possible to exclude the repetition of computational operations. The proposed algorithm is also described in the paper, and results of computer simulation, ensuring acceptable results in solving the initial problem, are presented. The scientific work [44] is devoted to the problem of multi-criteria optimization of enterprise production activity management (production of ceramic bearings). To solve the problem of finding compromise solutions, the authors use a linear mathematical programming model and analyze various acceptable solutions. The article [10] investigates the task of multicriteria optimization of enterprise production management. The solution to the problem under consideration is carried out with the use of the scalarization method of the vector target function, i.e. transformation of the original problem to the standard linear mathematical programming problem. The paper presents the results of a numerical experiment in MatLab.

In [31], the problem of cost optimization in the production of given volumes of products was considered. To solve it, a linear discrete-time multistep economic-mathematical model and dynamic programming method in modification [46] were used. The paper [13] considers a differential model of dynamic production planning optimization with a convex target function, which uses the Cobb–Douglas production function. Necessary optimality conditions in the form of Pontryagin's maximum principle are analyzed to find a solution. In [24], a discrete-time dynamical model of a "digital twin" of a production enterprise (using the example of a television equipment assembly plant) is proposed. This paper describes an approach based on the combined application of discrete event and agent-based simulation methods. A conceptual model of a digital factory with software implementation in the AnyLogic simulation environment is proposed. The paper [18] considers dynamical economic and mathematical models of management of various socio-economic processes.

Based on the above brief review of typical works adjacent to the topic of this study, the following conclusions can be made:

(1) the problems of modeling the dynamics of production enterprises are complex and relevant to the study of network industrial complexes;
(2) the majority of works on management optimization of production enterprises use static models of linear mathematical programming and different variants of the simplex method for the numerical solution of optimization problems;

(3) in works, which use nonlinear mathematical programming models, for the numerical solution of optimization production tasks, linearization methods of initial models are developed, which transform them into corresponding linear mathematical programming models, or gradient, heuristic, and other methods are developed;
(4) the solution of dynamical problems of the management optimization of production enterprises in the presence of various technical and economic constraints is based on the use of linear or nonlinear, multi-step, or differential economic-mathematical models, within which various modifications of dynamic programming methods, the maximum principle of Pontryagin, agent-based modeling, etc. are used to find optimal solutions.

3 Methods

Modeling the dynamics of regional network industrial complexes and solving the problems of optimization of relevant processes require the development of new economic and mathematical tools that take into account the specifics of the objects under study.

The basis for the development of automated and intelligent systems of management decision support for complex multifactor economic systems are economic-mathematical models of the objects and processes under consideration. One of the most common and intensively developing approaches to modeling socio-economic processes is the method of multi-agent or agent-based modeling (ABM). This method allows modeling complex dynamical systems to take into account the presence of heterogeneous agents and their interaction in a structured environment to achieve their goals. Then on the basis of the models generated using the ABM method, it is possible to develop effective tools for computer simulation of socio-economic systems functioning, as well as to solve complex practical problems. The results closest to the subject matter of this paper, using the ABM tools and taking into account the specifics of the Russian economy, as well as the development of social processes, are presented, for example, in the following works [4, 14, 19, 24–26, 30, 37, 40, 42], etc. The results of foreign specialists in the field of modeling socio-economic processes using ABM tools and network modeling are presented, for example, in the studies [6, 8, 9, 32, 47–49], etc.

It should be noted that within the application of the ABM method, there is a need to simulate the dynamics of specific agents in order to predict the acceptable values of the main parameters describing their state at a particular time, as well as to manage the processes in question in order to achieve acceptable or the best (optimal) values of the selected quality criteria of their implementation. Dynamical economic-mathematical models of management of various socio-economic processes are presented, for example, in the works [13, 14, 18, 22, 24, 31, 32, 36, 40, 41, 43, 46], etc.

One of the main tasks in the functioning of a regional industrial network complex is to create a tool to manage the dynamics of the objects and processes of the complex in order to ensure optimal or acceptable values of its performance indicators. The solution to this problem requires the availability of an information system, which makes it possible to forecast the state of the main parameters characterizing the objects and processes of the complex. At that, in the real situations of the functioning of a regional network industrial complex, unforeseen a priori situations arise or negative perturbations are realized, which should be taken into account when developing the economic-mathematical toolkit. For this purpose, it is necessary to have the corresponding economic-mathematical models and methods allowing for the optimization of the regional industrial network complex management taking into account the available technical and economic limitations, the presence of perturbations, and given target functions.

In this article, the problems of description of the dynamics and optimization of the regional network industrial complex functioning in the presence of risks (perturbations) and information uncertainty are considered. The economical and mathematical model in the form of a two-level multi-agent hierarchical intelligent semantic network is proposed for their formalization. It describes the formalization of the problems of parameter identification, structurally balanced interaction, the prognosis of development and optimization of a guaranteed (minimax approach) result of managing the condition of objects and processes of the regional industrial network complex in the presence of risks (disturbances) and information uncertainty within the framework of the proposed two-level multi-agent hierarchical intelligent semantic network. The paper provides a methodology for solving the problems under consideration.

This paper adjoins the studies [1, 2, 4, 14, 18, 19, 24, 25, 36, 43] and is based on the results of [3, 20, 21, 39–42, 45].

4 Results

4.1 Formalization of the Dynamics of a Two-Level Multi-agent Hierarchical Intelligent Semantic Network

The regional industrial complex is assumed to have a network multiagent organization and to consist of n industrial enterprises, $n \in \mathbf{N}$ (here and further, $\mathbf{N}$ is the set of all natural numbers) with parent enterprises—objects I_i, $i \in \overline{1,n} = \{1, 2, \ldots, n\}$, managed by their respective dominant agents P_i, which have different objectives and information support tools for management decision-making. Each i-th enterprise—the object I_i ($i \in \overline{1,n}$) may have subdivisions (workshops or branches)—subordinate objects II_{ij}, $j \in \overline{1, j_i}$ ($j_i \in \mathbf{N}$), managed by subordinate agents E_{ij}.

Below, the authors present the formalization of a *two-level multi-agent hierarchical intelligent semantic network* to describe the dynamics and optimization of the functioning of objects and processes of a regional industrial network complex in the presence of risks (disturbances) and information uncertainty, which formulates the considered in the paper problem of the guaranteed (minimax) optimization of the regional industrial network complex functioning, as a *two-level hierarchical minimax network management problem.*

The management process of a regional industrial network complex is considered in the given integer time period $\overline{0, T} = \{0, 1, \ldots, T\}$ $(T \in \mathbf{N})$.

Let us identify the following elements required to formalize the proposed two-level multi-agent hierarchical intelligent semantic network (all formalization elements are dimensionless):

$\left\{\mathbf{X}_*^{(i)}(t), \mathbf{U}_*^{(i)}(t), \mathbf{V}_*^{(i)}(t), \mathbf{S}_*^{(i)}(t), \mathbf{L}^{(i)}(t), \mathbf{M}^{(i)}(t), \mathbf{N}^{(i)}(t), \mathbf{K}^{(i)}(t), \mathbf{F}_t^{(i)}\right\}$ is a tuple of heterogeneous data describing constraints and conditions on the state of the i-th production enterprise (object I_i) in the time period $t \in \overline{0, T}$, managed by the agent P_i $(i \in \overline{1, n})$, where

$\mathbf{X}_*^{(i)}(t)$ is a polyhedron compact in the space $\mathbf{R}^{k_i}$ $(\mathbf{X}_*^{(i)}(t) \subset \mathbf{R}^{k_i})$, *limiting the change of the vector* $X^{(i)}(t) = \left\{X_1^{(i)}(t), X_2^{(i)}(t), \ldots, X_{k_i}^{(i)}(t)\right\}$—*the phase vector of an object* I_i in the time period $t \in \overline{0, T}$, the coordinates of which characterize the volumes of finished goods, materials, components, raw materials, etc. in that time period (this set describes the available technical and economic constraints on the parameters of the object I_i), $k_i \in \mathbf{N}$(here and further, for $k \in \mathbf{N}$, $\mathbf{R}^k$ is the k-dimensional vector space of column vectors, even if they are written in a row to save space);

$\mathbf{U}_*^{(i)}(t)$ is a finite set in the space $\mathbf{R}^{p_i}(\mathbf{U}_*^{(i)}(t) \subset \mathbf{R}^{p_i})$, *limiting the change of the vector* $U^{(i)}(t) = \left\{U_1^{(i)}(t), U_2^{(i)}(t), \ldots, U_{p_i}^{(i)}(t)\right\}$—*the vector of the control action (or simply control) of the agent* P_i in the time period $t \in \overline{0, T-1}$, the coordinates of which characterize, for example, the intensity of use of the production technology available in the enterprise, the amount of investment finance, etc. in that period of time (this set defines the available management resources of the agent P_i), $p_i \in \mathbf{N}$;

$\mathbf{V}_*^{(i)}(t)$ is a polyhedron compact in the space $\mathbf{R}^{q_i}$ $(\mathbf{V}_*^{(i)}(t) \subset \mathbf{R}^{q_i})$, *limiting the change of the vector* $V^{(i)}(t) = \left\{V_1^{(i)}(t), V_2^{(i)}(t), \ldots, V_{q_i}^{(i)}(t)\right\}$—the *vector of uncontrolled disturbances (risks)* over a period of time $t \in \overline{0, T-1}$, affecting the operation of the object I_i, the coordinates of which characterize, for example, the rate of inflation, damage from insurance claims, etc. in that period of time (this set is determined, for example, on the basis of available statistical data on the functioning of the object I_i and solving the corresponding forecasting problem), $q_i \in \mathbf{N}$;

$\mathbf{S}_*^{(i)}(t)$ is a polyhedron compact in the space $\mathbf{R}^{s_i}(\mathbf{S}_*^{(i)}(t) \subset \mathbf{R}^{s_i})$, *limiting the change of the vector* $S^{(i)}(t) = \left\{S_1^{(i)}(t), S_2^{(i)}(t), \ldots, S_{s_i}^{(i)}(t)\right\}$—*the demand vector for the object* I_i *products* in the time period $t \in \overline{0, T}$, the coordinates of which characterize the volume of demand for its products in that time period (this set is determined, for example, as a result of solving the relevant forecasting problem or is set a priori),$s_i \in \mathbf{N}$;

$\mathbf{L}^{(i)}(t) = \left\{L_1^{(i)}(t), L_2^{(i)}(t), \ldots, L_{l_i}^{(i)}(t)\right\}$ is a tuple of data describing the *conditions and constraints on the information supply of the agent* P_i in the decision-making process over a time period $t \in \overline{0, T}$, e.g. description of access to required databases, functions describing information signals, etc.,$l_i \in \mathbf{N}$;

$\mathbf{M}^{(i)}(t) = \{(i, m_1), (i, m_2), \ldots, (i, m_i)\}$ is an array of integer pairs defining the *existence of information links between the management entities of a regional industrial network complex* in the time period $t \in \overline{0, T}$, e.g. in terms of providing commercial information, using existing databases, etc., where a pair of $(i, k), k \in \overline{m_1, m_i}$ identifies the existing information link between the agents P_i and $P,\ P_k,\ E_{ij},\ j \in \overline{1, j_i}$, $m_i \in \overline{1, n}$;

$\mathbf{N}^{(i)}(t) = \{(i, 1), (i, 2), \ldots, (i, j_i)\}$ is an array of integer pairs defining the *existence of control relationships* between the control entities of a regional industrial network complex in the time period $t \in \overline{0, T}$, e.g. in terms of the provision of investment resources, technology, etc., where a pair $(i, j), j \in \overline{1, j_i}$, identifies the existing management relationship between the agents P_i and $P,\ E_{ij},\ j_i \in \mathbf{N}$;

$\mathbf{K}^{(i)}(t) = \{(i, k_1), (i, k_2), \ldots, (i, k_i)\}$ is an array of integer pairs defining the *existence of a relationship between the management entities* of a regional industrial network complex in the time period $t \in \overline{0, T}$, e.g. relations of subordination, equality, following, dominance, etc., where the pair $(i, k), k \in \overline{k_1, k_i}$ determines the existing relationship between the agents P_i and $P,\ P_k,\ E_{ij},\ j \in \overline{1, j_i}, k_i \in \overline{1, n}$;

$\mathbf{F}_t^{(i)}$ is the *target function of the agent* P_i, which is a real function of many variables, given by the representation of $\mathbf{F}_t^{(i)} : \mathbf{R}^{k_i} \rightarrow \mathbf{R}^1$, whose values for each $X^{(i)}(t) \in \mathbf{X}_*^{(i)}(t)$ are determined according to the formula $\mathbf{F}_t^{(i)} = \mathbf{F}_t^{(i)}\big(X^{(i)}(t)\big)$ and assess the quality of the phase vector state $X^{(i)}(t)$ of the object I_i in the time period $t \in \overline{0, T}$, such as the profits of that enterprise during that period of time;

$\Big\{\overline{\mathbf{X}}_*^{(ij)}(t), \overline{\mathbf{U}}_*^{(ij)}\big(t; U^{(i)}\big), \overline{\mathbf{V}}_*^{(ij)}(t), \overline{\mathbf{S}}_*^{(ij)}(t),\ \overline{\mathbf{L}}^{(ij)}(t),\ \overline{\mathbf{M}}^{(ij)}(t),\ \overline{\mathbf{K}}^{(ij)}(t),\ \overline{\mathbf{N}}^{(ij)}(t), \overline{\mathbf{F}}_t^{(ij)}\Big\}$ is a tuple of heterogeneous data describing constraints and conditions on the state of the j-th subdivision (object II_{ij}) of the i-th enterprise (object I_i) in the time period $t \in \overline{0, T},\ j \in \overline{1, j_i}\ (j_i \in \mathbf{N})$, managed by the agent $E_{ij}\ (i \in \overline{1, n})$, where

$\overline{\mathbf{X}}_*^{(ij)}(t)$ is a polyhedron compact in the space $\mathbf{R}^{\overline{k}_{ij}}$ ($\overline{\mathbf{X}}_*^{(ij)}(t) \subset \mathbf{R}^{\overline{k}_{ij}}$), *limiting the change of the vector* $\overline{X}^{(ij)}(t) = \Big\{\overline{X}_1^{(ij)}(t), \overline{X}_2^{(ij)}(t), \ldots, \overline{X}_{\overline{k}_{ij}}^{(ij)}(t)\Big\}$—the phase vector of the object II_{ij} in the time period $t \in \overline{0, T}$, the coordinates of which characterize the volumes, for example, of finished goods, materials, components, raw materials, etc. in that time period (this set describes the available technical and economic constraints on the object II_{ij} parameters), $\overline{k}_{ij} \in \mathbf{N}$;

$\overline{\mathbf{U}}_*^{(ij)}\big(t; U^{(i)}(t)\big)$—for each control vector $U^{(i)}(t) = \Big\{U_1^{(i)}(t), U_2^{(i)}(t), \ldots, U_{p_i}^{(i)}(t)\Big\} \in \mathbf{U}_*^{(i)}(t)$ of the agent P_i in the time period $t \in \overline{0, T-1}$, there is a finite set in the space $\mathbf{R}^{\overline{p}_{ij}}$($\overline{\mathbf{U}}_*^{(ij)}(t; U^{(i)}(t)) \subset \mathbf{R}^{\overline{p}_{ij}}$), limiting the change of the vector $\overline{U}^{(ij)}(t) = \Big\{\overline{U}_1^{(ij)}(t), \overline{U}_2^{(ij)}(t), \ldots, \overline{U}_{\overline{p}_{ij}}^{(ij)}(t)\Big\}$—*the vector of the control action (or simply control) of the agent* E_{ij} in the time period $t \in \overline{0, T-1}$, the coordinates of which characterize, for example, the intensity of use of the production technology, the amount of investment funds, etc., available in the j-th subdivision of the i-th production enterprise in this time period (this set defines the admissible management resources of the agent E_{ij}), $\overline{p}_{ij} \in \mathbf{N}$;

$\overline{\mathbf{V}}_{*}^{(ij)}(t)$ is a polyhedron compact in the space $\mathbf{R}^{\overline{q}_{ij}}$ ($\overline{\mathbf{V}}_{*}^{(ij)}(t) \subset \mathbf{R}^{\overline{q}_{ij}}$), *limiting the change of the vector* $\overline{V}^{(ij)}(t) = \left\{\overline{V}_{1}^{(ij)}(t), \overline{V}_{2}^{(ij)}(t), \ldots, \overline{V}_{\overline{q}_{ij}}^{(ij)}(t)\right\}$—the *vector of uncontrolled disturbances (risks)* in the time period $t \in \overline{0, T-1}$, affecting the operation of the object II_{ij}, the coordinates of which characterize e.g. the rate of inflation, damage from insurance claims, etc. for that period of time (this set is determined, for example, on the basis of available statistical data on the operation of the object II_{ij} and solving the corresponding forecasting problem),$\overline{q}_{ij} \in \mathbf{N}$;

$\overline{\mathbf{S}}_{*}^{(ij)}(t)$ is a polyhedron compact in the space $\mathbf{R}^{\overline{s}_{ij}}$ ($\overline{\mathbf{S}}_{*}^{(ij)}(t) \subset \mathbf{R}^{\overline{s}_{ij}}$), *limiting the change of the vector* $\overline{S}^{(ij)}(t) = \left\{\overline{S}_{1}^{(ij)}(t), \overline{S}_{2}^{(ij)}(t), \ldots, \overline{S}_{\overline{s}_{ij}}^{(ij)}(t)\right\}$—*the demand vector for the products of the object* II_{ij} in the time period $t \in \overline{0, T}$, which coordinates characterize the volume of demand for its products in that time period (this set is determined, for example, as a result of solving a relevant forecasting problem or is set a priori), $\overline{s}_{ij} \in \mathbf{N}$;

$\overline{\mathbf{L}}^{(ij)}(t) = \left\{\overline{L}_{1}^{(ij)}(t), \overline{L}_{2}^{(ij)}(t), \ldots, \overline{L}_{\overline{l}_{ij}}^{(ij)}(t)\right\}$ is a tuple of data describing the *conditions and constraints on the information supply of the agent* E_{ij} in the decision-making process in the time period $t \in \overline{0, T}$, e.g. description of access to required databases, functions describing information signals, etc.,$\overline{l}_{ij} \in \mathbf{N}$;

$\overline{\mathbf{M}}^{(ij)}(t) = \{(i, 1), (i, 2), \ldots, (i, j_i)\}$ is an array of integer pairs defining the *presence of control subject information links* the j-th subdivision of the object I_i in the time period $t \in \overline{0, T}$, e.g. in terms of providing commercial information, using existing databases, etc., where the pair (i, j), $j \in \overline{1, j_i}$, identifies the existing information link between the agents E_{ij} and P_i, $i \in \overline{1, n}$, $j_i \in \mathbf{N}$;

$\overline{\mathbf{K}}^{(ij)}(t) = \{(i, 1), (i, 2), \ldots, (i, j_i)\}$ is an array of integer pairs defining the *existence of management links between management subjects* of the j-th subdivision of the object I_i in the time period $t \in \overline{0, T}$, e.g. in terms of the provision of investment resources, technology, etc., where the pair (i, j), $j \in \overline{1, j_i}$, identifies the existing management link between the agents E_{ij} and P_i, $i \in \overline{1, n}$, $j_i \in \mathbf{N}$;

$\overline{\mathbf{N}}^{(ij)}(t) = \left\{(i, \overline{n}_1), (i, \overline{n}_2), \ldots, (i, \overline{n}_{j_i})\right\}$ is an array of integer pairs defining the *existence of a relationship between the management subjects* of the j-th subdivision of the object I_i in the time period $t \in \overline{0, T}$, e.g. relations of subordination, equality, following, dominance, etc., where the pair (i, k), $k \in \overline{\overline{n}_1, \overline{n}_{j_i}}$ determines the existing relationship between the agents E_{ij} and P_i, E_{ik}, $i \in \overline{1, n}$, $j \in \overline{1, j_i}$, $\overline{n}_{j_i} \in \mathbf{N}$;

$\overline{\mathbf{F}}_{t}^{(ij)}$ is the *target function of the agent* E_{ij}, which is a real function of many variables, given by the representation $\overline{\mathbf{F}}_{t}^{(ij)} : \mathbf{R}^{\overline{k}_{ij}} \to \mathbf{R}^{1}$, the values of which for each $\overline{X}^{(ij)}(t) \in \overline{\mathbf{X}}_{*}^{(ij)}(t)$ are determined according to the formula $\overline{\mathbf{F}}_{t}^{(ij)} = \overline{\mathbf{F}}_{t}^{(ij)}\left(\overline{X}^{(ij)}(t)\right)$ and assess the quality of the phase vector state $\overline{X}^{(ij)}(t)$ of the object II_{ij} in the time period $t \in \overline{0, T}$, e.g. the profits of that enterprise during that period of time.

Note that tuples of data $\left\{\mathbf{X}_*^{(i)}(t), \mathbf{U}_*^{(i)}(t), \mathbf{V}_*^{(i)}(t), \mathbf{S}_*^{(i)}(t),\ \mathbf{L}^{(i)}(t),\ \mathbf{M}^{(i)}(t), \mathbf{N}^{(i)}(t), \mathbf{K}^{(i)}(t), \mathbf{F}_t^{(i)}\right\}$ and $\left\{\overline{\mathbf{X}}_*^{(ij)}(t), \overline{\mathbf{U}}_*^{(ij)}(t; U^{(i)}(t)), \overline{\mathbf{V}}_*^{(ij)}(t), \overline{\mathbf{S}}_*^{(ij)}(t), \overline{\mathbf{L}}^{(ij)}(t), \overline{\mathbf{M}}^{(ij)}(t), \overline{\mathbf{K}}^{(ij)}(t), \overline{\mathbf{N}}^{(ij)}(t), \overline{\mathbf{F}}_t^{(ij)}\right\}$ are specified in a digital form, i.e. as binary codes, where $U^{(i)}(t) \in \mathbf{U}_*^{(i)}(t)$.

For $i \in \overline{1,n}$ let the operator $\Phi_t^{(i)}$ (e.g. linear [13]) be defined by the representation.

$$\Phi_t^{(i)} : \overline{0,T-1} \times \mathbf{R}^{k_i} \times \mathbf{R}^{p_i} \times \mathbf{R}^{q_i} \times \mathbf{R}^{s_i} \times \mathbf{A}^{(i)}(t) \to \mathbf{R}^{k_i}, \tag{1}$$

which for each collection of data $\left(t, X^{(i)}(t), U^{(i)}(t), V^{(i)}(t), S^{(i)}(t), A^{(i)}(t)\right) \in \overline{0,T-1} \times \mathbf{R}^{k_i} \times \mathbf{R}^{p_i} \times \mathbf{R}^{q_i} \times \mathbf{R}^{s_i} \times \mathbf{A}^{(i)}(t)$ determines a single phase vector $X^{(i)}(t+1)$, namely.

$$\begin{gathered} X^{(i)}(t+1) = \Phi_{\mathbf{t}}^{(\mathbf{i})}\left(\mathbf{t}, \mathbf{X}^{(\mathbf{i})}(\mathbf{t}), \mathbf{U}^{(\mathbf{i})}(\mathbf{t}), \mathbf{V}^{(\mathbf{i})}(\mathbf{t}), \mathbf{S}^{(\mathbf{i})}(\mathbf{t}), \mathbf{A}^{(\mathbf{i})}(\mathbf{t})\right), \\ X^{(i)}(0) = X_0^{(i)}, \end{gathered} \tag{2}$$

where $A^{(i)}(t) \in \mathbf{A}^{(i)}(t)$ and the tuple $\mathbf{A}^{(i)}(t) = \left\{\mathbf{L}^{(i)}(t), \mathbf{M}^{(i)}(t), \mathbf{N}^{(i)}(t), \mathbf{K}^{(i)}(t), \mathbf{F}_t^{(i)}\right\}$ defines the *existing links, structural and functional parameters of the object* I_i *and the agent* P_i in the time period $t \in \overline{0,T-1}; X_0^{(i)}$ is the given initial value of the phase vector of the object I_i.

The recurrent operator Eq. (2) describes *the controlled dynamics of the phase vector of the object* I_i.

It is assumed that the phase vector $X^{(i)}(t) = \left\{X_1^{(i)}(t), X_2^{(i)}(t), \ldots, X_{k_i}^{(i)}(t)\right\}$ of the object I_i in each time period $t \in \overline{0,T}$ *satisfies a given constraint*

$$X^{(i)}(t) \in \mathbf{X}_*^{(i)}(t) \subset \mathbf{R}^{k_i}, \tag{3}$$

where $\mathbf{X}_*^{(i)}(t)$ is a convex polyhedron compact in the space $\mathbf{R}^{k_i}$ (here and further, by definition, it is assumed that the one-element sets in the finite-dimensional vector spaces under consideration are convex polyhedron compacts); the control vector $U^{(i)}(t) = \left\{U_1^{(i)}(t), U_2^{(i)}(t), \ldots, U_{p_i}^{(i)}(t)\right\}$ of the agent P_i in each period of time $t \in \overline{0, T-1}$ satisfies *a given constraint*

$$U^{(i)}(t) \in \mathbf{U}_*^{(i)}(t) \subset \mathbf{R}^{p_i},$$

$$\mathbf{U}_*^{(i)}(t) = \left\{U^{(i)}(t) : U^{(i)}(t) \in \left\{U^{(i,1)}(t), U^{(i,2)}(t), \ldots, U^{\left(i, K_t^{(i)}\right)}(t)\right\} \subset \mathrm{R}^{P_i}\right\}, \tag{4}$$

where $\mathbf{U}_*^{(i)}(t)$ is a finite set of vectors, i.e. a finite set consisting of $K_t^{(i)}$ ($K_t^{(i)} \in \mathbf{N}$) vectors in the space $\mathbf{R}^{p_i}$; the vector of uncontrolled disturbances (risks) $V^{(i)}(t) = \left\{V_1^{(i)}(t), V_2^{(i)}(t), \ldots, V_{q_i}^{(i)}(t)\right\}$, affecting the operation of the object

I_i, in each time period $t \in \overline{0, T-1}$ satisfies *a given constraint*

$$V^{(i)}(t) \in \mathbf{V}_*^{(i)}(t) \subset \mathbf{R}^{q_i}, \tag{5}$$

where $\mathbf{V}_*^{(i)}(t)$ is a convex polyhedron compact in the space $\mathbf{R}^{q_i}$; the demand vector $S^{(i)}(t) = \left\{S_1^{(i)}(t), S_2^{(i)}(t), \ldots, S_{s_i}^{(i)}(t)\right\}$ for the product of the object I_i in each period of time $t \in \overline{0, T}$ satisfies a *given constraint*

$$S^{(i)}(t) \in \mathbf{S}_*^{(i)}(t) \subset \mathbf{R}^{s_i}, \tag{6}$$

where $\mathbf{S}_*^{(i)}(t)$, for each $t \in \overline{0, T}$, is a convex polyhedron compact in the space $\mathbf{R}^{s_i}$.

Further, for $i \in \overline{1, n}$ and $j \in \overline{1, j_i}$ let the operator $\overline{\Phi}_t^{(ij)}$(e.g. linear [13]) be defined by the representation

$$\overline{\Phi}_t^{(ij)} : \overline{0, T-1} \times \mathbf{R}^{\overline{k}_{ij}} \times \mathbf{R}^{p_i} \times \mathbf{R}^{\overline{p}_{ij}} \times \mathbf{R}^{\overline{q}_{ij}} \times \mathbf{R}^{\overline{s}_{ij}} \times \overline{\mathbf{A}}^{(ij)}(t) \to \mathbf{R}^{\overline{k}_{ij}}, \tag{7}$$

which for each collection of data $\left(t, \overline{X}^{(ij)}(t), U^{(i)}(t), \overline{U}^{(ij)}(t), \overline{V}^{(ij)}(t), \overline{S}^{(ij)}(t), \overline{A}^{(ij)}(t)\right) \in \overline{0, T-1} \times \mathbf{R}^{\overline{k}_{ij}} \times \mathbf{R}^{p_i} \times \mathbf{R}^{\overline{p}_{ij}} \times \mathbf{R}^{\overline{q}_{ij}} \times \mathbf{R}^{\overline{s}_{ij}} \times \overline{\mathbf{A}}^{(ij)}(t)$ determines a single phase vector $\overline{X}^{(ij)}(t+1)$ of the object II_{ij}, namely

$$\overline{X}^{(ij)}(t+1) = \overline{\Phi}_t^{(ij)}\left(t, \overline{X}^{(ij)}(t), U^{(i)}(t), \overline{U}^{(ij)}(t), \overline{V}^{(ij)}(t), \overline{S}^{(ij)}(t), \overline{A}^{(ij)}(t)\right),$$

$$\overline{X}^{(ij)}(0) = \overline{X}_0^{(ij)}, \tag{8}$$

where $\overline{A}^{(ij)}(t) \in \overline{\mathbf{A}}^{(ij)}(t)$ and the tuple $\overline{\mathbf{A}}^{(ij)}(t) = \left\{\overline{\mathbf{L}}^{(ij)}(t), \overline{\mathbf{M}}^{(ij)}(t), \overline{\mathbf{N}}^{(ij)}(t), \overline{\mathbf{K}}^{(ij)}(t), \overline{\mathbf{F}}_t^{(ij)}\right\}$ determines the *existing links and the structural and functional parameters of the object* II_{ij} *and the agent* E_{ij} in the time period $t \in \overline{0, T-1}$; $\overline{X}_0^{(ij)}$ is the given initial value of the phase vector of the object II_{ij}.

The recurrent operator Eq. (8) describes the *controlled dynamics of the phase vector of the object* II_{ij}.

It is assumed that the phase vector $\overline{X}^{(ij)}(t) = \left\{\overline{X}_1^{(ij)}(t), \overline{X}_2^{(ij)}(t), \ldots, \overline{X}_{\overline{k}_{ij}}^{(ij)}(t)\right\}$ of the object II_{ij} in each time period $t \in \overline{0, T}$ satisfies *a given constraint*

$$\overline{X}^{(ij)}(t) \in \overline{\mathbf{X}}_*^{(ij)}(t) \subset \mathbf{R}^{\overline{k}_{ij}}, \tag{9}$$

where $\overline{\mathbf{X}}_*^{(ij)}(t)$ is a convex polyhedron compact in the space $\mathbf{R}^{\overline{k}_{ij}}$; for each control vector $U^{(i)}(t) = \left\{U_1^{(i)}(t), U_2^{(i)}(t), \ldots, U_{p_i}^{(i)}(t)\right\} \in \mathbf{U}_*^{(i)}(t)$ of the agent P_i in the time period $t \in \overline{0, T-1}$, the control vector $\overline{U}^{(ij)}(t) = \left\{\overline{U}_1^{(ij)}(t), \overline{U}_2^{(ij)}(t), \ldots, \overline{U}_{\overline{p}_{ij}}^{(ij)}(t)\right\}$

of the agent E_{ij} in this period of time satisfies a given constraint

$$\overline{U}^{(ij)}(t) \in \overline{\mathbf{U}}_*^{(ij)}\big(t; U^{(i)}(t)\big) \subset \mathbf{R}^{\overline{p}_{ij}},$$

$$\overline{\mathbf{U}}_*^{(ij)}\big(t; U^{(i)}(t)\big) = \Big\{\overline{U}^{(ij)}(t) : \overline{U}^{(ij)}(t) \in$$

$$\in \Big\{\overline{U}^{(ij,1)}(t), \overline{U}^{(ij,2)}(t), \ldots, U^{(ij,\overline{K}_t^{(ij)})}(t)\Big\} \subset \mathbf{R}^{\overline{p}_{ij}}\Big\}, \tag{10}$$

where $\overline{\mathbf{U}}_*^{(ij)}\big(t; U^{(i)}(t)\big)$, for each $t \in \overline{0, T-1}$, is a finite set of vectors, i.e. a finite set consisting of $\overline{K}_t^{(ij)}$ ($\overline{K}_t^{(ij)} \in \mathbf{N}$) vectors in the space $\mathbf{R}^{\overline{p}_{ij}}$; the vector of uncontrolled disturbances (risks)$\overline{V}^{(ij)}(t) = \Big\{\overline{V}_1^{(ij)}(t), \overline{V}_2^{(ij)}(t), \ldots, \overline{V}_{\overline{q}_{ij}}^{(ij)}(t)\Big\}$, affecting the operation of the object II_{ij}, in each time period $t \in \overline{0, T-1}$ satisfies *a given constraint*

$$\overline{V}^{(ij)}(t) \in \overline{\mathbf{V}}_*^{(ij)}(t) \subset \mathbf{R}^{\overline{q}_{ij}}, \tag{11}$$

where $\overline{\mathbf{V}}_*^{(ij)}(t)$, for each $t \in \overline{0, T-1}$, is a convex polyhedron compact in the space $\mathbf{R}^{\overline{q}_{ij}}$; the demand vector $\overline{S}^{(ij)}(t) = \Big\{\overline{S}_1^{(ij)}(t), \overline{S}_2^{(ij)}(t), \ldots, \overline{S}_{\overline{s}_{ij}}^{(ij)}(t)\Big\}$ for the product of the object II_{ij} in each time period $t \in \overline{0, T}$ satisfies *a given constraint*

$$\overline{S}^{(ij)}(t) \in \overline{\mathbf{S}}_*^{(ij)}(t) \subset \mathbf{R}^{\overline{s}_{ij}}, \tag{12}$$

where $\overline{\mathbf{S}}_*^{(ij)}(t)$, for each $t \in \overline{0, T}$, is a convex polyhedron compact in the space $\mathbf{R}^{\overline{s}_{ij}}$.

The resulting dynamical system (1)–(12) is an economic-mathematical model that describes the dynamics and existing constraints on the main elements of the industrial network complex.

4.2 Description of Links and Relationships in a Two-Level Multi-agent Hierarchical Intelligent Semantic Network

Let us describe the links in the proposed two-level multi-agent hierarchical intelligent semantic network.

Primarily, consider the logical, informational, and control links available to the subjects of management of the regional industrial complex.

The activities of a set of agents P_i, $i \in \overline{1, n}$, is coordinated by the coordinating agent P, controlling the generalized object I, describing the dynamics of a regional industrial network complex, for which all agents P_i and E_{ij}, and objects managed by them I_i, $i \in \overline{1, n}$, and II_{ij},$j \in \overline{1, j_i}$, of the system under consideration, *are equal.*

The agent P assesses the state of the regional industrial network complex in the time period $t \in \overline{0, T}$ by the values of the target function $\mathbf{F}_t$, which are determined on the basis of a linear combination of the values of the target functions $\mathbf{F}_t^{(i)}$, defined on admissible realizations of the phase vectors $X^{(i)}(t)$ of the objects I_i, by assigning coefficients of significance λ_i, $i \in \overline{1, n}$. In fact, it allows the agent P to manage the behavior of the agents P_i and E_{ij},$i \in \overline{1, n}$, $j \in \overline{1, j_i}$.

Figure 1 shows the symbols for information links, control links, and relationships between agents and objects.

Figure 2 shows a diagram of the relationships and structural links between the objects and entities of the semantic network in question.

It is assumed that each of the dominant agent $P_i (i \in \overline{1, n})$, in each time period $t \in \overline{0, T}$, knows the state of the phase vector $X^{(i)}(t)$ of the object I_i, managed by him, and the state of the phase vectors $\overline{X}^{(ij)}(t)$ of the objects II_{ij},$j \in \overline{1, j_i}$, managed by the agents E_{ij}, $j \in \overline{1, j_i}$, and subordinating to him. Given that, in each time period $t \in \overline{0, T}$, the agent P_i informs each agent E_{ij}, $j \in \overline{1, j_i}$, about his control choices $U^{(i)}(t) \in \mathbf{U}_*^{(i)}(t)$, and in turn, each of the agents E_{ij} informs agent P_i about the control choices $\overline{U}^{(ij)}(t) \in \overline{\mathbf{U}}_*^{(ij)}\left(t; U^{(i)}(t)\right)$. It follows, by virtue of the given constraint (10), that the behavior of each subordinate agent E_{ij}, $j \in \overline{1, j_i}$, clearly depends on the behavior of the dominant agent P_i $(i \in \overline{1, n})$.

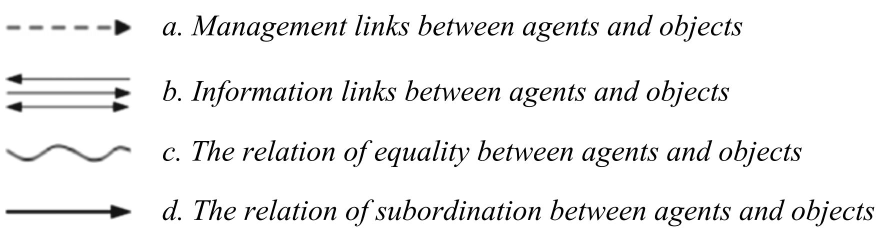

Fig. 1 The designations of information links, management links, and relationships between agents and objects

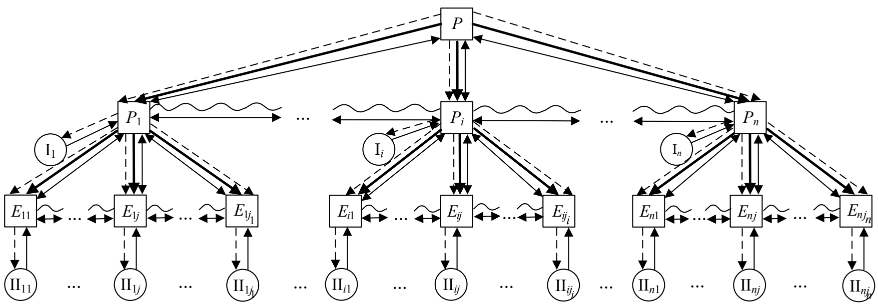

Fig. 2 Scheme of relationships and structural links between objects and subjects of the semantic network. *Source* Compiled by the author

Each of the subordinate agent E_{ij} $(i \in \overline{1,n}, j \in \overline{1, j_i})$, in each time period $t \in \overline{0,T}$, knows the state of the phase vector $\overline{X}^{(ij)}(t)$ of the object II_{ij}, which he managements, and knows the control $U^{(i)}(t) \in \mathbf{U}_*^{(i)}(t)$ of the agent P_i, communicated to him by the latter. Based on the data available, the agent E_{ij} implements the formation of his control $\overline{U}^{(ij)}(t) \in \overline{\mathbf{U}}_*^{(ij)}\left(t; U^{(i)}(t)\right)$, which depends on the behavior of the dominant agent P_i.

It is assumed that the coordinating agent P in each time period $t \in \overline{0, T-1}$ has full information on the choice of controls $U^{(i)}(t) \in \mathbf{U}_*^{(i)}(t)$ by the agents P_i , $i \in \overline{1,n}$, on the choice of controls $\overline{U}^{(ij)}(t) \in \overline{\mathbf{U}}_*^{(ij)}\left(t; U^{(i)}(t)\right)$ by the agents E_{ij}, $j \in \overline{1, j_i}$, and has full information about the state of the phase vectors $X^{(i)}(t)$ of the objects I_i, $i \in \overline{1,n}$, and $\overline{X}^{(ij)}(t)$, as well as the objects II_{ij},$j \in \overline{1, j_i}$. In each time period $t \in \overline{0, T-1}$, the agent P is interested in such behavior of each agent $P_i (i \in \overline{1,n})$, so that for each admissible realization of the phase vector $X^{(i)}(t)$ of the object I_i, it could organize the choice of his control $U^{(i)}(t) \in \mathbf{U}_*^{(i)}(t)$, which would guarantee him the minimum value of a given target function $\mathbf{F}_{t+1}^{(i)}$, defined on the phase vectors $X^{(i)}(t+1)$, taking into account possible worst-case risk vector realizations for him $V^{(i)}(t)$ and the demand vector $S^{(i)}(t)$, i.e. which would *define a minimax result*, provided that the subordinate agents E_{ij}, $j \in \overline{1, j_i}$, also contribute to this goal (here $X^{(i)}(t+1) = \Phi_t^{(i)}\left(t, X^{(i)}(t), U^{(i)}(t), V^{(i)}(t), S^{(i)}(t), A^{(i)}(t)\right)$, $X^{(i)}(0) = X_0^{(i)}$).

The aggregate of the agents P, P_i and E_{ij}, $i \in \overline{1,n}$, $j \in \overline{1, j_i}$ and the objects they manage I, I_i and II_{ij}, $i \in \overline{1,n}$,$j \in \overline{1, j_i}$, forms *the dominant regional level of networked industrial complex management level I*. Each agent E_{ij} $(i \in \overline{1,n}$, $j \in \overline{1, j_i})$, in each time period $t \in \overline{0, T-1}$, has full information on control choices $U^{(i)}(t) \in \mathbf{U}_*^{(i)}(t)$ made by the agent P_i to shape the control $\overline{U}^{(ij)}(t) \in \overline{\mathbf{U}}_*^{(ij)}\left(t; U^{(i)}(t)\right)$ and has full information on the state of the phase vector $\overline{X}^{(ij)}(t)$ of the object II_{ij}, managed by him. In each time period $t \in \overline{0, T-1}$, each agent $P_i (i \in \overline{1,n})$ is interested in the behavior of each agent E_{ij} $(j \in \overline{1, j_i})$, so that for each admissible realization phase vector $\overline{X}^{(ij)}(t)$ of the object II_{ij}, knowing the realization of his control $U^{(i)}(t) \in \mathbf{U}_*^{(i)}(t)$, he could organize the choice of control $\overline{U}^{(ij)}(t) \in \overline{\mathbf{U}}_*^{(ij)}\left(t; U^{(i)}(t)\right)$, which would guarantee to him the minimum value of a given target function $\overline{\mathbf{F}}_{t+1}^{(ij)}$, defined on the phase vectors $\overline{X}^{(ij)}(t+1)$, taking into account possible worst-case risk vector realizations for him $\overline{V}^{(ij)}(t)$ and the demand vector $\overline{S}^{(ij)}(t)$, i.e. determine the *minimax outcome*, provided that the dominant agent also contributes to this goal (here $\overline{X}^{(ij)}(t+1) = \overline{\Phi}_t^{(ij)}\left(t, \overline{X}^{(ij)}(t), U^{(i)}(t), \overline{U}^{(ij)}(t), \overline{V}^{(ij)}(t), \overline{S}^{(ij)}(t), \overline{A}^{(ij)}(t)\right)$,$\overline{X}^{(ij)}(0) = \overline{X}_0^{(ij)}$).

The aggregate of the agents E_{ij}, $i \in \overline{1,n}$, $j \in \overline{1, j_i}$ and the objects they manage II_{ij},$j \in \overline{1, j_i}$ form a subordinate production level of network industrial complex management—management level II. The formed dynamical system (1)–(12) and formalized logical, informational, and control relations between its objects and control agents will be called a *two-level multi-agent hierarchical intelligent semantic network* describing the control system of the regional network industrial complex.

4.3 Formalization of a Two-Level Hierarchical Minimax Control Problem for a Regional Industrial Network Complex

Based on the generated dynamical system (1)–(12) and the description of the goals of the agents $E_{ij}, i \in \overline{1, n}, j \in \overline{1, j_i}$, the paper formulates Problem 1—*a minimax step-by-step control of the object at the management level* II of the considered two-level multi-agent hierarchical intelligent semantic network.

As a result of solving this problem, for a fixed time period t ($t \in \overline{0, T-1}$), the index i ($i \in \overline{1, n}$), admissible at the management level II of the considered two-level multi-agent hierarchical intelligent semantic network, described by a dynamical system of the form (1)–(12), the realization of the phase vector $\overline{X}^{(ij)}(t)$ of the object II_{ij} ($j \in \overline{1, j_i}$), of the given target function $\overline{\mathbf{F}}_{t+1}^{(ij)}$ of the agent E_{ij} and admissible at management level I realization of control $U^{(i)}(t) \in \mathbf{U}_*^{(i)}(t)$ of the agent P_i, there is a *set* $\overline{\mathbf{U}}_{ij}^{(e)}\left(t; \overline{X}^{(ij)}(t), U^{(i)}(t)\right) \subseteq \overline{\mathbf{U}}_*^{(ij)}\left(t; U^{(i)}(t)\right)$ of *minimax control on the word controls* $\overline{U}_{ij}^{(e)}(t) \in \overline{\mathbf{U}}_*^{(ij)}\left(t; U^{(i)}(t)\right)$ of the agent E_{ij} and the number $\overline{c}_{ij}^{(e)}\left(t; \overline{X}^{(ij)}(t), U^{(i)}(t)\right)$— a *minimax result,* corresponding to the control action $U^{(i)}(t)$ of the agent P_i, which satisfy the relevant minimax condition.

Then, based on the generated dynamical system (1)–(12) and the description of the goals of the agents $P_i, i \in \overline{1, n}$, Problem 2 is formulated—*minimax step-by-step object* I_i *management* at the control level I of the two-level multi-agent hierarchical intelligent semantic network under consideration.

As a result of solving this problem, for a fixed time period t ($t \in \overline{0, T-1}$), the index i ($i \in \overline{1, n}$), admissible at the control level I of the considered two-level multi-agent hierarchical intelligent semantic network, described by a dynamical system of the form (1)–(12), the realization of a phase vector $X^{(i)}(t)$ of the object I_i and given target function $\mathbf{F}_{t+1}^{(i)}$ of the agent P_i, there is a *set* $\mathbf{U}_i^{(e)}\left(t; X^{(i)}(t)\right) \subseteq \mathbf{U}_*^{(i)}(t)$ *of minimax controls* $U_i^{(e)}(t) \in \mathbf{U}_*^{(i)}(t)$ *of the agent* P_i and the number $c_i^{(e)}\left(t; X^{(i)}(t)\right)$– the *minimax result*, which satisfy the corresponding *minimax condition.*

Based on the solutions of Problems 1 and 2, Problem 3 is formulated.

In this problem, for a fixed time period t ($t \in \overline{0, T-1}$) and index i ($i \in \overline{1, n}$), admissible at the management levels I and II of the considered two-level multi-agent hierarchical intelligent semantic network described by the dynamical system of the form (1)–(12) of phase vector realizations $X^{(i)}(t)$ of the objects I_i and phase vectors $\overline{X}^{(ij)}(t)$ of the objects II_{ij}, $j \in \overline{1, j_i}$, for the given target function $\mathbf{F}_{t+1}^{(i)}$ of the agent P_i and given collection target functions $\overline{\mathbf{F}}_{t+1}^{(ij)}$ of the agents E_{ij}, $j \in \overline{1, j_i}$, for each minimax control $U_i^{(e)}(t) \in \mathbf{U}_i^{(e)}\left(t; X^{(i)}(t)\right)$ of the agent P_i, which is found from the solution to the corresponding problem 2, for each $j \in \overline{1, j_i}$, from the solution to the corresponding problem 1, it is required to find *the set* $\overline{\mathbf{U}}_{ij}^{(e)}\left(t; \overline{X}^{(ij)}(t), U_i^{(e)}(t)\right)$ *of minimax controls* $\overline{U}_{ij}^{(e)}(t) \in \overline{\mathbf{U}}_*^{(ij)}\left(t; U_i^{(e)}(t)\right)$ *of the agent* E_{ij} *and the number of* $\overline{c}_{ij}^{(e)}\left(t; \overline{X}^{(ij)}(t), U_i^{(e)}(t)\right)$, which correspond to the control $U_i^{(e)}$ of the agent P_i and satisfy the minimax condition of Problem 1.

4.4 Methodology for Solving a Two-Level Hierarchical Minimax Regional Network Industrial Complex

Based on the solution of Problems 1–3 formulated in the paper, the methodology for the implementation of minimax step-by-step management of a regional industrial network complex described by a two-level multi-agent hierarchical intelligent semantic network in the form of the dynamical system (1)–(12) is implemented in the form of the following sequence of actions.

1. For each time period $t \in \overline{0, T-1}$, all data describing the economic-mathematical model of the problem in question in the form of the controlled dynamical system (1)–(12) are generated.

2. For a fixed index i ($i \in \overline{1, n}$), phase vector realizations $\overline{X}^{(ij)}(t)$ of the objects $\mathrm{II}_{ij}, j \in \overline{1, j_i}$, given collection target functions $\overline{\mathbf{F}}_{t+1}^{(ij)}$ of the agents $E_{ij}, j \in \overline{1, j_i}$, and each admissible at management level I realization of control $U^{(i)}(t) \in \mathbf{U}_*^{(i)}(t)$ of the agent P_i, the results j_i of Problems 1 make it possible to find the sets $\mathbf{U}_{ij}^{(e)}\left(t; \overline{X}^{(ij)}(t), U^{(i)}(t)\right)$ of minimax controls $\overline{U}_{ij}^{(e)}(t) \in \overline{\mathbf{U}}_*^{(ij)}\left(t; U^{(i)}(t)\right)$ of the agents E_{ij}, $j \in \overline{1, j_i}$, corresponding to the control $U^{(i)}(t)$ of the agent P_i.

3. For admissible at the management level I realizations of phase vectors $X^{(i)}(t)$ of the objects $\mathrm{I}_i, i \in \overline{1, n}$, and given collection target functions $\mathbf{F}_{t+1}^{(i)}$ of the agents P_i, $i \in \overline{1, n}$, the results n of Problems 2 makes it possible to find the sets $\mathbf{U}_i^{(e)}\left(t; X^{(i)}(t)\right) \subseteq \mathbf{U}_*^{(i)}(t), i \in \overline{1, n}$, of minimax controls $U_i^{(e)}(t) \in \mathbf{U}_*^{(i)}(t)$ of the agents P_i.

4. For each minimax control $U_i^{(e)}(t) \in \mathbf{U}_i^{(e)}\left(t; X^{(i)}(t)\right)$ of the agent P_i, $i \in \overline{1, n}$, the results j_i of Problem 3 gives the possibility to find the set $\tilde{\mathbf{U}}_i^{(e)}\left(t; \tilde{X}^{(i)}(t), U_i^{(e)}(t)\right) = \prod_{j=1}^{j_i} \overline{\mathbf{U}}_{ij}^{(e)}\left(t; \overline{X}^{(ij)}(t), U_i^{(e)}(t)\right) = \left\{\overline{U}_{i1}^{(e)}(t), \overline{U}_{i2}^{(e)}(t), \ldots, \overline{U}_{ij_i}^{(e)}(t)\right\} = \left\{\tilde{U}_i^{(e)}(t)\right\}$ of minimax controls of a collection of agents $E_{ij}, j \in \overline{1, j_i}$, or the generalized agent $\overline{E}_i$, subordinated to the agent P_i, for the management level II, and the value of the vector $\tilde{c}_i^{(e)}\left(t; \tilde{X}^{(i)}(t), U_i^{(e)}(t)\right) = \left(\overline{c}_{i1}^{(e)}\left(t; \overline{X}^{(i1)}(t), U_i^{(e)}(t)\right), \overline{c}_{i2}^{(e)}\left(t; \overline{X}^{(i2)}(t), U_i^{(e)}(t)\right), \overline{c}_{ij_i}^{(e)}\left(t; \overline{X}^{(ij_i)}(t), U_i^{(e)}(t)\right)\right)' \in \mathbf{R}^{j_i}$—the result of the minimax management for the agent $\overline{E}_i$, where

the vector $\tilde{X}^{(i)}(t) = \left(\overline{X}^{(i,1)}(t), \overline{X}^{(i,2)}(t), \ldots, \overline{X}^{(i,j_i)}(t)\right)' \in \mathbf{R}^{\tilde{k}_i}$, $\tilde{k}_i = \sum_{j=1}^{j_i} \overline{k}_{ij}$, and the vector $\tilde{U}_i^{(e)}(t) = \left(\overline{U}_{i1}^{(e)}(t), \overline{U}_{i2}^{(e)}(t), \ldots, \overline{U}_{ij_i}^{(e)}(t)\right)' \in \mathbf{R}^{\tilde{p}_i}$, $\tilde{p}_i = \sum_{j=1}^{j_i} \overline{p}_{ij}$, i.e. a tuple of results is generated: $\left\{\mathbf{U}^{(e)}(t; X(t)), \left\{\mathbf{U}_i^{(e)}\left(t; \tilde{X}^{(i)}(t), U_i^{(e)}(t)\right)\right\}_{i\in\overline{1,n}}, \left\{\tilde{c}_i^{(e)}\left(t; \tilde{X}^{(i)}(t), U_i^{(e)}(t)\right)\right\}_{i\in\overline{1,n}}\right\}$. The formed elements of the solution to Problems 3 correspond to a fixed minimax control $U_i^{(e)}(t)$ of the agent P_i.

5. For the set of numerical coefficients, shaped by the coordinating agent P,$\lambda_i \geq 0$, $i \in \overline{1,n}$,$\sum_{i=1}^{n} \lambda_i = 1$, assessing the significance of the performance of its subordinate agents P_i, $i \in \overline{1,n}$, the optimal guaranteed value of the indicator $\mathbf{F}_{t+1}^{(e)}$ is calculated according to the following formula

$$\mathbf{F}_{t+1}^{(e)} = \sum_{i=1}^{n} \lambda_i \cdot \left\| \tilde{c}_i^{(e)}\left(t; X^{(i)}(t), U_i^{(e)}(t)\right) \right\|_{j_i},$$

where for any vector$c \in R^{j_i}$, the symbol $\|c\|_{j_i}$ denotes the Euclidean norm of this vector in the space $\mathbf{R}^{j_i}$.

6. The results obtained for each time period $t \in \overline{0, T-1}$ are displayed in an agent-friendly form P, P_i, $i \in \overline{1,n}$, and E_{ij}, $j \in \overline{1, j_i}$.

5 Discussion

In this work, the problem of developing an economic-mathematical model of a regional network industrial complex was studied in order to predict the state of the parameters of its objects and optimize the control of specific processes.

As a result of the analysis, the main features of the objects of regional network industrial complexes were identified, which must be taken into account when developing the corresponding economic and mathematical models:

(1) objects are dynamic; (2) to describe the state of objects, it is necessary to take into account the presence of many parameters, i.e. they are multivariable; (3) there are business entities—agents who have the ability to manage the relevant objects, i.e. multi-agent system; (4) management agents have different criteria for assessing the quality of process implementation; (5) real management processes are multi-level and hierarchical; (6) in management processes, there are information, control connections and semantic relations between agents.

The listed features of the objects of regional network industrial complexes and the analysis of scientific sources led to the conclusion that they are very complex systems for the implementation of economic and mathematical modeling and there is no data on the developed models of such systems in the scientific literature.

In this article, for a formalized description of the dynamics and optimization of the functioning of objects of a regional network industrial complex, multi-agent tools, network modeling and a minimax approach are used to optimize the guaranteed results of the control processes under study. The basis for the development of automated and intelligent management decision support systems for complex multi-factor economic systems is economic and mathematical models of the objects and processes under consideration. One of the most general and intensively developing approaches to modeling socio-economic processes is the use of ABM models and methods. This technology makes it possible to take into account, when modeling complex dynamic systems, the presence of heterogeneous agents and their interaction in a structured environment in order to achieve the set goals. Based on the models generated using the ABM method, it is possible to develop effective tools for computer simulation of the functioning of socio-economic systems, as well as to solve complex practical problems. It should be noted that within the framework of the application of the ABM method, it becomes necessary to model the dynamics of specific agents in order to predict the acceptable values of the main parameters that describe their state in a specific period of time, as well as to control the processes under consideration in order to achieve acceptable or best (optimal) values of the selected criteria for their quality implementation.

In this article, for the processes of predicting the state and optimizing the management of the production potential of the region, with the possibility of using a hierarchical agent-based control system, a new discrete controlled dynamic model has been developed in the form of a two-level multi-agent hierarchical intelligent semantic network. The model developed for the processes under consideration is deterministic, in which the dynamics of sets of main factors (phase vectors) characterizing the state (potential) of industrial objects of the region as a whole and specific production enterprises with a two-level spatial structure is described by the corresponding operator discrete recurrent equations in the presence of control actions (controls) and disturbances (risks). In the proposed management system, two levels of managerial decision-making are distinguished—the dominant (regional or first level of management), which is at the disposal of a generalized regional agent, and the second subordinate (the level of production enterprises or the second level of management), which is at the disposal of production agents. The control system is hierarchical, in which the choice of control by a generalized regional agent determines the resource capabilities of control of the corresponding production agents. All agents of the proposed management system are united a priori by certain information, management links and semantic relations. Realizations of the phase vectors of system objects, controls and risks are constrained by given geometric constraints, which have the form of compact polyhedron in the corresponding finite-dimensional vector spaces. Such restrictions reflect the existing technical, economic, resource and physical restrictions on the system parameters. The industrial potential of the region as a whole and the manufacturing enterprises that form it is estimated by the corresponding convex objective functions (convex functionals that estimate the mismatch of the actual realizations of the phase states of objects from their desired states) and all agents of the control system are interested in their minimum values.

The article presents a new economic and mathematical formalization and a general scheme for solving the problems of predicting the state and optimizing the management of a regional network industrial complex based on the proposed economic-mathematical model in the form of a two-level multi-agent hierarchical intelligent semantic network.

The results obtained in this work can serve as a basis for further research and for the development of specific economic and mathematical models that take into account the real conditions and features of the functioning of regional network industrial complexes. On the basis of such models, it is supposed to develop computer intelligent systems for supporting managerial decision-making.

6 Conclusions

The economical and mathematical model in the form of a two-level multi-agent hierarchical intelligent semantic network is proposed for the formalized description of dynamics and optimization of the regional network industrial complex in the presence of risks (perturbations) and information uncertainty. The formalization of the problems of parameter identification, structurally balanced interaction, prediction of development, and step-by-step optimization of the guaranteed (minimax approach) result of managing the state of objects and processes of the regional industrial network complex in the presence of risks (disturbances) and information uncertainty within the proposed two-level multi-agent hierarchical intelligent semantic network is described. The paper presents a methodology for the implementation of minimax step-by-step control of the regional network industrial complex on the basis of solutions of the formulated minimax problems. The results obtained in the paper can be used in computer simulation and the creation of multilevel control systems for complex economic and technical processes functioning under uncertainty and risk.

Acknowledgements The work was carried out with financial support by the Russian Science Foundation (Project No. 22-28-01868 "Development of an agent-based model of the network industrial complex in the context of digital transformation").

References

1. Akberdina, V. (2018). Digitalization of industrial markets: Regional characteristics. *The Manager, 9*(6), 78–87. doi:https://doi.org/10.29141/2218-5003-2018-9-6-8.
2. Akberdina, V., & Barybina, A. (2021). Prerequisites and principles of digital platformization of the economy. *Lecture Notes in Information Systems and Organisation, 44*, 37–48. https://doi.org/https://doi.org/10.1007/978-3-030-73261-5_4.
3. Akberdina, V. V., & Romanova, O. A. (2021). Regional aspects of industrial development: A review of approaches to the formation of priorities and regulatory mechanisms. *Regional Economy, 17*(3), 714–736.

4. Aksyonov, K., Bykov, E., Aksyonova, O., Goncharova, N., & Nevolina, A. (2017). Multi-agent simulation of the resource conversion processes with the sample application to the logistical problem. In *UKSim-AMSS 11th European Modelling Symposium on Mathematical Modelling and Computer Simulation. Manchester, England* (pp.177–181). https://doi.org/10.1109/EMS.2017.39.
5. Alampiev, P. M. (1980). *The Main Problems of the Formation of Industrial Complexes*. Mysl.
6. Amir, R., & Lazzati, N. (2011). Network effects, market structure and industry performance. *Journal of Economic Theory, 146*(6), 2389–2419. https:// doi.org/https://doi.org/10.1016/j.jet.2011.10.006.
7. Bandman, M. K., Bandman, O. L., & Esipova, T. N. (1990). *Territorial Production Complexes: Forecasting the Formation Process using the Petri Net*. Nauka.
8. Barbati, M., Bruno, G., & Genovese, A. (2012). Applications of agent-based models for optimization problems: A literature review. *Expert Systems with Applications, 39*(5), 6020–6028. https://doi.org/10.1016/j.eswa.2011.12.015
9. Billari, F. G., Fent, T., Prskawetz, A., & Scheffran, J. (2006). *Agent-Based Computational Modelling: Applications in Demography, Social, Economic and Environmental Sciences (Contributions to Economics)*. Physica-Verlag. https://doi.org/10.1007/3-7908-1721-X
10. Cheng, W., & Xiao-Bing, L. (2013). Integrated production planning and control: A multi-objective optimization model. *Journal of Industrial Engineering and Management, 6*(4), 815–830.
11. Czamanski, D. Z., & Czamanski, S. (1977). Industrial complexes: Their typology structure and relation to economic development. *Papers of the Regional Science Association, 38*(1), 93–111.
12. Czamanski, S., & Ablas, L. A. Q. (1979). Identification of industrial clusters and complexes: A comparison of methods and findings. *Urban Studies, 16*(1), 61–80. https://doi.org/10.1080/713702464
13. David, S. A., Oliveira, C., Derick, D., & Quintino, D. D. (2012). Dynamic model for planning and business optimization. *Modern Economy, 3*(4), 384–391. https://doi.org/10.4236/me.2012.34049
14. Emelyanov, A. A., Vlasova, E. A., & Duma, R. V. (2014). *Simulation Modeling of Economic Processes. Textbook*. Finansy i statistika.
15. Evdokimova, E. N. (2009). Features of the regional industrial complex as a control object. *Vestnik of Ryazan State Radio Engineering University, 4*(30), 75–79.
16. Huallachain, B. O. (1984). The identification of industrial complexes. *Annals of the Association of American Geographers, 74*(3), 420–436.
17. Idziev, G. I., Arslanov, Sh. D., Arslanova, Kh. D., & Rabadanova, A. A. (2014). System modernization of the regional industrial complex. *Issues of Structuring the Economy, 3*, 71–76.
18. Kleiner, G. B., & Rybachuk, M. A. (2017). *Systemic Balance of the Economy*. Nauchnaya biblioteka.
19. Korovin,G.B. (2020). Architecture of an agent-based model of digital transformation of the industrial complex of the region. *Journal of New Economy, 21*(3), 158–174. Doi:https://doi.org/10.29141/2658-5081-2020-21-3-8.
20. Krasovskii, N. N. (1968). *Theory of Motion Control*. Nauka.
21. Krasovskii, N. N., & Subbotin, A. I. (1988). *Game-Theoretical Control Problems*. Springer.
22. Lotov, A. V. (1984). *Introduction to Economic and Mathematical Modeling*. Nauka.
23. Madejski, J. (2007). Survey of the agent-based approach to intelligent manufacturing. *Journal of Achievements in Materials and Manufacturing Engineering, 21*(1), 67–70.
24. Makarov, V.L., Bakhtizin, A.R., Beklaryan, G.L., & Akopov, A.S. (2021). Digital plant: Methods of discrete-event modeling and optimization of production characteristics. *Business Informatics*, *15*(2), 7–20. https://doi.org/ https://doi.org/10.17323/2587-814X.2021.2.7.20.
25. Makarov, V.L., Bakhtizin, A.R., & Sushko, E.D. (2017). Regulation of industrial emissions based on an agent-based approach. *Economic and Social Changes: Facts, Trends, Forecast, 6*(54), 42–58. doi:https://doi.org/10.15838/esc.2017.6.54.3.
26. Markov, L.S., Markova, V.M., & Kotelkin, D.D. (2013). Agent-based approach to modeling industry evolution: Russian coal industry. *Region: Economics and Sociology, 4*, 242–265.

27. Mazilov, E. A. (2022). *Development of the Industrial Complex in the Context of the Modernization of the Regional Economy*. Litres.
28. Morkovkin, D. E. (2010). The industrial complex of the region as an object of management. *Microeconomics, 5*, 97–101.
29. Margineanu, C., & Lixandroiu, D. (2021). Optimization of industrial management processes. *IOP Conference Series: Materials Science and Engineering, 1009*, 012039.
30. Novikova, T.S., & Tsyplakov, A.A. (2020). Social policy in a multi-industry agent-oriented model. *Economic and Social Changes: Facts, Trends, Forecast, 13*(3),129–142. doi: https://doi.org/10.15838/esc.2020.3.69.9.
31. Olanrele, O. O., Olaiya, K. A., Aderonmu, M. A., Adegbayo, O. O., & Sanusi, B. Y. (2014). Development of a dynamic programming model for optimizing production planning. *International Journal of Management Technology, 2*(3), 12–17.
32. Orsenigo, L., Pammolli, F., Riccaboni, M., Bonaccorsi, A., & Turchetti, G. (1997). The evolution of knowledge and the dynamics of an industry network. *Journal of Management & Governance, 1*(2), 147–175.
33. Pastukhov, A. L. (2020). Modernization of industrial complexes as a basis for sustainable development. *Economic Science Today, 11*, 99–104.
34. Polozhentseva, Yu.S., & Klevtsova, M.G. (2021). Transformation of the development of the industrial complex in the digital economy. *University Bulletin, 2*, 71–79. doi: https://doi.org/10.26425/1816-4277-2021-2-71-79.
35. Probst, A. E. (1965). *The Effectiveness of the Territorial Organization of Production*. Mysl.
36. Propoi, A. I. (1973). *Elements of the Theory of the Optimal Discrete Processes*. Nauka.
37. Ramzaev, V. M., Khaimovich, I. N., Chumak, V. G., & Kukolnikova, E. A. (2017). The use of agent-based modeling for the analysis of high-tech integrated structures of the region's industry. *Bulletin of the Samara Municipal Institute of Management, 2*, 98–105.
38. Shevchenko, I. K. (2005). Intersectoral complex as an element of the spatial organization of the economy. *News of the Southern Federal University, Technical Sciences, 6*, 39–43.
39. Shorikov, A. F. (1997). *Minimax Estimation and Control in Discrete-Time Dynamical Systems*. Publishing House of the Ural State University.
40. Shorikov, A. F. (2006). Methodology for modeling multilevel systems: Hierarchy and dynamics. *Applied Informatics, 1*(1), 136–141.
41. Shorikov, A.F. (2022). Forecasting and minimax estimation of the state of a production system in the presence of risks. *Applied Informatics, 17*(4(100)). https://doi.org/10.37791/2687-0649-2022-17-4-97-112
42. Shorikov, A.F., & Butsenko, E.V. (2021). Network economic and mathematical modeling of optimization of adaptive control of business planning processes. *Economics and Mathematical Methods, 57*(3), 110–125. https://doi.org/10.31857/S042473880016413-3
43. Ter-Krikorov, A. M. (1977). *Optimal Control and Mathematical Economics*. Nauka.
44. Szopa, R., & Marczyk, B. (2011). Optimization of production problems using mathematical programming. *Polish Journal of Management Studies, 4*, 231–238.
45. Tyulyukin, V.A., & Shorikov, A.F. (1988). On algorithm for constructing the reachability sets of linear control system. In *Non-Smooth Optimization Problems and Control* (pp. 55–61). Sverdlovsk: UB AS USSR.
46. Wagner, H. M., & Whitin, T. M. (2004). Dynamic version of the economic lot size model. *Management Science, 50*(12), 1770–1774.
47. Walker, G., Kogut, B., & Shan, W. (1997). Social capital, structural holes and the formation of an industry network. *Organization Science, 8*(2), 109–125.
48. Windrum, P., Fagiolo, G., & Moneta, A. (2007). Empirical validation of agent-based models: alternatives and prospects.*Journal of Artificial Societies and Social Simulation, 10*(2), 1–8.
49. Wooldridge, M., & Jennings, N. (1995). Intelligent agents: Theory and practice. *Knowledge Engineering Review, 10*(2), 115–152.
50. Zhang, Q., Chen, Yu., Lin, W., & Chen, Ya. (2021). Optimizing medical enterprise's operations management considering corporate social responsibility under industry 5.0. *Discrete Dynamics in Nature and Society, 2021*(2), 9298166. https: //doi.org/https://doi.org/10.1155/2021/9298166.

Digital Transition of Industrial Enterprises: Potential, Management, Strategies

The Use of Digital Twins for Elaboration of Strategic Guidelines to Ensure Sustainable Development of Industrial Enterprises

Olga Chernova, Olga Dolgova, and Baraa Ali

Abstract Many scientists associate the prospects for sustainable development of industrial enterprises with the development of strategic partnerships. Although there are a number of studies that address different issues related to strategic management of sustainable development in industrial enterprises, little attention is paid to the problems of modeling resource flows within the framework of strategic interactions. This is largely due to the complexity of collecting information about the production processes at the enterprises. To solve this problem, we suggest applying digital twins, the existence of which is based on simulation models. The purpose of this article is to develop a simulation model for the resource flows of an industrial enterprise within the framework of a strategic partnership. This approach will allow making informed managerial decisions to achieve the goals of sustainable development. A simulation model discussed in this article will be developed on the example of a sugar factory. The difference between this model and the existing ones is that the resource flow parameters are determined taking into account the existing production conditions and the interests of the participants involved in strategic interactions, *i.e.* by the volume of demand and the expected sales price. The simulation model is based on the principles of system dynamics. The indicators that set the sustainable development vector are determined by economic, social and environmental components. The decision-making process on sales volumes is described using Java code. The model experimental verification showed that it makes possible not only to analyze the parameters describing the enterprise's sustainable development taking into consideration various cooperation alternatives, but also to determine the best interaction option that meets the goals of sustainable development. The study results may be used to form digital twins as a practical method to improve efficiency of industrial enterprises.

O. Chernova (✉) · O. Dolgova · B. Ali
South Federal University, 88 Gorkogo St, Rostov-On-Don 344002, Russian Federation
e-mail: chernova.olga71@yandex.ru

O. Dolgova
e-mail: oldolgova@sfedu.ru

B. Ali
e-mail: baraaali595@gmail.com

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_26

Keywords Industrial enterprise · Digital twin · Sustainable development · Simulation · Resource flows · Strategic partnership · Sugar industry

1 Introduction

Many researchers associate the improvement of sustainable development of industrial enterprises with strategic partnerships at certain stages of added value creation. It is believed that strategic partnerships make it possible to ensure the resource flow stability, to share scarce resources, and to implement closed-loop business models that reduce the negative impact on the environment. The developers of a strategy (which implies creation of strategic partnerships) face the task of assessing the prospects of interaction options in terms of achieving certain sustainability parameters. The solution of this problem is complicated by the difficulties of collecting data related to the enterprises' production processes, which determine the peculiarities of the generated resource flows. Therefore, when modeling the strategy of sustainable development for industrial enterprises, researchers most often focus on the financial and economic parameters of interactions.

However, the rapid development of digital technologies (big data, cloud technologies, the Internet of things) has brought the possibility of using digital twins as an effective means of solution for the problems related to optimization of business processes by replacement of physical tools and processes with digital tools and processes [13]. The use of digital twins to simulate the development of certain industries has already become increasingly popular among foreign researchers, but is not yet widespread in Russian practice.

Since the basis of digital twins is a simulation model, its development creates the possibility of using digital twins in industry. Therefore, the purpose of this article is to work out a simulation model for the resource flows of an industrial enterprise within the framework of a strategic partnership. This approach will allow making informed managerial decisions to achieve the goals of sustainable development. We have developed the simulation model discussed in this article and illustrated its use through a case study based on a sugar factory.

2 Literature Review

In modern scientific literature, the concept of the digital twin is used by many researchers to consider various aspects of industrial process management. Most frequently, digital twins are used for modeling energy flows in various industries [5, 8, 16, 22]. Also, quite often, digital twins are applied to develop monitoring systems for safety management [24], planning logistics trajectories [6], resource planning and scheduling quality control [14]. Digital twin modeling is also carried out to monitor the status of remote assets.

Although digital twins are emerging as a new technological paradigm, the complexity of their creation has hampered the development of digital twins in many traditional industries, including the sugar industry. Nevertheless, sustainable development of any industry (including in the sugar one) requires simulation to be actively used as the basis for creating digital twins.

The factors and conditions for sustainable development vary significantly depending on the industry and the particular contexts of its functioning, therefore, modeling the sustainable development parameters should always take into account industry specific peculiarities. For example, the sugar industry is characterized by its great dependence on sources of raw materials, a high level of water intensity, and significant volumes of production waste. Any increase in sugar production is usually achieved through over-exploiting natural resources. Traditionally, the objectives of the sustainable development in the sugar industry are considered in terms of its economic efficiency: the percentage of sugar yield from beets/cane; volumes of sugar production; profitability, etc. [1]. However, recent years show that the factors related to spatial arrangement of resource flows between the participants of sugar production and consumption have become increasingly important. This is largely due to the fact that strategic partnerships in value chains make it possible to effectively redistribute natural, financial and other resources in order to significantly improve the sustainable development of both the sugar industry and food ecosystems [17].

When considering various interaction scenarios, the researchers develop several solutions to select the models that meet the objectives of sustainable development best of all. For example, Nieder-Heitmann et al. proposed to use multi-criteria analysis as an instrument for investigation of sugarcane biorefinery scenarios [18]. A similar problem was solved by López-Ortega et al. who offered comparative analysis as an effective means to study the technical and economic indicators of the project for each scenario [15]. Based on the methodology of multi-objective optimization, Shavazipour et al. proposed a model for planning supply chains under deep uncertainty [20]. Safder et al. offered a Monte Carlo simulation as a way of optimal configuration and economic analysis of industrial networks as illustrated by the case of a sugar mill and a chemical plant [19]. Some studies are devoted to modeling energy consumption processes at a sugar factory, considering the possibility of using sugar production waste as an energy source [12]. The self-sufficiency of a sugar mill in terms of its supply with water and energy through biomass recycling and water reuse is reflected in the works of Bantacut and Novitasari, Lewis et al. [2, 13]. A model of a sugar factory producing animal feed and bioethanol from by-products and waste of sugar production is described by Henke et al. [7].

All these models differ in the set of parameters used and characteristics of conditions in which the sugar industry operates (the uncertainty level, conditions of competition or symbiosis). Nevertheless, in general, they are characterized by the fact that, as a rule, they focus on either financial and economic parameters of interaction, or social and environmental ones. In addition, they usually aim at optimizing the performance of a sugar plant itself and do not take into account the interests of other interacting parties.

As part of our study, we intend to remove these restrictions by including indicators that reflect the interests of external actors, i.e., farmers supplying raw materials as well as final and intermediate buyers of sugar products. We assume that the resource flow parameters will be determined based on the existing production conditions.

3 Methodology

In this study, we are going to clarify how sustainable development goals in the sugar industry, expressed by certain indicators, determine the volumes of resource flows at a sugar mill in terms of buying sugar cane and sugar beets and selling the primary product and by-products. The offered methodology may serve as guidelines for making informed decisions on choosing a direction for further development of strategic cooperation based on achieved parameters of sustainable development in the sugar industry and the most efficient use of the resource potential of the parties involved in the manufacturing and consumption of sugar products. Accordingly, the article is structured as follows:

The first part of the study presents a simulation model of the resource flows in the sugar industry. The model is built based on the principles of system dynamics. The choice of simulation modeling as a tool for this study is determined by the fact that, compared to any other paradigm, this approach allows deeper penetration into the essence of what is happening in the system. Moreover, it provides a perfect opportunity to identify cause-and-effect relationships between objects and phenomena. At the same time, since the purpose of modeling implies a sufficiently high level of abstraction, the system-dynamics technique allows the researcher to reveal all the important relationships without going into detail. Another important advantage of this method is the ability to create a decision support mechanism that allows the user to simulate various market situations. The indicators that set the vector for sustainable development of the sugar industry are determined by the generalization of sustainable development features specific to food production systems in terms of their economic, social and environmental components [9, 21, 23]. To simplify the modeling process, within the framework of this study, we identified four main criteria that the chosen strategy must meet:

(a) Percentage of sugar yield from beets/cane—economic component;
(b) Sugar price—social component;
(c) Percentage of recycled waste per 1 ton of sugar beets/cane used—environmental component.
(d) Offer price $\geq$ product price $\geq$ cost price—a condition for the consistency of the strategic partners' interests.

To illustrate the model efficiency, such simplification seems quite appropriate, since it will not affect any of the fundamental components. Including additional criteria will make the model too unwieldy and unsuitable for demonstration.

However, if necessary, the number of criteria may be increased or changed, which will allow setting certain priorities for strategic development.

In the second part of the study, the model is tested on an illustrative example of the sugar industry development in the region. The sources of data (characterizing the sugar industry in Egypt) were the Ministry of Planning and Economic Development [25] and the USDA Foreign Agricultural Service [27].

The section 'Discussion' provides recommendations on how to use the resource flow model for developing a strategy of the sustainable development in the sugar industry. The article ends with the conclusions about the limitations of this study results and the prospects for further development of this investigation.

4 Findings and Scientific Contribution

4.1 Simulation Model Development

The key elements of the model are the following:

1. A sugar mill producing crystal sugar and by-products, which can be used in other industries.

2. Farmers who supply sugar beets and/or sugar cane to the factory.

3. Buyers (intermediate and final) who purchase sugar and by-products of sugar manufacturing. In this model, it is assumed that the products are purchased directly from the sugar factory (without intermediaries).

4. Parameters established by the user, that determine the conditions for concluding a transaction (price, sales volume, warehouse stock, processing price of one ton of sugar, and the percentage of sugar yield from beets/cane).

5. The following variables, calculated during the simulation: Volume of sugar sales to each buyer (in monetary and quantitative terms); Volume of by-product sales (in monetary and quantitative terms); Quantity of unsold sugar (in tons); Quantity of unsold by-products (in tons); Financial results; Level of domestic demand satisfaction by own production; Sugar price; Percentage of recycled by-products per one ton of sugar beets/cane used.

The research task was stated as follows. Farmers supply a certain amount of raw materials (sugar beets and/or sugar cane) at a certain price (these parameters are set by the user). The model also includes a random factor—a dynamic variable 'yield', which reflects the yield of farmers' agricultural products. This indicator is a random determinant approximated with a triangular probability density function with the smallest number being 0.5, the largest—1.5, and the most likely value—1.0. Each time the model is run, this number is regenerated. The model assumes that the factory buys all of the raw materials offered at any price.

Taking into account the fact that the existing technology involves significant volumes of waste and by-products derived from the sugar production process, the user should specify the parameter of their share in the total volume of processed raw materials. This indicator is set by the ‘Sugar output’ parameter. As a rule, the amount of waste and by-products is a certain constant value, determined by the technologies used at a sugar factory. However, the value of this parameter can be adjusted if it appears expedient to change the manufacturing structure in favor of certain by-products. For example, the growing demand for ethanol makes some sugar mills produce more biofuels than refined sugar.

It is assumed that all waste and by-products are placed in the warehouse for factory waste, while produced sugar in the warehouse for finished products.

Waste and by-products are sold to the buyers who have different needs for certain types of waste and by-products and who are willing to offer different prices. These indicators are set by the parameters ‘Demand’ and ‘Price of waste’, accordingly. There are 2 types of buyers in the model: end ones, who buy waste for personal use, and intermediaries, who are engaged in resale.

Within the framework of the developed model, the factory aims at selling all waste, so it is ready to sell them at any price. However, the priority is to make profits, so the orders of the customers who offered the highest price are satisfied first, the rest of the customers are dealt with on a ‘first come, first served’ basis.

The factory aims at maximizing its profits when selling sugar to the customers. However, the minimum price per one ton is specified, that is, the price below which it is not profitable for the producer to sell, since the proceeds will not cover the costs. If the price offered by the customer falls below the minimum level, the purchase and sale transaction is not effected. The minimum price is calculated based on the production costs of one ton of sugar (the cost of raw material procurement / sugar output + production costs).

If the factory may fail to sell all the sugar or all the waste and by-products taking into account the user-defined parameters, a corresponding text message will be displayed.

Figure 1 shows possible interaction between physical and virtual components of a sugar factory digital twin. When a continuous transfer of data from the elements of the physical world to the simulation model is arranged a digital twin is created based on this model.

Figure 2 shows the developed simulation model of a sugar factory, which can be used as the basis for creating its digital twin. The following elements of system dynamics are presented in the model:

- Accumulators that simulate the movement of goods in warehouses;
- Flows that simulate the movement of goods in space;
- Parameters—indicators set by the user through the interface;
- Variables—indicators set within the model;
- Dynamic variables (numerical and textual) —variables whose value will change during the experiment.

Events represent the data-driven sales decision-making process which can be easily implemented through the object-oriented programming approach using Java code (the language supported by Anylogic software).

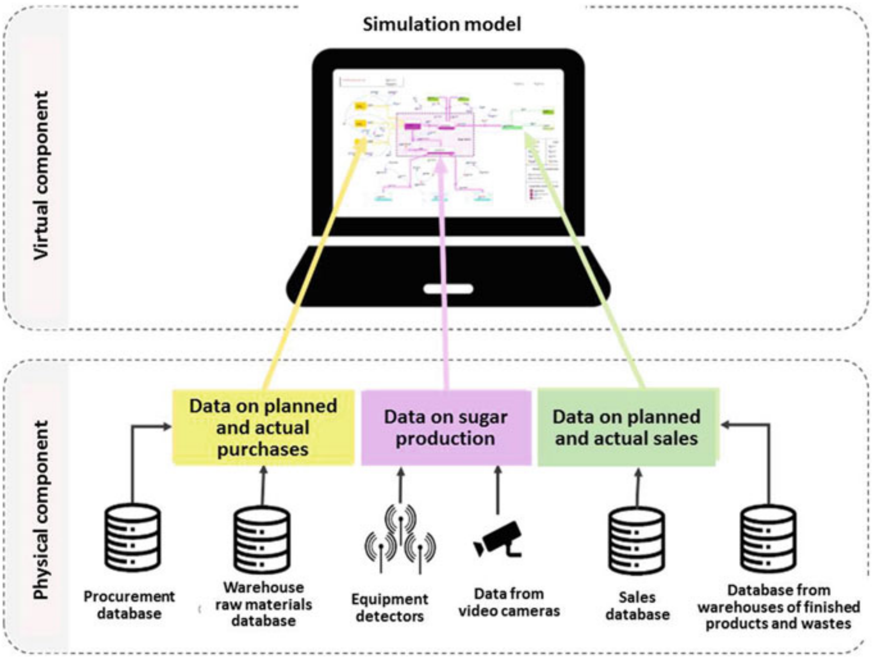

Fig. 1 Possible interaction between physical and virtual components within a sugar factory digital twin

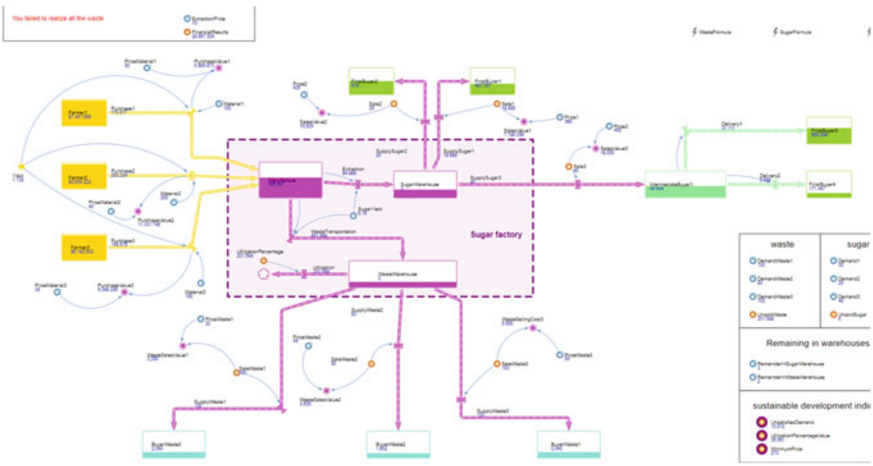

Fig. 2 Sugar factory simulation model

The choice of the Anylogic software model as a development environment is explained by the presence of a large number of modeling libraries, high-quality visualization tools and the ability to control the model by the program code. The implementation of model logic through program code was chosen to improve the convenience of introducing changes to the model.

Unlike other models, the model we developed includes not only a sugar factory, but also various 'external stakeholders'. Figure 2 shows the model elements related to different types of such 'stakeholders' marked by different colors: farmers supplying raw materials are highlighted in yellow; green—buyers of sugar; blue—buyers of production waste. The fuchsia color elements refer directly to the sugar factory.

The model has a user-friendly interface that is shown before the simulation starts. The user sets the values of the model parameters by moving the slider within the specified limits (minimum and maximum).

You can learn more about the code that implements the logic of the model and see the figures showing the results of experiments 1 and 2 in the repository [27].

4.2 Research Validation

Experiment 1 (basic). During the experiment, conditional data were used, corresponding to actual situation in the Egyptian sugar market. It was assumed that for a conditional sugar factory, the volumes of raw materials supplied by different farmers were 100, 250 and 150 tons of sugar beets, respectively. The yield percentage of sugar was set at 15%. The parameters of demand for sugar from three consumers were specified as: 30, 25 and 40 tons. It was assumed that not all waste was in the same demand therefore the probability of selling all waste was low. In this connection, the following waste demand values were set: 100, 80 and 100 tons. The prices offered by each of the farmers and buyers of sugar and waste were respectively: Raw materials—50$, 40$, 30$; Sugar—390$, 425$, 450$; Waste—55$, 45$, 32$.

The random variable in the form of a yield index was assigned the value 1.133. The reserve of sugar in the warehouse was set at 3 tons, and the reserve of waste at 2 tons.

The experiment results showed that with the above parameters, the factory would sell all the sugar produced, but there remained an unsatisfied demand of 10.1 tons. The demand for waste was fully satisfied, but the factory was not able to sell all the available waste (as evidenced by the text alert and the volume of unsold waste).

The sustainable development indicators had the following values: profit—$20,957, minimum price—$270 per ton, percentage of waste disposal—35.6%.

Experiment 2 (demo). This experiment was carried out to demonstrate how the model works with different input data.

The supply of raw materials was set as: 130, 100 and 150 tons. In order to demonstrate the model response to a significant excess of demand for waste over the demand for sugar, the following demand parameters were set: Sugar—28, 15, 30 tons; Waste—130, 230, 500 tons.

To clearly demonstrate the situation in which not all demand was satisfied, the following prices were determined: Raw materials—$50, $40, $30; Sugar—$200, $425, $450; Waste—$55, $45, $32.

The indicators of sugar production, the production costs and the volumes of stocks in warehouses remained at the level of the previous experiment.

In the second experiment, the sugar yield was set lower than expected (0.795), which led to decrease of raw materials purchased by the factory compared to experiment 1. The minimum selling price for sugar was $273 per ton. Therefore, Company 1, which bade $200, could not purchase it. Under these circumstances, a situation was created, in which the factory could not sell all the sugar produced and it began accumulating in warehouses. At the same time, some buyers could not purchase it because the price was too high for them.

However, the factory sold all the generated waste and by-products, having achieved a 0% recycling and reuse rate. Moreover, there was an unsatisfied demand for waste from Companies 1 and 2, since all of these secondary products were sold to Company 3, which offered the highest price. It should be noted that despite the fact that all waste was sold to Company 3, nevertheless, its demand for waste was not satisfied to the full extent (by 243 tons). The total volume of unsatisfied demand for waste was 603.3 tons.

The factory's profit in this experiment was $19,052. The positive result (despite the fact that the factory did not sell all the produced sugar) can be explained by the sale of all available waste at a rather high price.

In terms of the factory's sustainable development, this situation is less preferable than the first one, taking into account its social and economic results. The performed calculations show that under the specified conditions, it is not possible to reconcile the interests of all interacting participants: Company 1 selling sugar and Companies 2 and 3 buying waste. Therefore, this partnership option is considered ineffective. Hence, based on the obtained simulation results, the factory should consider technological changes to reduce the costs of sugar production, which will lead to reduction of the minimum price.

Similar experiments can be carried out for other initial conditions, including changes in the number of farmers and buyers, the volume of raw materials, the prices, and the volume of demand for sugar and its by-products.

5 Discussion

The experiments demonstrated the possibility of using the proposed resource flow simulation model for solving the problems related to the improvement of sustainable development at enterprises in the sugar manufacturing industry. By setting the parameters that characterize the current situation in the sugar market, as well as entering data on potential buyers of sugar and by-products, it is possible to analyze the parameters of the sugar industry sustainable development under various options of cooperation, and to choose the best alternative for the interaction that will meet the goals of such development. Thus, the experimental verification has confirmed the possibility of using the proposed model to face the strategic challenges of sustainable development in the sugar industry.

As the existing successful foreign experience shows, the strategic interactions between the sugar industry and other related industries increases the level of its sustainable development through circular business model implementation [4]. The existing models of the strategic development in the sugar industry demonstrate that sustainability may be increased through partnerships [3, 10, 11], which is consistent with our findings. At the same time, in comparison with the available literature, our model allows us to take into account the various interests of all participants interacting with their strategic counterparts.

6 Conclusion

The need to find and quantify the compromise between economic feasibility and impact on the environment requires a decision-making system that would become an instrument for elaboration of the sustainable development strategy, which can be used at different industrial enterprises. Digital twins would greatly contribute to the solution of this problem. However, the digital twins created nowadays usually directly reflect production processes only. They are rarely used to solve the problems of strategic planning. In our work, a simulation model of resource flows has been built (illustrated by a sugar mill case study), which can be used by a sugar factory to form its digital twin when working out a strategy for its sustainable development.

The main limitation of our research is that it selects three criteria for sustainable development. In the context of specific regional conditions, it is advisable to use a larger number of criteria for a deeper understanding of which option of strategic partnerships will help increase the sustainability of the sugar industry. Besides, to create a digital twin, a greater detail of the sugar production process is required, including taking into account the indicators of specific equipment, the number and type of personnel, production infrastructure, etc. Our future research will take these limitations into consideration.

References

1. Aguilar-Rivera, N. (2019). A framework for the analysis of socioeconomic and geographic sugarcane agro industry sustainability. *Socio-Economic Planning Sciences, 66*, 149–160. https://doi.org/10.1016/j.seps.2018.07.006
2. Bantacut, T., & Novitasari, D. (2016). Energy and water self-sufficiency assessment of the white sugar production process in Indonesia using a complex mass balance model. *Journal of Cleaner Production, 126*, 478–492. https://doi.org/10.1016/J.JCLEPRO.2016.02.092

3. Bathrinath, S., Dhanasekar, M., Dhanorvignesh, B., Kamaldeen, Z., Santhi, B., Bhalaji, R., & Koppiahraj, K. (2022). Modeling sustainability risks in sugar industry using AHP-BWM. *Materials Today: Proceedings, 50*(5), 1397–1404. https://doi.org/10.1016/j.matpr.2021.08.324
4. Chernova, O.A. & Ali, B. (2021). Cooperative strategies of food enterprises amid the COVID-19 pandemic. *Upravlenets-the Manager,* 12(5), 70–83. https://doi.org/10.29141/2218-5003-2021-12-5-5.
5. Di Cosmo, F., Polenghi, A., Roda, I., & Macchi, M. (2022). Proposal and test of a configurable production system Digital Model to support Energy-based Asset Management. *IFAC-Papers OnLine, 55*(19), 133–138. https://doi.org/10.1016/j.ifacol.2022.09.196
6. Ding, K., Chan, F., Zhang, X., Zhou, G., & Zhang, F. (2019). Defining a digital twin-based cyber-physical production system for autonomous manufacturing in smart shop floors. *International Journal of Production Research, 57*(20), 6315–6334. https://doi.org/10.1080/00207543.2019.1566661
7. Henke, S., Bubník, Z., Hinková, A., & Pour, V. (2006). Model of a sugar factory with bioethanol production in program Sugars™. *Journal of Food Engineering, 77*(3), 416–420. https://doi.org/10.1016/j.jfoodeng.2005.07.007
8. Huang, W., Zhang, Y., & Zeng, W. (2022). Development and application of digital twin technology for integrated regional energy systems in smart cities. *Sustainable Computing: Informatics and Systems, 36*, 100781. https://doi.org/10.1016/j.suscom.2022.100781
9. Gerbens-Leenes, P., Moll, H., & Schoot, U. (2003). Design and development of a measuring method for environmental sustainability in food production system. *Ecological Economics, 46*(2), 231–248. https://doi.org/10.1016/S0921-8009(03)00140-X
10. Jarumaneeroj, P., Dusadeerungsikul, P., Chotivanich, T., & Akkerman, R. (2021). A multi-objective modeling approach to harvesting resource scheduling: Decision support for a more sustainable Thai sugar industry. *Computers & Industrial Engineering, 162*, 107694. https://doi.org/10.1016/j.cie.2021.107694
11. Kapanji, K., Farzad, S., & Görgens, J. (2021). Life cycle and sustainability assessments of biorefineries producing glucaric acid, sorbitol or levulinic acid annexed to a sugar mill. *Journal of Cleaner Production, 295*, 126339. https://doi.org/10.1016/j.jclepro.2021.126339
12. Ch., Lambert, Laulan, B., Decloux, M., Romdhana, H., & Courtois, F. (2018). Simulation of a sugar beet factory using a chemical engineering software (ProSimPlus®) to perform Pinch and exergy analysis. *Journal of Food Engineering, 225*, 1–11. https://doi.org/10.1016/j.jfoodeng.2018.01.004
13. Lewis, A., Khodabocus, F., Dhokun, V., & Khalife, M. (2010). Thermodynamic simulation and evaluation of sugar refinery evaporators using a steady state modelling approach. *Applied Thermal Engineering, 30*(14–15), 2180–2186. https://doi.org/10.1016/j.applthermaleng.2010.05.031
14. Lopes, M., Costigliola, A., Pinto, R., Vieira, S., & Sousa, J. (2020). Pharmaceutical quality control laboratory digital twin–a novel governance model for resource planning and scheduling. *International Journal of Production Research, 58*(21), 6553–6567. https://doi.org/10.1080/00207543.2019.1683250
15. López-Ortega, M., Guadalajara, Y., Junqueira, T., Sampaio, I., Bonomi, A., & Sánchez, A. (2021). Sustainability analysis of bioethanol production in Mexico by a retrofitted sugarcane industry based on the Brazilian expertise. *Energy, 232*, 121056. https://doi.org/10.1016/j.energy.2021.121056
16. Sh., Ma, Ding, W., Liu, Y., Sh., Ren, & Yang, H. (2022). Digital twin and big data-driven sustainable smart manufacturing based on information management systems for energy-intensive industries. *Applied Energy, 326*, 119986. https://doi.org/10.1016/j.apenergy.2022.119986
17. Manyise, T., & Dentoni, D. (2021). Value chain partnerships and farmer entrepreneurship as balancing ecosystem services: Implications for agri-food systems resilience. *Ecosystem Services, 49*, 101279. https://doi.org/10.1016/j.ecoser.2021.101279
18. Nieder-Heitmann, M., Haigh, K., & Görgens, J. (2019). Life cycle assessment and multi-criteria analysis of sugarcane biorefinery scenarios: Finding a sustainable solution for the South African sugar industry. *Journal of Cleaner Production, 239*, 118039. https://doi.org/10.1016/j.jclepro.2019.118039

19. Safder, U., Lim, J., How, B., Ifaei, P., Heo, S., Ch., & Yoo. (2022). Optimal configuration and economic analysis of PRO-retrofitted industrial networks for sustainable energy production and material recovery considering uncertainties: Bioethanol and sugar mill case study. *Renewable Energy, 182*, 797–816. https://doi.org/10.1016/j.renene.2021.10.047
20. Shavazipour, B., Stray, J., & Stewart, T. (2020). Sustainable planning in sugar-bioethanol supply chain under deep uncertainty: A case study of South African sugarcane industry. *Computers & Chemical Engineering, 143*, 107091. https://doi.org/10.1016/j.compchemeng.2020.107091
21. Sundkvist, Å., Milestad, R., & Jansson, A.-M. (2005). On the importance of tightening feedback loops for sustainable development of food systems. *Food Policy, 30*(2), 224–239. https://doi.org/10.1016/j.foodpol.2005.02.003
22. Wang, Y., Kang, X., & Chen, Z. (2022). A Survey of Digital Twin Techniques in Smart Manufacturing and Management of Energy Applications. *Green Energy and Intelligent Transportation, 100014*, https://doi.org/10.1016/j.geits.2022.100014.
23. Yue, Q., Wu, H., Wang, Y., & Guo, P. (2021). Achieving sustainable development goals in agricultural energy-water-food nexus system: An integrated inexact multi-objective optimization approach. *Resources, Conservation and Recycling, 174*, 105833. https://doi.org/10.1016/j.resconrec.2021.105833
24. Zhao, Z., Shen, L., Yang, C., Wu, W., Zhang, M., & Huang, G. (2021). IoT and digital twin enabled smart tracking for safety management. *Computers & Operations Research, 128*, 105183. https://doi.org/10.1016/j.cor.2020.105183
25. Ministry of Planning and Economic Development (2021). *Egypt's 2021. Voluntary National Review.* https://sustainabledevelopment.un.org/content/documents/279512021_VNR_Report_Egypt.pdf.
26. USDA Foreign Agricultural Service (2021). Egypt: Sugar Annual. https://www.fas.usda.gov/data/egypt-sugar-annual-6.
27. Electronic Resources Portal. South Federal University (2022). Sugar Factory Simulation. https://hub.sfedu.ru/repository/material/801308173/.

The Impact of Digitalization Processes on the Innovative Activity of Small Industrial Enterprises

Elena S. Mezentseva and Grigoriy B. Korovin

Abstract Small enterprises are drivers of innovative development in most developed countries. Due to their specificity—flexibility, adaptability, on the one hand, and limited resources and dependence on the external environment, on the other hand—they have advantages and disadvantages in digitalization processes. Modern development takes place within the framework of Industry 4.0, the basis of which is digital transformation. Digitalization has brought global changes to the innovation processes in enterprises and has opened up previously unexisting opportunities for small enterprises. The aim of the work was to identify areas of influence of the digital transformation of the industry on innovation processes at small enterprises and their innovative activity. We identified factors of digital transformation that influence innovation processes at small enterprises, embedding them into digital innovation ecosystems. The article describes features of managing innovative processes at small enterprises in the context of digitalization. We carried out the analysis of digitalization, the level of digital maturity of the Russian industry; the analysis of the dynamics of innovative activity of small industrial enterprises in Russia; and highlighted its most innovatively active sectors. We carried out an inventory of state support measures aimed at digitalization and innovative development of small enterprises. Our research provides directions for improving the state policy on the digitalization of the economy from the point of view of developing an ecosystem approach to supporting innovative entrepreneurship.

Keywords Digital transformation · Innovation · Innovative activity · Industry · Small and medium-sized enterprises · Government support

E. S. Mezentseva (✉) · G. B. Korovin
Institute of Economics of the Ural Branch of the Russian Academy of Sciences, 29 Moskovskaya Street, Ekaterinburg 620014, Russian Federation
e-mail: mezentseva.es@uiec.ru

G. B. Korovin
e-mail: korovin.gb@uiec.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_27

1 Introduction

The industry is currently undergoing a digital transformation based on the concept of Industry 4.0 and smart factories. Empirical evidence suggests that digitalization has a direct positive impact on company performance [1]. In modern conditions, it is of particular importance to identify and measure the results and effects of digital transformation. One of the main aspects of this assessment is innovation, including the development and implementation of new digital technologies, information technology management.

The high practical relevance of the topic of digital transformation and innovation management makes it necessary to stimulate the study of this issue and subsequent theoretical and methodological developments.

Small enterprises are drivers of innovative development in most developed economies. The digitalization of their activities has its own specifics. On the other hand, they are greatly influenced by the external environment, namely the digitalization of large enterprises and public administration. Thus, the issue of assessing how digital transformation affects innovation processes in small enterprises is relevant.

The aim of the work is to determine the directions of influence of the digital transformation of industry on innovation processes in small enterprises and their innovative activity. To achieve the goal, we solve the following tasks:

- to conduct a bibliographic analysis on the topic of digitalization of the industry, specifics for large, medium and small enterprises, its relationship with innovation processes;
- to analyze the current situation in Russia in terms of digital transformation of small industrial enterprises, the level of their innovative activity;
- to study the legislative framework for the digitalization of the industry and revise government measures to support digital transformation, highlighting measures addressed to small industrial enterprises;
- to make recommendations on improving the state policy to support the innovative activity of small industrial enterprises of the Russian Federation based on the digitalization of public services.

This study contributes to the development of theoretical and methodological approaches to assessing the impact of digital transformation of the industry on innovation processes in small enterprises in the system of their interaction with large enterprises and the state.

2 Literature Review

In recent years, economic analysis of industrial development has been carried out within the framework of the Industry 4.0 concept. Among the scientific works devoted to the digital economy and Industry 4.0, one can find studies on certain aspects of the digitalization of industry, such as innovative strategies for industrial modernization in the context of the digitalization of the economy, features of the implementation of the principles of the fourth industrial revolution [2], modeling of efficiency factors of production and technological processes [3], and the role of production management in Industry 4.0 [4].

A number of authors explore the relationship between innovation and digitalization at the level of countries and regions [5, 6], the features of the innovation process in the context of digitalization [7, 8]. The relationship between digital transformation and innovative development is considered, in particular, in the article Tukkel et al. [9], which explores the benefits and challenges of digitalization for developing economies.

Most authors note the positive effects of digitalization. Gobble [10] notes that digitally innovating companies have not only prospered, they have maintained a significant and persistent gap in productivity and financial performance. In our article [11], we conducted a preliminary analysis of the impact of digitalization on the results of innovative activities of Russian industrial enterprises.

Russian authors [12] conclude that digital technologies will lead to the transformation of each of the stages of the innovation process, which will create a number of positive aspects. In this case, it is possible to reduce or eliminate some of the risks associated with innovation, which will create more favorable conditions for the intensification of innovation activity at various levels of the economy. At the same time, one should take into account a certain range of problems created by the digitalization of the innovation process, the elimination of which will require the development of certain management decisions and mechanisms for their negative impact.

Another topic related to the innovativeness of small enterprises is their foreign direct investment and internationalization [13, 14]. Although this is usually the case for large enterprises, small enterprises have a number of advantages and motivations for entering international markets. According to Wells' small technology theory [15], enterprises in small markets such as developing countries have greater flexibility and lower technology costs, which allows them to conquer the market faster and at a lower cost. Johnson et al. studied strategies for the global integration of Taiwanese SMEs into the IT industry [16]. Rennie [17] and McDougall and Oviatt [18] proposed a theory of international entrepreneurship. It argues that the internationalization of SMEs is mainly related to the international vision of entrepreneurs and international experience, their development of internationalization is either proactive or reactive. In most cases, SMEs are involved in global value chains by joining industrial clusters [19]. Giuliani et al. believe that the competitive difference of SMEs stems from their ability to "modernize" and "improve", and this competitiveness often manifests itself in the ability to innovate or increase the added value of products [20]. Some SMEs receive investment channels from their overseas suppliers. Moreover, SMEs can also create their own networks through enterprise clusters to reduce transaction costs, increase productivity, and promote information flow [14].

During the crisis associated with the pandemic, the use of digital technologies, the subsequent introduction of the principles of industry 4.0, and automation of production accelerated. This may lead to a decrease in employment in large industries and in the public sector [21, 22]. The development of small and medium-sized enterprises is considered as one of the tools for adapting to these processes. The role of small entrepreneurship in the innovative development of economics is undeniable. New firms are able to create and develop promising markets, especially in the context of changing technologies and crisis phenomena.

The principles of Industry 4.0 are being successfully implemented not only in large enterprises, but also in small and medium-sized enterprises. Small businesses face the need to improve productivity, the increasing market demand for a higher degree of personalization of products and services. According to the authors Matt et al., Industry 4.0 will enable SMEs to resolve the dilemma of the need to increase automation while reducing batch sizes [23].

However, literature analysis showed that a rather limited number of scientific works are devoted to the topic of digitalization of small industrial enterprises; they mainly consider general issues of implementing the principles of Industry 4.0 in small enterprises [24, 25]. However, in recent years in European countries, more and more authors are turning to the topic of the impact of digital technologies on small and medium enterprises. Safar et al. [25] and Muller [26] describe a specific framework for introducing new, innovative as well as digital business models in SMEs.

According to the authors of a paper [27], the integration of innovation and digitalization into a coordinated development process is becoming a prerequisite for SMEs. They propose a research program dedicated to the possible contribution of the use of innovative tools and methods to the digitalization process.

In Russia, there are practically no studies on the digitalization of small industrial businesses. In our previous works [28], we identified the need for special studies for the implementation of Industry 4.0 technologies in small industrial enterprises, which will allow them to be transformed into smart factories, and also highlighted the features of digitalization processes for enterprises of different sizes. Thus, the issue of innovative activity of small enterprises in the context of digitalization of industry in Russia remains a relevant area of research.

3 Materials and Methods

The theoretical and methodological basis of the study is the scientific results presented in publications in the field of the fourth industrial revolution, digitalization of industry, digital transformation of small and medium-sized enterprises, and innovative development.

The methodological basis of the research is the network and institutional approaches. Methods of theoretical generalization, systemic, logical, structural, comparative analysis, statistical methods are applied. To solve research problems related to the impact of digital transformation of the industry on innovation processes at small enterprises in Russia, we used the following main research methods: analysis of scientific publications, a descriptive method for analyzing the dynamics of changes in indicators of digitalization and innovative activity of Russian industrial enterprises. Thus, to solve the set tasks, we use a complex of complementary research methods: methods of theoretical analysis of the literature on the problem under study; methods of study, generalization and analysis of experience and existing results of management practice; quantitative and qualitative methods for collecting empirical information.

For the purpose of the study, we did a literature review on digitalization of industry and innovation, in particular on small and medium enterprises, in Russia, where we analyzed articles and conference papers published before November 2022. Three databases were used for literature analysis: Web of Science Core Collection, Scopus, and eLibrary (Russian electronic library of scientific publications integrated with Russian Science Citation Index). We used key words "Digitalization of Industry", "Digitalization in Small Manufacturing Business", "Small and Medium Enterprises and Industry 4.0", "Innovation and digitalization".

As a result of the bibliographic analysis, we found that a rather limited number of scientific works are devoted to the digitalization of industrial SMEs. Among publications in English, we found several articles in journals, several book chapters; most of the publications are articles in conference proceedings that are more of empirical character. Among the publications in Russian, there are practically no scientific papers on the topic of industrial small business in the context of Industry 4.0 and digitalization. The same applies to statistics on the level of digitalization of manufacturing SMEs in Russia. There is no such data. Statistical studies of the level of digitalization in the Russian Federation concern only large and medium-sized businesses. However, we used Rosstat data to assess the dynamics of innovation activity of small industrial enterprises.

The paper analyzes the digital maturity of industrial enterprises, and assesses the dynamics of innovative activity of small industrial enterprises. The information base of the study is the data of state statistics of Russia, regulatory information on state support for the digitalization of industry, data from statistical bulletins of the Institute for Statistical Research and the Economics of Knowledge of the National Research University Higher School of Economics, scientific reports of RANEPA, and expert opinions of heads of industrial enterprises.

4 Change of Innovation Processes in Small Enterprises in the Context of Digital Transformation

The modern development of the economy takes place within the framework of Industry 4.0 and digitalization. Industry 4.0 is aimed, on the one hand, at the introduction of highly efficient and automated production processes characteristic of mass production, and on the other hand, at the formation of an industrial environment where individual and customer-specific products are produced in accordance with mass customization strategies [29].

The emergence of disruptive technologies and the acceleration of technological renewal is one of the main trends in global production. Simachev et al. [30] among the most important trends also highlight the increasing role of small and medium-sized enterprises as a driver of structural changes and economic growth. The transformation of production chains, the growth of requests for customization, digitalization, and service will determine the need for industrial policy to take into account horizontal and vertical links between production and other sectors in the economy.

Specialists from ISSEK HSE [31] assessed the trajectories of advancement of 76 world economies in the Global Innovation Index (GII) in 2017–2021. The final rating is calculated as the average of two sub-indices—innovation resources (institutions, human capital and science, infrastructure, market and business development level) and their results (development of technologies and the knowledge economy, results of creative activity). Russia closes the first third of the ranking of world economies in terms of innovative development, using its innovative potential by only 56.9%. In general, the final position on the five-year horizon (45th place) remains almost unchanged, for the period 2017–2021 the value of the GII rating decreased slightly—from 38.8 to 36.6 points.

An analysis of the GII longitudinal data shows that, in order to achieve sustainable growth rates, the Russian economy needs not only to increase investment in science and innovation and stimulate the innovative activity of businesses (both large high-tech and flexible, adaptive small businesses), but also provide favorable conditions for the rapid introduction of new technologies, products and services to the market.

Let us consider the factors that affect innovative development, including small enterprises, in the context of digitalization. First, the driver of the digital economy is data. Their volume is constantly growing exponentially. They are resources for digital innovation. Big Data technologies are key in terms of digitalization. Secondly, the functional basis of the innovation process is "servicing", i.e. service orientation. Flexible business models are emerging, and they are focused on solving the client's problem through the provision of additional services and individualization of the product in accordance with its requirements. Large companies share their infrastructure and data and attract new players through their digital platforms. There is a dramatic expansion of market entry opportunities for small and medium-sized companies due to the spread of digital platforms. The low or notional price of renting digital infrastructure provides opportunities for seed startups to enter the market. Thanks to service-oriented innovation models, large companies can stimulate the diffusion of digital technologies to small and medium-sized enterprises, intensifying their activities.

Thirdly, digitalization provides new opportunities for collaboration at all stages of the innovation process. The constant exchange of ideas and sharing of data makes the innovation process accelerated and continuous. The digital transformation of the innovation ecosystem provides new opportunities for the transfer of knowledge and the organization of network communications, where ready-made solutions and data are exchanged. Dolphsma notes that a decentralized communication structure reduces transaction costs and increases synergy for the innovation ecosystem and the economy as a whole [32], and digitalization makes it possible to create just such structures at the lowest cost.

Thus, the hallmark of digital transformation is the rapid acceleration of the innovation cycle. The latest technologies significantly reduce the time of creation and commercialization of innovations. Digital transformation requires the development of new technologies and the corresponding restructuring of business processes. Digital modeling and digital twins make it possible to incorporate the characteristics of global competitiveness and high consumer requirements into products, as well as to increase the level of customization. In after-sales service, thanks to digital technologies, there is a transition to a service business model ("goods as a service") and predictive maintenance (from "repair according to the regulations" to "repair on condition").

5 Innovation Management in Small Enterprises in the Context of Digitalization

The success of innovation in the new digital era largely depends on an integrated approach to the transformation of all key aspects of the company's activities, the creation of a technological platform on which all the company's key ecosystems will be built [8].

In the digital economy, innovation management is associated with a quick response of management to a reduction in the life cycle of products, technological, social, marketing and institutional innovations, with the definition of parameters and the creation of an adequate environment and starting innovation platforms [33].

Bykovskaya emphasizes that the digitalization of the innovation process in the context of network interaction of subjects and objects is based on digital technologies, management decisions regarding the search, creation, processing, exchange and transfer of various information, and financial transactions between partners, stakeholders within joint project [7]. Digital technologies ensure the effectiveness of coordination, synchronization of actions of all participants in the innovation process.

One of the criteria for assessing the achievement of the goals of digital transformation is the level of digital maturity of industries, as well as public authorities [34]. As part of the current study, it is also important to talk about the digital maturity of individual companies. Research is developing various approaches to defining and measuring digital maturity: as a tool for comparing the achieved level with the target, and for cross-industry comparison of the level of digitalization. For example, the OECD assesses the digital maturity of business sector organizations based on three dimensions:

– ICT opportunities (training employees in digital skills, availability of ICT specialists, introduction of digital technologies);
– advanced ICT functions (information security, business management software adaptation, own developments);

– web maturity (availability of a website with the possibility of conducting electronic commerce, placing online advertising) [35].

Digital transformation consistently entails rethinking the business model, changing business processes, creating a new corporate culture, and developing the company through the introduction and application of digital innovations [36]. Diagnostics of a company's digital maturity will allow it to develop its own strategy for introducing new digital technologies.

Researchers from France and Canada [37] believe that the actual problem of applying Industry 4.0 technologies in small and medium-sized enterprises is their typical management style and short-term strategy, which differ from larger firms. Despite a growing number of new tools and technologies, most of them are underused or completely ignored by small businesses. Their research shows "that the least expensive and least revolutionary technologies (simulation, cloud computing) are most widely used in small and medium enterprises, while those that allow for deep business transformations (CPS, machine-to-machine communication, large data, robots) are still ignored by small and medium enterprises" [37]. Further research is needed to develop specific strategies, methods and tools for the effective digitalization of SMEs in the industry and the growth of their innovative potential.

6 The Current Situation in the Field of Digitalization of Industry and Innovative Small Business in Russia

The manufacturing industries make a significant contribution to the total cost of Russian organizations for the implementation and use of digital technologies—8.7%, or 256.6 billion rubles in 2020 [35]. The manufacturing industry is one of the sectors for which monitoring of digital maturity is carried out as part of the achievement of the national goal "Digital Transformation". In November 2021, a strategy for the digital transformation of the manufacturing industries was approved [38], which, among other things, is aimed at achieving its digital maturity. The Russian manufacturing industry is noticeably ahead of other sectors of the economy in terms of the use of digital technologies [39]. The overall value of the digital maturity of the manufacturing industry was 21% in 2021, and by the end of 2022 it is planned to reach a value of 40% [35].

In 2021, the level of innovative activity of small industrial enterprises, defined as the share of enterprises engaged in innovative activities, in their total number, amounted to 6.9%. This is the highest indicator for innovative activity for 2011–2021 (Table 1) [40, 41]. Partially, the growth of indicators can be explained by the fact that the calculation of indicators in 2011–2017 performed for small enterprises that carried out technological innovations, and from 2019, non-technological innovations are also taken into account.

The highest values of the indicator of the level of innovative activity in 2021 were recorded at enterprises producing medicines and medical materials (23.75%),

Table 1 Main indicators of innovative activity of small industrial enterprises

	2011	2013	2015	2017	2019	2021
Level of innovative activity, percent	5.1	4.8	4.5	5.2	5.8	6.9
Costs for innovation activities (million rubles)	9479.3	13510.5	12151.8	19220.4	27340.2	54441.8
As a percentage of the total volume of shipped goods, performed works, services	0.86	1.03	0.64	0.81	0.96	1.3
The volume of innovative goods, works, services (million rubles)	16389.7	27126.6	31270.9	37523.0	67055.9	118825.9
As a percentage of the total volume of shipped goods, performed works, services	1.5	2.1	1.6	1.6	2.4	2.8

computers, electronic and optical products (20.4%), electrical equipment (13.1%), chemicals and chemical products (11.7%), production of machinery and equipment not included in other groups (11.4%), other finished products (11.2%) [41].

The cost of innovative activities of small enterprises amounted to 27.3 billion rubles in 2019 and 54.4 billion rubles in 2021. The growth of costs has been occurring since 2017. The indicator of the intensity of costs for innovation activities (i.e. their share in the total volume of shipped products of small enterprises) rarely exceeds 1%. Its highest values were recorded in the production of medicines and medical materials (5.8%), motor vehicles (4%), computers, electronic and optical products (2.7%).

The actual volume of innovative industrial products produced in the small business sector in 2019 reached 67.1 billion rubles, in 2021 it already amounted to 118.8 billion rubles. A significant increase in the scale of production for the period 2011–2021 was revealed. The output of new and improved goods, works and services increased by 2.5 times (in constant prices) and reached its maximum values. Specialists of ISSEK HSE calculated the level of innovative activity of small enterprises in various industries based on alternative sources. It surpasses the corresponding data of federal statistical observation. Thus, the value of the obtained indicator for 2021 was 19.5% against the statistical 6.9% for small industrial enterprises in 2021 [42].

Among all industries that carry out innovations, it is possible to single out groups with the highest level of activity. Firstly, these are the knowledge-intensive services sectors—activities in the field of information and communication (26.3%), professional, scientific and technical activities (24.4%), where small enterprises carry out research and development, invest in intangible assets such as software, licenses, patents to support their own activities. Among them are enterprises—residents of

Skolkovo, winners of competitions under the programs of the Innovation Promotion Fund, business entities implementing the results of intellectual activity. Secondly, the manufacturing and extractive sectors (19.4 and 18.7%, respectively), turned out to be the most productive in terms of the production of innovative products and the introduction of innovative technologies.

According to Russian Academy of National Economy and Public Administration experts [43], promising markets for the digital economy in Russia are likely to be filled with small firms. Cases of individual regions and cities already demonstrate the significant role of entrepreneurship in Russia in the formation of new industries: engineering in Tolyatti, information technology in Tatarstan, radio electronics and biotechnology in Tomsk, robots in the Perm region, etc.

Thus, with a low level of innovation activity and its slightly growing dynamics in small industrial enterprises, there are industries that demonstrate leading indicators, there are small enterprises—industry leaders in the field of digital technologies. Accounting for their experience can be useful for formulating a policy to stimulate innovative development.

7 State Support Measures for Small Enterprise in the Field of Innovation and Digitalization

Today, digital innovations are being created faster than the state and business are used to making decisions. This requires new approaches to industrial policy, the rules of the innovation market, as well as the acceleration of bureaucratic processes. In this regard, the governments of different countries not only adopt digital strategies themselves, but also build their entire socio-economic policy based on the fact that digital technologies are becoming a key component of the economy.

For example, the German digital strategy “Digital Strategy 2025” consists of ten steps that need to be taken for the digital transformation of Germany [5]. Two of them are directly aimed at small enterprises: the second one—is a support for start-ups as engines of digital transformation with the help of large technological companies; the sixth one is the introduction of new business models for small and medium-sized businesses.

We should note that one of the key difficulties in implementing the policy of digital transformation of the manufacturing industry in Russia is to ensure full coverage of enterprises not only large backbone companies (including state-owned companies and state corporations), but also small and medium-sized private businesses must go through the transformation of production and business processes, which will create new, more efficient production ecosystems based on digital platforms (including within the concept of virtual factories) [35].

Thus, it is advisable to focus on the improvement of policies and measures to support the digital transformation of industry on the tasks of “massification” of the introduction of digital technologies by enterprises. To do this, it is necessary to overcome such barriers as lack of financial resources, lack of competencies (both for management of digital transformation projects—for management, and for the use of digital technologies and for production and service personnel), "patchwork" automation and digitalization, carried out at earlier stages on the basis of disparate IT solutions, mostly foreign, lack of practices and culture of working with data, information security risks (for some industries).

In Russia, over the past 10 years, various instruments to support innovation and mechanisms of the innovation ecosystem have been formed at the federal level. There are a lot of discussions about the quality of the available tools, their demand on the part of the innovative business and their applicability in Russian legislation. At the same time, at the regional level, there is an increase in the activity of regional authorities in work aimed primarily at retaining and attracting start-ups and innovative projects [43]. RANEPA specialists in their study identified successful regional practices aimed at implementing projects in the field of digital transformation. The realization of the possibilities of the digital economy is largely determined by the policy of the regional authorities to stimulate entrepreneurial initiative and grow technology leaders. In the implementation of the digitalization of the economy, the development of human capital in the field of innovation, digital technologies, and IT entrepreneurship is also of particular importance. A large number of Russian regions are included in the support and development of projects aimed at increasing digital literacy and training innovative personnel.

In 2021, the Ministry of Digital Development of Russia launched the Program to Support the Digitalization of Small and Medium Enterprises as part of the federal project "Digital Technologies" of the national program "Digital Economy of the Russian Federation". Companies with an annual income of up to 2 billion rubles and the number of employees no more than 250 people can purchase SaaS solutions from Russian developers with a 50% discount.

It is also necessary to note the Federal project "Creation of a Digital Platform with a mechanism for targeted selection and the possibility of remotely obtaining support measures and special services for small and medium-sized enterprises and self-employed citizens" [44]. It implies the creation of a single digital ecosystem containing comprehensive up-to-date information on all measures and institutions to support small and medium-sized enterprises and allowing an entrepreneur to select and receive remotely the support measures he needs. Since February 2022, 20 online services have already been available on the SME.RF Digital Platform, more than 180 thousand users have already registered, and more than 170 support measures are available for online application.

As promising areas of state support, we consider the digitalization of all administrative processes, control and supervisory requirements and support tools. Long-term support measures should be aimed at adapting to crisis and post-crisis conditions, including support for changing the structure of the SME sector towards an increase in the share of the Internet economy (online trading, delivery, online services, etc.), support and training for the digital transformation of enterprises (mobile applications, digital platforms, etc.).

Thus, it is necessary to continue to develop the digitalization of public services that support SMEs, to create institutional conditions for the formation of innovative entrepreneurial ecosystems, and expand tools that contribute to the development of human capital in the field of digital literacy and entrepreneurial skills.

8 Conclusion

Digitization and digital transformation are giving to small enterprises new benefits in innovation. In addition to directly new production technologies, they include new information processing technologies, communication methods, service models, digital platforms, access to new markets. All this significantly accelerates innovation processes.

Among all the industries where small enterprises innovate in Russia, we have identified the groups with the highest level of activity—the knowledge-intensive services and manufacturing sectors.

Small enterprises function as part of a digital innovation ecosystem. In accordance with this, it is necessary to change the approach to managing innovation activities in small enterprises, on the one hand, and approaches to state support for innovative activity of enterprises in the context of digital transformation through the digitalization of public services and the development of interactions within the ecosystem, on the other.

Digital transformation requires building new business models, changing business processes, creating a new corporate culture, and developing the company through the introduction and application of digital innovations. It is important to assess the level of digital maturity of an enterprise in order to form an adequate strategy for its innovative development associated with the introduction of digital technologies.

In modern conditions, promising forms of state support for small enterprises in the field of digitalization are the programs to support the digital transformation of business, the elimination of the digital divide, the formation of innovative entrepreneurial ecosystems based on digital platforms.

The limitation of this study was that in Russia there are practically no scientific works devoted to the digitalization of small industrial business. Data on the digitalization of industrial enterprises is limited; often it is the result of surveys or case studies. Statistics on the level of digitalization of small businesses, especially industrial SMEs, are not available. Data on the innovation activity of SMEs also have similar limitations.

Our study has contributed to the development of theoretical and methodological approaches to assessing the impact of digital transformation of the industry on innovation processes in small enterprises and their innovation activity. We have proposed directions for improving the state policy on the digitalization of the economy in terms of developing an ecosystem approach to supporting innovative entrepreneurship.

As promising areas of research, we can talk about the development of a methodology for assessing the innovative effects of digital transformation of the industry for small businesses, as well as the effectiveness of state support measures for digitalization in terms of the development of innovative activities at small enterprises in the industry of the Russian Federation.

Acknowledgements The article is supported by the Russian Scientific Foundation, project no. 22-28-01868 "Development of an agent-based model of a network industrial complex in the context of digital transformation".

References

1. Abou-Foul, M., Ruiz-Alba, J. L., & Soares, A. (2020). The impact of digitalization and servitization on the financial performance of a firm: An empirical analysis. *Production Planning & Control, 32*(12), 975–989. https://doi.org/10.1080/09537287.2020.1780508.
2. Klochko, E., & Brizhak, O. (2019). Prospects of using virtual technologies in modern corporate business systems. *Advances in Intelligent Systems and Computing, 726*, 308–319. https://doi.org/10.1007/978-3-319-90835-9_36.
3. Kudryavtseva, S. S., Shinkevich, M. V., & Ostanina, S. S. (2021). Modeling the factors behind digitalization of the real sector of the economy. In V. Kumar, J. Rezaei, V. Akberdina, & E. Kuzmin (Eds.), *Digital transformation in industry. Lecture notes in information systems and organisation* (Vol. 44). Springer. https://doi.org/10.1007/978-3-030-73261-5_7.
4. Gölzer, P., & Fritzsche, A. (2017). Data-driven operations management: Organisational implications of the digital transformation in industrial practice. *Production Planning and Control, 28*(16), 1332–1343. https://doi.org/10.1080/09537287.2017.1375148.
5. Urinson, Ya. M., & Panfilov, K. S. (2020). Digitalization as a factor in the development of innovative strategies on the example of some countries. *Business. Society. Power, 2–3*, 117–125. https://publications.hse.ru/articles/412066803.
6. Veselovsky, M. Ya., & Pogodina, T. V. (2019). Digital technologies and their influence on the innovative development of the regional industrial complex. *Issues of Regional Economics, 1*(38), 21–26. https://unitech-mo.ru/upload/files/science/problems-of-regional-economy/file/2019_1.pdf.
7. Bykovskaya, E. N., Kharchilava, G. P., & Kafiyatullina, Yu. N. (2018). Modern trends in the digitalization of the innovation process. *Management, 1*(19), 38–43. https://doi.org/10.26425/2309-3633-2018-1-38-43.
8. Razinkina, I. V., & Lazarev, N. V. (2020). Innovative activity in the digital economy. *Creative Economy, 14*(11), 2757–2772. https://doi.org/10.18334/ce.14.11.111081.
9. Tukkel, I. L., Yashin, S. N., & Ivanov, A. A. (2019). Digital transformation as an important part of innovative development. *Innovations, 3,* 45–50. https://maginnov.ru/ru/zhurnal/arhiv/2019/innovacii-n3-2019/cifrovaya-transformaciya-kak-vazhnaya-chast-innovacionnogo-razvitiya.
10. Gobble, M. M. (2018). Digitalization, digitization, and innovation. *Research-Technology Management, 61*(4), 56–59. https://doi.org/10.1080/08956308.2018.1471280.
11. Mezentseva, E. S. (2022). Innovative effects of digital transformation of industrial enterprises. *Regional Economy: Theory and Practice, 20*(4), 659–677. https://doi.org/10.24891/re.20.4.659.
12. Igolkin, S. L., Zhilnikov, A. Yu., Gubertov, E. A., & Provotorov, I. A. (2020). Digitalization of innovative process: Evolution and problems. *Advances in Economics, Business and Management Research, Proceedings of the Russian Conference on Digital Economy and Knowledge Management (RuDEcK 2020), 148*, 249–252. https://doi.org/10.2991/aebmr.k.200730.046.
13. Dominguez, N. (2018). *SME internationalization strategies: Innovation to conquer new markets*. Wiley-ISTE. http://doi.org/https://doi.org/10.1002/9781119453413.

14. Pu, H., & Zheng, Y. (2015). The FDI of small- and middle-sized enterprises: A literature review. *Technology and Investment, 6*, 63–70. https://doi.org/10.4236/ti.2015.61006.
15. Wells, L. T. (1983). *Third world multinationals: The rise of foreign investments from developing countries*. MIT Press.
16. Johnson, J. H., Arya, B., & Mirchandani, D. A. (2013). Global integration strategies of small and medium multinationals: Evidence from Taiwan. *Journal of World Business, 48*, 47–57. https://doi.org/10.1016/j.jwb.2012.06.006.
17. Rennie, M. W. (1993). Global competitiveness: Born global. *McKinsey Quarterly, 4*, 45–52.
18. McDougall, P. P., & Oviatt, B. (1994). Toward a theory of international new ventures. *Journal of International Business Studies, 25*, 45–64. https://doi.org/10.1057/palgrave.jibs.8490193.
19. Pietrobelli, C., & Rabellotti, R. (2004). *Upgrading in clusters and value chains in Latin America: The role of policies*. Inter-American Development Bank.
20. Giuliani, E., Pietrobelli, C., & Rabellotti, R. (2005). Upgrading in global value chains: Lessons from Latin American clusters. *World Development, 33*, 549–573. https://doi.org/10.1016/j.worlddev.2005.01.002.
21. Schwab, K. (2017). *The fourth industrial revolution*. World Economic Forum.
22. Zemtsov, S., Barinova, V., & Semenova, R. (2019). The risks of digitalization and the adaptation of regional labor markets in Russia. *Foresight and STI Governance, 13*(2), 84–96. https://doi.org/10.17323/2500-2597.2019.2.84.96.
23. Matt, D. T., Rauch, E., & Fraccaroli, D. (2016). Smart factory for SMEs: Designing a holistic production system by Industry 4.0 vision in small and medium enterprises (SMEs). *ZWF, 111*(1–2), 52–55. https://doi.org/10.3139/104.111471.
24. Matt, D. T., & Rauch, E. (2020). SME 4.0: The role of small- and medium-sized enterprises in the digital transformation. In D. T. Matt, V. Modr, & H. Zsifkovits (Eds.), *Industry 4.0 for SMEs. Challenges, opportunities and requirements*. https://doi.org/10.1007/978-3-030-25425-4.
25. Safar, L., Sopko, J., Bednar, S., & Poklemba, R. (2018). Concept of SME business model for Industry 4.0 environment. *TEM Journal, 7*(3), 626–637. https://doi.org/10.18421/TEM73-20.
26. Muller, J. M. (2019). Business model innovation in small- and medium-sized enterprises: Strategies for Industry 4.0 providers and users. *Journal of Manufacturing Technology Management, 30*(8), 1127–1142. https://doi.org/10.1108/JMTM-01-2018-0008.
27. Kooli-Chaabane, H., Camargo, M., & Boly, V. (2019). Innovation and digitalization in SME's: A research agenda. In *The 28th International Association for Management of Technology (IAMOT)*, Mumbai, India. https://www.researchgate.net/publication/331547648_Innovation_and_digitalization_in_SMEs_a_research_agenda.
28. Mezentseva, E. (2022). Digital transformation of Russian industry: The specifics of large, medium and small enterprises. In V. Kumar, J. Leng, V. Akberdina, & E. Kuzmin (Eds.), *Digital transformation in industry. Lecture notes in information systems and organisation* (Vol. 54). Springer. https://doi.org/10.1007/978-3-030-94617-3_22.
29. Modrak, V., Marton, D., & Bednar, S. (2014). Modeling and determining product variety for mass-customized manufacturing. *Procedia CIRP, 23*, 258–263. https://doi.org/10.1016/j.procir.2014.10.090.
30. Simachev, Y. V., Fedyunina, A. A., & Kuzyk, M. G. (2022). New contours of industrial policy. In *XXIII April International Scientific Conference on the Development of Economy and Society*. HSE Publishing House. https://conf.hse.ru/2022/papers/.
31. ISSEK HSE. (2022). *Recipes for success: How to achieve innovation leadership and economic growth?* Moscow: HSE Publishing House. https://issek.hse.ru/mirror/pubs/share/642245136.pdf.
32. Dolphsma, V. (2017). *State failures: Society, markets and rules*. Publishing House of Institute of Gaidar.
33. Lyakhov, D. (2020). Features of innovation management in the context of digitalization. *Economy Vector, 9*. http://www.vectoreconomy.ru/images/publications/2020/9/innovationmanagement/Lyakhov.pdf.
34. Pirannejad, A., & Ingrams, A. (2022). Open government maturity models: A global comparison. *Social Science Computer Review*, *0*(0). https://doi.org/10.1177/08944393211063107.

35. HSE. (2022). Digital transformation: Expectations and reality. *Report to XXIII April International Scientific Conference on the Development of Economy and Society.* Moscow: HSE Publishing House. https://publications.hse.ru/pubs/share/direct/623194265.pdf.
36. Abramov, V. I., & Borzov, A. A. (2022). The role of innovative potential in the digital transformation of the company. *Actual Problems of Economics and Management, 2*, 5–13. https://www.sstu.ru/upload/medialibrary/ad8/AKTUALNYE-PROBLEMY_2022_-2_34-_.pdf.
37. Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., & Barbaray, R. (2018). The industrial management of SMEs in the era of Industry 4.0. *International Journal of Production Research, 56*(3), 1–19. https://doi.org/10.1080/00207543.2017.1372647.
38. Government of Russia. (2021). *Decree №3142-r of 6.11.2021 "On approval of the strategic direction in the field of digital transformation of the manufacturing industries"*. http://static.government.ru/media/files/Yu4vXEtPvMyDVAw88UuBGB3dGEr6r8zP.pdf.
39. HSE. (2020). *Digital activity of manufacturing enterprises in 2019*. https://issek.hse.ru/mirror/pubs/share/333003484.
40. ISSEK HSE. (2020). *State and development of innovative activity in the field of small business.* https://issek.hse.ru/mirror/pubs/share/392488458.pdf.
41. Rosstat. (2022). *Science, innovation and technology*. https://rosstat.gov.ru/statistics/science.
42. ISSEK HSE. (2022). *What does open data say about the innovative activity of small businesses?* https://issek.hse.ru/mirror/pubs/share/590666024.pdf.
43. RANEPA. (2020). S. Zemtsov (Ed.), *National report "High-tech business in the Russian regions"*. Moscow: RANEPA, AIRR. http://i-regions.org/upload/iblock/581/Hi_Tech_all_view.pdf.
44. Ministry of Economic Development of RF. (2021). *Digital platform for SMEs*. https://www.economy.gov.ru/material/directions/nacionalnyy_proekt_maloe_i_srednee_predprinimatelstvo_i_podderzhka_individualnoy_predprinimatelskoy_iniciativy/cifrovaya_platforma_msp/.

Artificial Intelligence Transformation in the Industry: Challenges and Opportunities

Fatima Roumate

Abstract Artificial intelligence (AI) ensures alternative solutions to global issues, ranging from food security to economic development and the development of health services. AI transformation is impacting all sectors and all products. These innovative technologies are a culmination point in this fourth industrial revolution. This paper deals with AI transformation in the industry. The starting point is the transition from digital to AI transformation in the industry. Major challenges are imposed by AI transformation in the industry related to regulation and technological sovereignty. As concluded in this paper, optimal actions are needed since AI transformation in the industry is strengthening the gap between the Global North and the Global South. Rethinking legal standards is an obligation rather than a choice, considering that codes are not laws and the importance of ethics in AI for the global governance of AI.

Keywords Artificial intelligence · Industry · Legal standards · Ethics · AI

1 Introduction

Artificial intelligence (AI) offers new opportunities and alternative solutions to industry, ranging from research and development to production processes, marketing, customer services, and delivery system. However, these innovative technologies bring new challenges to all sectors from food, to health care and automated cars. AI transformation is the current characteristic of this fourth industrial revolution. This paper attempts to examine opportunities and challenges related to the transition from digital to AI transformation in the industry. This transformation is an important feature of the new world economic order characterized by the race toward AI.

The main questions one should ask are: How AI transformation will reshape the industry? What are the opportunities offered by AI transformation to industry and what are the challenges imposed by AI to industry and what are the consequences of

F. Roumate (✉)
International Institute of Scientific Research, Marrakech, Morocco
e-mail: iirs.institute@gmail.com

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_28

AI transformation in industry? To answer these questions, we ‘ll have a closer look at AI as a culmination point in the fourth industrial revolution with a special focus on the challenges imposed by AI transformation in the industry including those related to international legal standards and technological sovereignty.

To accomplish these objectives, the paper is divided into four additional sections. Section 2 analyzes the transition from digital to AI transformation in the Industry. In Sect. 3, the paper draws on various challenges related to AI in the industry. Section 4 concludes that the governments, as principal actors in international economic society, are forced to rethink national and international AI strategies. A new international economic order is in progress considering the rise of new technological and economic forces which means emerging of new players and new rules of international economic relations.

2 Methods

This paper is based on the several approaches needed to define and evaluate challenges imposed by AI transformation in the industry to international economic society. Multidisciplinary approaches are needed to achieve the goal of this study. First, the political approach is necessary to measure the impact of AI on international economic relations. The second is the legal approach which is also important to determine the challenges related to international economic law. The third one is the prospective approach used to analyze challenges related to artificial intelligence trends.

3 Background

3.1 Industry from Digital to AI Transformation

Artificial intelligence offers tremendous opportunities to the industry. This sector is already prepared for this new step in this fourth revolution which means the transition from digitalization to AI transformation. The industry is already digitalized and ready for a new transformation using AI. Digital transformation means «(…) is the deliberate and ongoing digital evolution of a company, business model, idea process, or methodology, both strategically and tactically (…)» [1]. According to IBM, digital transformation aims to «build a technical and operational foundation, to evolve and respond in the best possible way to unpredictable and ever-changing customer expectations, market conditions and local or global events» [2]. This leads to how technology is changing not only customers’ expectations, partners, and employees but most important how technology is invested in the business and manufacturing process [3]. AI is a huge boost to the digitalization of the industry and it’s an advanced level in the digitalization process. AI transformation focuses more on how data is used in industry and for the industry. The goal is to increase flexible and efficient production based on the improvement of machine efficiency availability based on the use of AI technologies [4]. AI is not something new but it started in 1950. AI transformation continues to make changes in all institutions including companies since this date.

According to Nvidia, AI is used for the first time by a group of scientists in one meeting at the University of Dartmouth, New Hampshire. The main goal of scientific research was how to get the machine to think like a human. That means that scientific research in AI is a cornerstone of AI transformation in the industry and other sectors since 1950 [5]. This process is the most important argument that the AI transformation is already a reality and now we are in a new step characterized by big data which is the bride between digital and AI and digital transformation.

The culmination point in this process is COVID-19 which is an important step in international relations including international economic relations. The global transition to a new economic world order is linked to this pandemic with all changes and challenges imposed by the massive use of AI in all fields and by all actors. COVID-19 is a new Westphalian system based on AI as a cornerstone of the new international economic world order considering the emergence of new powerful states and the global investment in AI. According to the Tortoise Global AI Index, global AI investment reached $77.5 billion in 2021 [6]. The US is the winner considering the global investment of AI companies. China's public investment in AI is set to far outstrip the rest of the world's investment in AI. In a sense and considering AI transformation's impact on the industry, "A McKinsey survey found that 11% of 1,140 business executives believe their current business models will be economically viable through 2023" [7]. According to PwC, "60% of companies believe that digital transformation will be critical to their growth in 2022" [7].

In industry, AI technologies are widely used at different levels from production to marketing and customer services, etc. Therefore, they are used more in information technologies by about 44% of 835 companies [8]. In Customer Service, AI is used to collect and analyze customer data to predict their choices and ensure good service. AI is a tool that supports business Operations and decision-making processes. In a sense, «IBM estimates that by 2025, the data-based decision-making tools market will be $2 trillion» [8]. Automation implies several fields such as finance and accounting tasks which will be fully automated in the coming years. Artificial Intelligence can help streamline many human resources. AI is creating a profound change in the industry considering the power of big data which is a new oil in the AI economy. AI tools ensure flexibility and efficiency during the manufacturing process and this good increase growth and ensure easy access to customized product for all social categories [4].

As a study by Roland Berger shows, by 2035, intelligent, digitally networked systems and process chains could account for additional growth of roughly €420 billion in western Europe alone [9]. AI can also contribute up to US$ 15.7 trillion to the global economy in 2030 [9]. According to PWC «in a survey of more than 650 business executives, including 89 chief information and chief technology officers, 60% say capitalizing on digital transformation initiatives is very important to their businesses in 2022. It ranks second, behind the enduring priority of hiring and retaining talent (77%)» [9]. According to the same survey, «59% of these companies will invest a lot in digital transformation in 2022 (….) and 42% of all business leaders will accelerate digital transformation initiatives and 53% of CIOs indicating they will accelerate digital transformation initiatives (…)» [9]. AI strategies adopted by companies to ensure AI transformation are based on a key priority which is reinventing the cloud and data [9]. However, 61% of the companies consider that AI is the most important pillar in their AI strategies followed by digital identity (57%), 5G (56%), and the Internet of Things (54%) according to the PWC's survey [9]. According to the same survey, less importance is given to the metaverse (including virtual reality, augmented reality, and immersive interfaces) at 46%, Cryptocurrency, and digital assists at 43%, and Digital twins at 37% [9]. The results of this survey are proof of the transition to an advanced step in the AI transformation process that started in 1950. However, this will impose new challenges to international economic society.

3.2 Challenges Imposed by AI Transformation in the Industry

For AI challenges, we have two types. The first type is related to the dual use of AI which means that AI is used for civil and military goals. AI is sometimes used as a weapon for example cybersecurity. The second type is legal challenges considering that in the AI era, national legislations become heavily traditional. AI influences also all international law branches such as international economic law and international health law, but also international law of human rights, in this case, social and economic rights. We have some good international mechanisms; the first one is the Budapest Convention on Cybercrime adopted by the Council of Europe. Even if adherence to this convention is open to all countries, it remains a regional instrument limited only to cybercrime. The second international mechanism is the World Trade Organization Technical Barriers to Trade Agreement which covers some of these advanced technologies such as autonomous vehicles. However, it needs to be updated to the current and future challenges of AI [10].

The third is the international instrument on the ethics of AI. In this context, we underline the recommendation on the ethics in AI adopted by UNESCO in November 2021. Eleven policy areas set out in this international mechanism addressed to the Member States based on sovereignty and equality as it was included in the international law. According to this recommendation, coordination between academia, transnational corporation, and international organization is needed to enhance international cooperation and to rethink the legal framework considering ethics as a pillar in all possible and feasible solutions for technological development [11]. International cooperation and collaboration in the field of AI to bridge geo-technological lines is necessary to insure the benefit of AI industrial transformation to all countries [11]. Technological exchanges between the global north as in the global south and inside countries between public and private sectors are a cornerstone of this fourth industrial revolution. This recommendation is a presenting a “strategy” able to ensure AI industrial transformation considering human rights and all international legal frameworks related to this field. Even if the recommendation is not a banned document, it’s the first instrument in this field and it could guide international society in the AI governance process. Ethics of AI aims to create a bridge between algorithms and law and to bring a solution to all challenges imposed by AI to all countries considering the gap between the Global North and the Global South.

Other challenges are related to technological sovereignty which is a large notion that refers to other types of sovereignty such as innovation and scientific sovereignty [12]. Edler et al. defined «technology sovereignty as the ability of a state or a federation of states to provide the technologies it deems critical for its welfare, competitiveness, and ability to act, and to be able to develop these or source them from other economic areas without one-sided structural dependency» [13]. Technological sovereignty refers to technology independence in all fields, politics, economy, and society. This means states should be able to choose their political and economic systems without any intervention or influence from other states such as the use of AI to manipulate public opinion and to change election results. Therefore, technological sovereignty depends on other types of sovereignty, for example, innovation and scientific sovereignty. Technological sovereignty is a condition to sovereignty as a principle of international law and it’s a key to other types of sovereignty (economic, agriculture, science, innovation, etc.). This explains the race and competition for AI and technological sovereignty.

Technological sovereignty covers sovereignty in all space and all fields. This notion is ranging from politics to the economy because technology, including AI, is influencing all actors and fields. Vladimir Putin warned Russians that the country that led in technologies using artificial intelligence will dominate the globe [14]. Angela Merkel said, «…on the one hand, we want to retain our digital sovereignty but, on the other, we want to act multilaterally, and not shut ourselves off. Of course, digital sovereignty is very important» [15]. The problem with these new notions is that there is no unified definition that makes a common understanding difficult.

During the keynote speech of the three-day World Internet Conference in the city of Wuzhen, Chinese President Xi Jinping said «China is willing to work with the international community for the common welfare of all people, to uphold the concept of cyberspace sovereignty and to make the global cyberspace governance system fairer and more reasonable» [16] and he urged executives in the tech industry to «respect cyberspace sovereignty» [16]. Common governance of AI and cyberspace with cooperation start first with a consensus on notions. The definition of this notion is the first step toward a common understanding of the challenges.

State’s competition for technological sovereignty could be illustrated using three criteria: AI and robotics investment, 5G technologies, and Research and Development in AI.

AI and Robotics Investment

In the industrial field, the International Federation of Robots presented 2020 a new world report under the title «Record 2.7 Million Robots Work in Factories Around the Globe—#WorldRo» and it expects average growth of 12% per year from 2020 to 2022. Global sales value for service robots reaches US$12,9bn [17].

China remains the strongest market for industrial robots reaching about 783,000 units—plus 21% in 2019. Japan ranks second with about 355,000 units—plus 12%. The USA reached a new operational stock record of about 293.200 units—up 7%. Europe reached an operational stock of 580,000 units in 2019—plus 7% [17].

This increased investment in industrial robotics is explained by this report on the COVID-19 impact on the AI transformation process in this sector which takes advantage of social distancing.

5G Technologies

50 companies are involved in this war but behind them, we have states, especially, China and the US. In this context, the commercial value of the internet of things is 12 billion and it's linked to 5G. China is leading in 5G [18]. Over 200,000 5G base stations were built by Huawei on May 20, 2020, and this company spent 800 million dollars on 5G research and development. Huawei takes 30–40% of the global market and 15% of patients. Therefore the game is not over. The 2020 ranking from the World Intellectual Property Organization (WIPO) reveals that the U.S. is leading in innovation [19]. It's the third country after Switzerland, and Sweden, in the high-income group while China is leading the Upper middle-income countries composed also of Malaysia, and Bulgaria. Competition for technological sovereignty is not limited to States. Transnational Companies especially Big tech are also competing with States and racing for technological sovereignty. They are monopolizing cyberspace with their innovation and they are guiding consumers' choices and influencing consuming habits. IBM said, «technological sovereignty should be based on presence, values, and trust, not the geographic location of the company» [20]. Codes are laws, but are they superior to the constitution and international law? Codes must be complying with local laws including data privacy laws [21].

This leads us to rethink the governance of AI linked to the governance of the Internet which should be based on a multidisciplinary approach. Governance of this sector should be the first mission of the State considering the impact of AI in all walks of life because protecting, defending, and promoting human rights is the main goal of the state and because individuals have a social contract with the state not with the big tech who are looking for profit [22].

4 Conclusion

In the era of AI, new reforms are needed at different levels considering the new identity of the international economic society with the increasing role of transnational corporations that have invested in AI more than in some states.

Great powers and small states should rethink the legal framework concerning their relations with transnational corporations, especially Big Tech to ensure peace and security for all. Governments should work with transnational corporations to build an enabling environment for data protection, transparency, and trustworthiness.

In the same context, international organizations should be, not only, a space of negotiation limited to the Member States, but it's time to create new tools which could facilitate the integration of transnational companies in the global governance of AI.

AI strategies in the industry need to focus at the same time on growth as a way to ensure development. That means it's necessary to create a balance between profit and human rights considering the gap between the Global North and the Global South. In a sense, national and international strategies on AI should be based on the ethics of AI which is the only way to create a balance between codes and law.

References

1. Mazzone, D. (2014). *Digital or death: Digital transformation—The only choice for business to survive smash and conquer* (1st ed.). Smashbox Consulting.
2. IBM. (2022). *What is digital transformation?* www.ibm.com/topics/digital-transformation.
3. Kane, G. C. (2017). *Digital transformation' is a misnomer: It's not about digital or transformation. It's about adaptation.* https://sloanreview.mit.edu/article/digital-transformation-is-a-misnomer/.
4. Siemens. (2022). *Artificial intelligence in industry: Intelligent production.* https://new.siemens.com/global/en/company/stories/industry/ai-in-industries.html.
5. Copeland, M. (2016). *What's the difference between artificial intelligence, machine learning, and deep learning?* www.blogs.nvidia.com/blog/2016/07/29/whats-difference-artificial-intelligence-machine-learning-deep-learning-ai/.
6. INDIAai. (2021). *Global AI investment reaches record high in 2021.* http://indiaai.gov.in/news/global-ai-investment-reaches-record-high-in-2021.
7. Alteia. (2022). *The role of artificial intelligence in digital transformation.* https://alteia.com/resources/blog/artificial-intelligence-in-digital-transformation/.
8. Bloomberg Media Studios and IBM. (2020). *Built for change perspectives: How smarter businesses transform in an uncertain world?* https://www.ibm.com/downloads/cas/R2M2RMQ1.
9. PWC. (2022). *CIOs, CTOs and technology leaders: Latest findings from PwC's Pulse Survey.* https://www.pwc.com/us/en/library/pulse-survey/executive-views-2022/technology-leaders.html.
10. Smeets, M. (2021)**.** *Adapting to the digital trade era: Challenges and opportunities.* https://www.wto.org/english/res_e/publications_e/adtera_e.htm.
11. UNESCO. (2022). *Recommendation on the ethics of artificial intelligence.* http://www.unesdoc.unesco.org/ark:/48223/pf0000381137.
12. Roumate, F. (2021). Ethics on AI and technological sovereignty. *Communications. Media. Design*, *6*(4), 139–151. https://cmd-journal.hse.ru/article/view/13766.

13. Edler, J., et al. (2020). *Technology sovereignty from demand to the concept*. Fraunhofer Institute for System and Innovation Research ISI, Karlsruhe, Germany. https://www.isi.fraunhofer.de/content/dam/isi/dokumente/publikationen/technology_sovereignty.pdf.
14. Indermit, G. (2020). *Whoever leads in artificial intelligence in 2030 will rule the world until 2100.* https://www.brookings.edu/blog/future-development/2020/01/17/whoever-leads-in-artificial-intelligence-in-2030-will-rule-the-world-until-2100/.
15. The Federal Chancellor. (2019). *Speech by Federal Chancellor Dr. Angela Merkel opening the 14th annual meeting of the Internet Governance Forum in Berlin on 26 November*. https://www.bundeskanzler.de/bk-en/news/speech-by-federal-chancellor-dr-angela-merkel-opening-the-14th-annual-meeting-of-the-internet-governance-forum-in-berlin-on-26-november-2019-1701494.
16. Xinhua. (2016). *President Xi stresses int'l cooperation in cyberspace governance.* https://www.wuzhenwic.org/2016-11/17/c_61495.htm.
17. International Federation Robot. (2020). *IFR presents World Robotics Report 2020.* https://ifr.org/ifr-press-releases/news/record-2.7-million-robots-work-in-factories-around-the-globe.
18. CTIA. (2018). *The global race to 5G, report*. www.ctia.org/news/race-to-5g-report.
19. Therese Wood. (2021). *Global stars: The most innovative countries, ranked by income group.* https://www.visualcapitalist.com/national-innovation-the-most-innovative-countries-by-income/.
20. Jetter, M., & Lecrec, J.-M. (2020). *IBM Policy Lab.* www.ibm.com/blogs/policy/digital-sovereignty/.
21. Roumate, F. (2021). Artificial intelligence, ethics, and international human rights law. *International Review of Information Ethics, 29*(23/2021). www.crids.eu/cooperations/ethics-working-group-ifap/ifap_contributions/roumate_f_2021-03_artificial-intelligence-ethics-and-international-human-rights-law.pdf.
22. Roumate, F. (2022). AI and international relations: A new balance of power in a new world order. *Communications. Media. Design*, *7*(1), 23–33. https://cmd-journal.hse.ru/article/view/14377.

Mobile Technology in the Digital Transformation Strategy of Industrial Enterprises

Wang Can

Abstract In the context of Industry 4.0, a variety of advanced technologies such as big data, artificial intelligence, cloud computing, and mobile technology have integrated design, supply, manufacturing, and sales. Interconnection and collaborative work provide efficient and high-quality overall solutions for the manufacturing industry, realize intelligent, precise, personalized and customized products or services. Mobile technology plays an important role in the development of industrial enterprises, which can implement the intelligent enterprise management, enhance the operation efficiency, improve the standardization of operation and management, and promote the core competitiveness. The digital economy's ideas and methods centered on mobile technologies such as the fifth generation (5G) are integrated into all aspects of the manufacturing process, running through the entire manufacturing system and traditional production. By analyzing the significance and value of mobile technology for the development of industrial enterprises, this study discusses the strategic path of mobile technology to advance the digital transformation of enterprises in industrially developed, developing and backward regions.

Keywords Mobile technology · Digital transformation · Strategic analysis · Industrial enterprise

1 Introduction

Mobile technology is increasingly becoming an organizational information technology (IT), which has received great attention and a lot of investment from enterprises. In its 2013 report, Intuition [15] showed that the compound annual growth rate of mobile data traffic of Fortune 500 companies reached 78%; in 2014, the percentage of the world's companies or organizations that installed enterprise applications on employees' mobile devices was 90%. As of December 2017, mobile technology

W. Can (✉)
Southern Federal University, 105/42 Bolshaya Sadovaya St., Rostov-on-Don 344006, Russian Federation
e-mail: 156041318@qq.com

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_29

ranked first with 77% of the top five technology fields that attracted major attention in the world, and became an essential element in most enterprises' information systems.

To understand how these shifts will affect the global marketplace over the next five years, Chinese researchers have performed a study of 363 corporate decision-makers [7]. The research identified four key technologies (Fig. 1).

The majority of respondents (57%) say that mobile technologies will have the greatest positive impact on their business over the next five years. Survey respondents across the companies of all sizes see mobility as a game-changer, and more than half of them within each industry note that their firms will invest heavily in mobile technologies over this period (Fig. 2).

What mobile technology brings is not only the integration of technologies, but also the transformation of the times. Against the background of Industry 4.0, the value chain, management and transaction costs of enterprises have changed, which affects the implementation of the original strategy of industrial companies. Considering the huge group of mobile users and the enterprise's substantial investment in

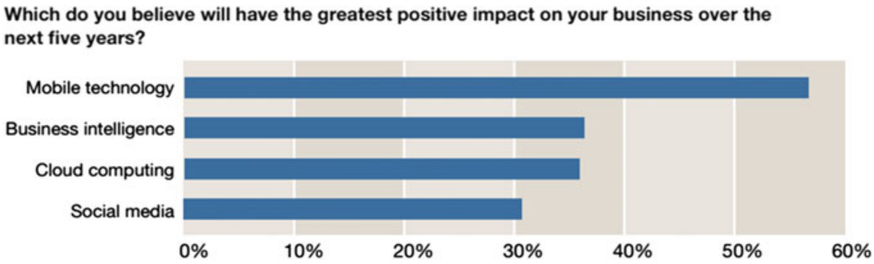

Fig. 1 Key technologies with the greatest effect on companies in five years [7]

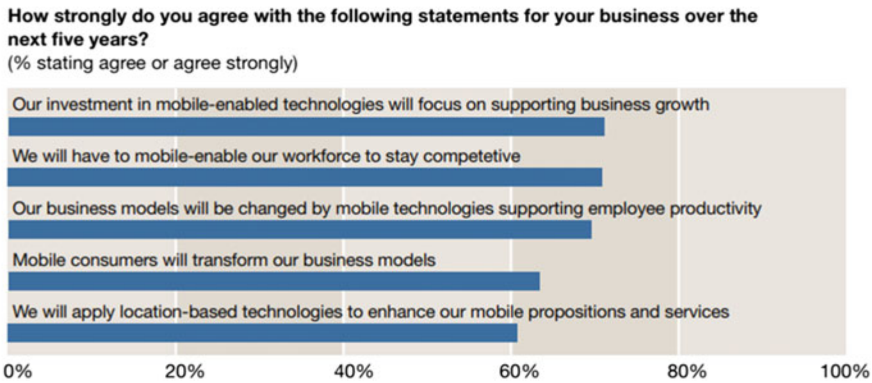

Fig. 2 Respondents' expectations about the role of mobility in business growth [16]

Table 1 Utilizing mobile technology to deliver final products [14]

Manufacturing sectors	Final products provided to increase the province's GDP (thousands of yuan)	Share of added GDP (%)
Food manufacturing and tobacco processing industry	75,653,154.05	12.24
Textile industry	15,955,106.01	2.58
Apparel leather down industry	18,394,988.00	2.98
Chemical industry	18,212,321.41	2.95
Metal products industry	5,379,190.90	0.87
Electrical machinery and equipment	15,723,375.00	2.54
Communication equipment, computer electronic equipment	2,089,044.91	0.34
Other sectors	6,863,041.60	1.11

informatization, mobile technology has been widely used in the internal communication and external cooperation to improve the competitiveness of enterprises and promote their overall economic development [8].

For example, in Henan Province, China, the input–output table is used to calculate the pulling effect of the total amount of final products provided by manufacturers using mobile technology on the economy as shown in Table 1.

As shown in Table 1, the increased GDP driven by the final products provided by various manufacturing sectors accounts for nearly half of GDP (45.21%), which indicates that the manufacturing sector has a greater driving effect on economic development.

1.1 Problem Statement

Digital transformation refers to the transformation associated with the application of digital technology covering sales, marketing, products, services, new business models, etc. Digital transformation of the enterprise is deep reconfiguration and reconstruction of business and management supported by mobile technology, which is a strategic task for enterprises to enhance their core competitiveness.

This study holds that digital transformation implies using mobile digital technology to integrate and upgrade the scientific-technological innovation and industrial development activities of the enterprise, and form the twinned complementary state of the industry chain business and the digital platform in which the enterprise operates, so as to enhance the core competitiveness of enterprises.

In the context of Industry 4.0, with the rapid development of science and technology and the advent of new technology revolutions, mobile technology plays a vital role in the development of industrial companies. The ideas and methods with 5G and other mobile technologies as the core are integrated into all aspects of the manufacturing process, run through the entire production system, and organically combine traditional manufacturing with mobile information technology, mobile communication technology, and mobile technology platforms [23]. This paper explores the strategic path to promote the digital transformation of industrial enterprises in different regions in China through the use of mobile technology.

1.2 Research Questions

1. What is the role mobile technology plays in promoting the digital transformation of industrial enterprises?
2. In Industry 4.0, what are the strategic paths that mobile technology can take to drive the digital transformation of industrial companies?
3. How to put forward an innovation strategy for the digital transformation of industrial enterprises from the perspective of technological innovation?

1.3 Research Significance

Research significance of the study is threefold.

Increase production efficiency. Digital transformation is conducive to the realization of digital technology, thus improving the quality of products and services and increasing business efficiency. Fully digitizing and upgrading the industrial chain, including technological R&D, product design, production and construction, and operation and maintenance can encourage the deep integration of digital technology and industrialization, enhance the efficiency of production and operation, and boost the overall economic efficiency.

Optimize resource allocation. Digital transformation is beneficial to mining and service industry chain demand. By collecting the data resources of the whole industry chain, the detailed data resources covering the upper and lower reaches of the industry chain are formed, and the demand precise analysis is carried out by using data modeling and data mining that help the whole industry chain to link upstream and downstream on-demand production, on-demand supply, and minimize inventory through the construction of smart supply chain to achieve the optimal allocation of resources in the whole industry chain [5].

Improve the level of industrial chain governance. Digital transformation is conducive to the upgrading of the overall level of modernization of industrial chain governance. Through the digital platform system, the systematic digital management of human, financial and material resources of nuclear enterprises is realized, the application rules of data resource management are established, and the data resource pool of the industrial chain is constructed and perfected, mining the data characteristics and data value behind all business links, improving data asset management ability, enabling industry chain management level through data governance.

2 Literature Review

Digital transformation is a transformation and subversion of the way of thinking.

The rapid evolution of IT and high concentration of data has exerted a huge impact on the development of society and completely changed people's way of life; most companies are also becoming more aware of the importance of big data. In the era of the accelerated development of artificial intelligence (AI), enterprises have to adapt to the changes happening. Most enterprises will use AI and big data deep integration, thereby improving manufacturing, services and marketing in order to optimize business processes and thus improve enterprise productivity [6]. However, not all of the goals can be achieved in the implementation process, so traditional IT cannot provide enough technical support for AI and big data, thus inhibiting the digital transformation of enterprises.

At present, the vigorous growth of China's digital economy and the continuous promotion of healthy development of the manufacturing industry provide favorable opportunities for the digital transformation of Chinese industrial companies. However, there are a number of problems, such as weak awareness of digital transformation, large differences in transformation progress, and difficulties in obtaining and integrating digital resources that still constrain the digital transformation of Chinese industrial companies. Look at these issues in more detail.

1. Lack of awareness of enterprises' digital transformation. Currently, some Chinese enterprises are not aware of the urgency of digital transformation. In particular, some small and medium-sized enterprises (SMEs) do not have a deep understanding of it or interpret it as the updating and upgrading of software, equipment or production lines. Due to the poor informatization and lack of business data, it is difficult for SMEs to survive in the digital economy era, and the digital transformation of SMEs deserves special attention.

2. Large differences in the digital transformation progress. There are obvious differences in the progress of digital transformation among industrial enterprises in different regions of China. Some leading enterprises in developed regions have entered the stage of digital and network development, but in underdeveloped regions, some enterprises are still at the initial stage of informatization or concentrated at the stage of application and coverage of IT in individual business links, which leads to the weak digital foundation of China's manufacturing industry as a whole.

3. Difficulties in obtaining and integrating data resources. In the digital economy era, the collection, analysis, mining and application of data resources are the important basis for its value. The digital transformation of the manufacturing industry cannot be separated from the support of data resources. It requires not only the collection, summary and analysis of the production, operation and related business process data of the enterprise, but also the mastery of the information on upstream and downstream enterprises in the industrial chain, knowledge of related industries, information on market supervision and even citizens. In addition, the collection of data resources is mainly restricted by the way enterprises use data. Some enterprises attach importance to collecting and analyzing data resources, and can timely implant mobile technology into the data acquisition methods. Some enterprises still use traditional data acquisition methods resulting in the low quality and efficiency of the collected data, thus affecting the subsequent analysis and application of data resources.

Therefore, there are still some inadequacies in the research on the digital transformation strategy of industrial enterprises. However, the use of mobile technology can promote the application of AI and big data in enterprises, and advance enterprise innovation and development. With the use of mobile technology, big data services can fully meet the needs of users and provide some guidance for enterprises to develop more high value-added and personalized products. The application of big data and mobile technology can help enterprises realize intelligent marketing, intelligent customer service, intelligent design, etc. and stimulate enterprise business innovation. In this paper, we deal with mobile technology integrated into enterprises in different regions of China as a starting point of using mobile technology to promote the digital transformation of industrial enterprises strategy.

3 Material and Methods

3.1 Realization Path (Literature Analysis Method)

This article uses general scientific research methods, such as literature survey, analysis and synthesis method.

Mobile technology plays a crucial role in improving the competitiveness of industrial companies. Mobile technology can be represented by the integration of mobile communication and information technology [25]. Mobile technology includes mobile information technology, mobile communication technology, mobile technology platform, and mobile application services. This research focuses on the impact of mobile communication technology, especially 5G, on the digital transformation of industrial companies.

Mobile technology has brought great changes to human society. In recent years, it has become the focus of attention in the industry due to the integration of mobile communication technology and IT. With mobile technology gradually maturing, mobile interaction, online connection available anywhere anytime, communication and information exchange provide the possibility to accelerate digital transformation of industry [11].

3.2 *Influence Elements*

Analyze the advantages of mobile technology integration into industrial companies.

Firstly, it helps improve manufacturing productivity and further reduce production costs. Since the reform and opening up, China's manufacturing industry has experienced rapid development, basically transforming from an agricultural to industrial country. However, the manufacturing industry has long suffered from the problem of low production efficiency. With the rise in labor prices, China needs to actively use information to modernize its manufacturing industry with intelligent technology, reduce production costs by improving production efficiency, offset the growing pressure of production costs caused by escalating labor expenses, and thus maintain the international price advantage of the manufacturing potential. As a new IT generation, mobile technology has strong advantages in network information technology for the manufacturing industry. The transformations in China, especially in the sphere of informatization and intelligence, can play a major role in promoting the Made in China label and help the country accelerate the realization of the Industry 4.0 principles. In fact, China's temporary key advantage in the field of mobile technology is the result of the long-term promotion of industrialization and informatization integration and active stimulation of the manufacturing industry's intelligent development. The evolution of mobile technology and network communication has a positive interactive development relationship between the macro-economy including the manufacturing industry and the need for the transformation and upgrading of the industrial structure [24].

Secondly, mobile technology integration helps offset the pressure of rising labor costs and maintain the price advantage of export products. The introduction of mobile technology to manufacturing can be reflected in all aspects of its production, operation, and management. From the perspective of production, mobile technology has a higher transmission rate, shorter time delay, stronger network stability and security, and lower costs, which will play a major role in improving the informatization and intelligence level of manufacturing. The vigorous improvement in R&D and manufacturing capabilities of intelligent equipment, as well as the rapid popularization of such equipment in production have added fresh impetus to develop artificial intelligence and mobile technology in China [18]. Due to the number of labor applications utilized in labor-intensive industries, production costs are reduced substantially. Since the beginning of the twenty-first century, labor costs have risen more than ten times. China's export price advantage based on low labor prices is weakening, and to a certain extent, the country's international competitiveness has also been falling. Moreover, in order to deal with the hollowing out of the manufacturing industry and maintain its core advantages, developed countries led by the United States proposed a "re-industrialization" strategy, trying to rebuild their manufacturing advantages, increase their employment rate and reduce the trade deficit with China. This initiative resulted in more intense competition faced by China in the international market. In this context, informatization and intelligent upgrading of the manufacturing industry using mobile technology will help ease the pressure on production costs brought about by rising labor costs, thereby maintaining China's long-standing export price advantage, so as to improve the global competitiveness of Chinese manufacturing.

Thirdly, mobile technology integration helps accelerate the transformation and upgrading of the manufacturing industry and optimize the structure of China's export commodities. The industrial structure of any state reflects its socio-economic level. Developed and developing countries generally have different industrial structures. The manufacturing industry in China as a newly industrialized country accounts for a large proportion of GDP. The country's industrial structure is undergoing a massive upgrading with the accelerated development of the service industry and a relative decline in the proportion of the manufacturing industry. In fact, in the process of China's industrial structure transformation, with the share of the manufacturing industry declining and the service industry increasing, the two industries are not contradictory, but are in the relationship of interdependence and synergy. Once a certain upgrade level is achieved, for the manufacturing industry to develop further, it should be supported by technology and capital-intensive producer services [1]. Mobile technology can provide more advanced mobile network IT support for the development of producer services and form a stronger driving force for the expansion of the manufacturing industry itself.

4 Results

According to the characteristics of unbalanced industrial development in different regions of China, the country's territory is divided into industrially developed (coastal and Beijing-centered regions), medium-developed (Northeast and Central Plains) and backward industrial areas (Southwest, Northwest) [2]. GDP growth rates of the three types of regions are given in Tables 2, 3 and 4.

As seen from Tables 2, 3 and 4, China's economic pattern is unbalanced and different regions have obvious differences. According to different industrial development levels in China, this paper explores the path of using mobile technology to promote the digital transformation of industrial enterprises.

Table 2 GDP growth rate of industrially developed regions in 2018 [14]

Coastal and Beijing-centered regions	GDP (unit: 100 million yuan)	GDP growth rate (%)
Shanghai	32,679.87	7.8
Beijing	30,320	7.7
Shenzhen	24,221.98	7.6
Guangzhou	22,859.32	6.8
Tianjin	18,809.64	6.8

Table 3 GDP growth rate of medium-developed industrial regions in 2018 [14]

Northeast and Central Plains	GDP (unit: 100 million yuan)	GDP growth rate (%)
Jinan	7856.56	6.4
Xuzhou	30,320	6.2
Harbin	24,221.98	5.3
Shenyang	22,859.32	5.4
Shijiazhuang	18,809.64	5.8

Table 4 GDP growth rate of backward industrial areas in 2018 [14]

Southwest, Northwest	GDP (unit: 100 million yuan)	GDP growth rate (%)
Nanning	4341.2	5.1
Guiyang	3798.45	4.9
Lanzhou	2732.94	4.5
Yinchuan	1901.48	4.2
Xining	1286.41	3.6

4.1 Strategies for Increasing the Digital Transformation of Industrial Companies in Industrially Developed Regions

The development of industrial economy should account for the aspect of improving the innovation ability of mobile technology.

Innovation is the cornerstone of national rejuvenation and social progress. Technological innovation is a difficult problem faced by China's industrial development. The improvement of technological innovation capability should play an important role in the national industrial overall development strategy and be viewed as a central link to enhance industrial competitiveness of all regions, including industrially developed ones, such as the southeastern coastal areas and the Beijing-centered areas. Positive technological shifts will allow enhancing the original innovation capabilities, expanding the integrated ones, as well as boosting the ability to import, digest, absorb and re-innovate.

The learning and introduction of mobile technology is an important factor that directly promotes industrial productivity and competitiveness. It is also an inescapable process in backward countries and regions. Amid technological innovation, foreign advanced high-tech achievements should be adopted selectively [17]. Special attention should be paid to adjusting measures to local conditions and regional industries, and learning advanced mobile technology in a diversified manner.

The manufacturing industry in the coastal areas and around Beijing has good prerequisites for development. When determining the directions for industry advancement, attention should be paid to the forward-looking introduction and active use of mobile technology in the fields of electronic information, bioengineering, new materials, fine chemicals, energy technology, and high-tech light and textile industry. Diverse mining technologies absorb the advanced scientific knowledge generated within the industry of the country and the world. In particular, it is necessary not only to purchase advanced equipment, but change the way technology is introduced and learn related domains. It is necessary to shift from the introduction of hardware to the introduction of software, as well as to combine both. This is the only way to be close to reality and raise the mobile technology level of the regional industry [22], strengthen the system conducive to technological innovation, effectively allocate technological innovation resources, promote the commercialization of new technologies, protect technological innovation achievements, and facilitate the introduction of foreign capital and technology [10].

Therefore, the southeastern coastal and Beijing-centered areas should formulate planning and control policies to guide foreign capital to invest more in high-tech industries and the technological transformation of the existing enterprises, accelerate the upgrading of the industrial structure, maximize the overall utility of the system, and promote the improvement of technological innovation capabilities.

4.2 Strategies for Enhancing the Digital Transformation of Industrial Enterprises in Medium-Developed Industrial Regions

The medium-developed industrial regions include the Northeast and the Central Plains, which are at the midstream level of regional industrial competitiveness. The main difference between these two regions lies in the application of mobile technology in enterprise management. Since the two regions concentrate a large number of state-owned enterprises, they are the key areas for the reform, especially in Northeast China [21]. The practice of reforming state-owned enterprises over the past few years has proved that without learning advanced management experience and management innovation, the industry will not have vitality.

While introducing technology and independent innovation, attention should be paid to learning and adaptation. Management innovation is a relatively large category, including enterprise production management innovation, enterprise system innovation, organizational structure innovation, etc.

To establish a management innovation strategy, industrial enterprises set the goal of its future development, so as to realize the strategic management. According to the principle of dynamic balance of corporate environment, goals and capabilities, select the appropriate strategic combination to continuously strengthen the company competitiveness. Practice has shown that promoting strategic management is conducive to establishing long-term development directions and goals for enterprises, improving corporate image and efficiency, and ensuring the comprehensive implementation of modern management, so that industrial enterprises enjoy stronger competitiveness [13]. In addition, the modern enterprise system requires a sound corporate governance structure, fully clarifying the responsibilities, rights and interests of the board of directors, supervisors and managers. From the experience of developed regions and nations, it should be learned how to solve the problems with reforming state-owned enterprises, establishing a modern system of such enterprises, dealing with corporate governance structure, etc. [26].

The mobile office system can be used to improve management efficiency. Mobile office allows enterprise managers to quickly and comprehensively control the overall timely and effective system information, and make well-timed management and control responses. Sorting out the business suitable for mobile office and realizing the efficiency of enterprise management through the system is the key path for the long-term stable development of the enterprise. Mobile management can effectively guide enterprise experience, problems, methods, knowledge, etc., effectively disseminate, share, utilize, resonate and reflect, and prompt employees to use more appropriate methods and measures to avoid the same mistakes and reduce unnecessary duplication of work [9]. The mobile office carrier provides integrated tools, such as employee management, task management, business management, office management, communication, collaborative documents, and video conferencing, which can be utilized flexibly and effectively, greatly promoting business management to a new level and enhancing competitiveness.

Therefore, mobile office can realize intelligent enterprise management and improve operation efficiency, standardization of operation, and core competitiveness.

4.3 Strategies for Increasing the Digital Transformation of Industrial Companies in Industrially Backward Regions

The backward industrial areas include the southwest and northwest regions. These two regions are characterized by slow industrial development and weak foundation in China. The industrial development in the western region should mainly improve the competitiveness through the advancement of characteristic economy by using mobile technology.

The western region is rich in natural resources, including the Yangtze River, the Yellow River, the Pearl River and other rivers in the region, with huge reserves of water energy. In order to develop industry in the region and turn resource advantages into economic advantages, it is necessary to increase the processing depth of resources and increase the added value of products [3]. However, the realization of this transformation method requires advanced technical conditions. The technology available in the region cannot support the comprehensive development of its industry, which requires the selection of transportation hubs, central cities, resource concentration areas, and important ports. Therefore, the model of "first center and then diffusion" is adopted as the center to drive the overall industrial development in the western region.

Table 5 Potential impact of mobile technology on companies in regions with different levels of industrial development

Industrial development level	Use of mobile technology	Digital transformation
Industrially developed areas	Strengthen the ability to innovate using mobile technology	Improve innovative-technological ability
Medium-developed industrial areas	Using mobile technology to enhance the company's strategic management capability	Promote strategic management and development ability
Backward industrial areas	Using mobile technology to develop characteristic economy	Increase competitiveness

At present, the western region already has the foundation of some advantageous industrial chains, such as coal chemical industry, salt chemical industry, petrochemical industry, natural gas chemical industry, electro-chemical, etc. in Urumqi and its surrounding areas, Inner Mongolia Erdos, and Shenmu in northern Shaanxi [4]. The western region should prioritize the development of industries in these areas, make full use of resource advantages, actively carry out deep processing of resources, extend the industrial chain, increase the added value of resource-based products as much as possible, and accelerate the formation of a number of high-tech industries [19]. Among other goals are to organize dynamic management, ensure strong market competitiveness of characteristic industrial clusters in the west, promote rational agglomeration and development of industries, form a growth pole for industrial expansion, and drive the progress in surrounding areas through the trickle-down effect, form scale effects, and enhance industrial competitiveness level.

As seen from the above, the use of mobile technology has an impact on industrially developed, medium-developed and backward industrial regions, and different areas experience different influences. The impact of mobile technology on digital transformation of companies in regions with different levels of industrial development is shown in Table 5.

By virtue of its special advantages in industrial transformation and upgrading, mobile technology has become an important factor in China's economic transformation to high-quality development.

5 Prospects and Applications

China's manufacturing industry plays a significant part in the global market. It produces a wide range of products used all over the world. Look at the business practice of Chinese enterprises in Russia in the field of 5G networks and make tentative conclusions about its influence in this domain.

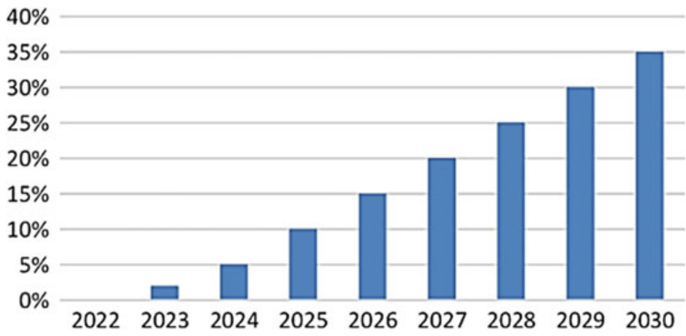

Fig. 3. 5G Penetration Forecast for 15 million-plus cities in Russia [12]

Forecasts for 5G adoption in Russia suggest commercial deployments from 2020, with the total 5G base set to reach 46 million by 2025, equivalent to 20% of connections [20]. The forecast for the penetration rate of 5G devices for million-plus cities of Russia until 2030 is shown in Fig. 3.

5G technology has a number of specific characteristics boosting its efficiency and competitiveness. Among these advantages are the following.

5G propagation speed. High speed is one of the biggest features of 5G. Compared with 4G networks, 5G networks have higher speeds, and the peak requirements for 5G base stations are not less than 20 Gb/s. This is the peak speed, which can greatly improve the production agility of the manufacturing industry.

5G communication capacity. The high capacity of 5G can solve the problem of dense personnel, and 5G signals can cover several miles, which is very beneficial to factories covering large areas such as automobile assembly plants. Another issue is signal penetration: until very high frequencies are reached, there will be no problems with the 5G network, which will help manufacturers improve their operations.

5G low latency. When responding to an emergency, the low latency of 5G can improve the ability to quickly reach and notify the first respond, and protect the safety of equipment and personnel; the low latency performance can also improve overall efficiency in daily operations.

5G low power consumption. If 5G is to support large-scale manufacturer applications, it must have power consumption requirements. 5G can reduce power consumption, allowing most IOT products to be charged once a week, or even once a month, which can greatly improve user experience and reduce costs.

The launch of 5G in Russia will help industrial companies achieve their goals. In addition, the development of 5G communication networks will have a significant impact on the implementation of many projects and initiatives. The introduction of 5G technology will significantly impact economic potential in Russia.

6 Conclusion

The use of mobile technology will allow industrial companies to increase production efficiency, optimize resource allocation and improve the level of industrial chain governance. Through the integration of mobile technology and industrial companies, the mobile digital transformation will be realized and management accelerated. It also improves the ability of industrial companies to effectively pursue resource integration goals and enhances the overall competitiveness of industrial companies. Company managers should not wait for mobile technology to change it, but should be leaders in introducing new technologies and new ideas, consciously strengthen technological innovation, expand the application of mobile technology led by the latest technological advances and innovative thinking, and continuously promote the digital transformation of industrial companies.

References

1. Dongmei, L. (2020). Research on the current situation and development of mobile app new media innovation. *China Media Science and Technology*, *8*, 45–47. https://doi.org/10.19483/j.cnki.11-4653/n.2020.08.007
2. Duogui, Y., & Kaidi, L. (2018). Analysis on economic development gap and evolution between North and South China. *Journal of Chinese Academy of Sciences, 33*(10), 1083–1092. https://doi.org/10.16418/j.issn.1000-3045.2018.10.009
3. Farmisano, R., & Hao, M. (2019). Strategic management research: A survey of 40 years. *Foreign Economy and Management*, *41*(12), 19–49. https://doi.org/10.16538/j.cnki.fem.2019.12.002
4. KeJia, X., Jiang, L., & Jinwei, H. (2022). Path and key points of digital transformation. *Quality and Certification, 1*, 52–53. https://doi.org/10.16691/j.cnki.10-1214/t.2022.01.002
5. Liang, M., & Min, W. (2010). The construction and application of regional manufacturing competitiveness evaluation system. *Several Business Times, 13*, 126–127. https://doi.org/10.3969/j.issn.1002-5863.2010.13.05
6. Liang, Z. (2021). Analysis on selection of leading industries and upgrading of industrial structure in Henan province. *Operation and Management*, *3*, 182–187. https:///www.climatecouncil.org.au/d.wanfangdata.com.cn/periodical/ChlQZXJpb2RpY2FsQ0hJTmV3UzIwMjIxMDEzEg5qeXlnbDIwMjEwMzAzNhoIczNoY3Y5NmY%3D
7. Lijun, C. (2011). Discussion and research on mobile technology. *Value Engineering, 30*(30), 140–141. https://doi.org/10.3969/j.issn.1006-4311.2011.30.1002
8. Nannan, X. (2020). Research on the application of mobile technology in industrial manufacturing. *ICT and Policy, 11*, 79–85. https://doi.org/10.3969/j.issn.1008-9217.2020.11.015
9. National Bureau of Statistics, National Development and Reform Commission, Ministry of Science and Technology. (2010). China high-tech industry statistical yearbook. *Beijing: China Statistics Press,* 56–58. https://doi.org/10.3969/j.issn.1000-7695.2021.22.047
10. Network Central Asia. (2014). Enterprise strategy analysis. *Economic Research Guide,* 38–41. https://doi.org//book.douban.com/subject/27118807
11. Pengfei, N. (2002). Theoretical research and empirical analysis of China's urban competitiveness. *China Economic Research, 5*, 62–69. https://doi.org/10.3969/j.issn.1006-480X.2002.05.00
12. Polev, A. (2017). Research on the international marketing strategy of Chinese enterprises in Russia: Huawei and Xiaomi as examples. *Heilongjiang: Harbin University of Technology.* https://doi.org/10.76666/d.D01332519

13. Porter, M. E., & Heppelmann, J. E. (2021). How smart, connected products are transforming competition. *Harvard Business Review*, *11*, 96–114. https://doi.org/10.19900/j.cnki.ISSN1008-4800.2021.07.00
14. Shaoyan, Z., Feijie, H., & Jun, X. (2020). Platform strategy for enterprise digital transformation. *Field Observation, 12*, 35. https://doi.org/10.3969/j.issn.1674-1315.2020.12.018
15. Shu, Z. (2014). Industry 4.0 and intelligent manufacturing. *Mechanical Design and Manufacturing Engineering, 8*, 1–5. https://doi.org/10.3969/j.issn.2095-509X.2014.08.001
16. Wenhua, C. (2011). A preliminary study of China's regional competitiveness. *Modern Information Economy, 4*, 244–245. https://doi.org/10.3969/j.issn.1001-828X.2011.04.202
17. Xin, Y. (2008). On the advantage comparison of technological innovation of large, medium and small enterprises. *Mall Modernization, 24*, 93. https://doi.org/10.3969/j.issn.1006-3102.2008.24.064
18. Xinyao, X. (2022). Discussion on Industry 4.0 and intelligent manufacturing. *China's Strategic Emerging Industries*, *11*, 179–181. https://doi.org/10.12230/j.issn.2095-6657.2022.11.057
19. Xiushan, C., & Bihua, S. (2000). *Regional economic theory. Commercial Economy, 10*, 12–18. https://doi.org/10.3969/j.issn.0257-2826.2000.10.002
20. Xueling, G., & Yanhua, G. (2010). Adjustment, problems and influence of Russian industrial structure. *Fudan Journal (Social Science Edition), 2,* 117–125. https://doi.org10.3969/j.issn.0257-0289.2010.02.016
21. Yan, M. (2021). Realization path of mobile application of Office OA System. *Enterprise Reform and Management, 15*, 88–89. https://www.climatecouncil.org.au/d.wanfangdata.com.cn/periodical/qyggygl202115040
22. Yan, R., & Wei, K. (2020). Evaluation and empirical study on competitiveness of China's regional innovation ecosystem. *Science and Technology Management Research, 39*(4), 64–71. https://doi.org/10.3969/j.issn.1000-76
23. Yonghua, L. (2021). Application analysis of 5G technology in mobile communication network. *China New Communications, 23*(13), 24–25. https://doi.org/10.3969/j.issn.1673-4866.2021.13.013
24. Yunzhi, L. (2014). Research on management architecture in the era of Industry 4.0. *Management Observation, 24*, 95–96. https://doi.org/10.3969/j.issn.1674-2877.2014.24.038
25. Zhicheng, C., & Song, Z. (2014). Industry 4.0 and intelligent linkage strategy. *Information Technology and Multiplication, 6*, 76–78, 89. https://doi.org/10.3969/j.issn.1672-9528.2014.06.30
26. Ziyang, W., Wei, W., & Wuxiang, Z. (2020). Exploration of Tianhong's digital transformation path from the perspective of business model. *Journal of Management, 17*(12), 1739–1750. https://doi.org/10.3969/j.issn.167

Managing the Digital Potential Development of an Industrial Enterprise: The Incremental Approach

Artem Darenin and Olga Chernova

Abstract One of the main directions of modern industrial enterprises' development is the implementation of digital transformations in production. Despite a significant amount of research in the field of modernization management, the specificity of digital technologies development shows the inefficiency of traditional solutions and sets challenges in identifying new approaches to managing digitalization processes. This research aims to substantiate the advantages of the incremental approach to managing the digital potential development of an industrial enterprise over traditional strategic planning approaches. By analyzing scientific publications on the research issues and applying a context-oriented approach, the article determines the place of the incremental approach in the mechanism for managing digitalization in industry and its role in solving strategic and tactical objectives of the digital potential development of an industrial enterprise. The results of the study can underlie the formation of a comprehensive mechanism for managing digital transformation in industry.

Keywords Industrial enterprise · Digital potential · Incremental approach · Management mechanism · Strategic planning

1 Introduction

Industry 4.0—the paradigm of neo-industrial development—brings up the question of the ability of Russian industrial enterprises to develop their digital potential ensuring sustainable digital transformation. The concept of sustainable digital transformation is related to the concept of sustainable digital development expressed in the unity and balance of economic, social, and environmental progress. Digital

A. Darenin (✉) · O. Chernova
Southern Federal University, 88 Gorkogo Str., Rostov-on-Don 344002, Russian Federation
e-mail: aid-dar0330@rambler.ru

O. Chernova
e-mail: chernova.olga71@yandex.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_30

technologies make a tangible positive contribution to the achievement of the sustainable development goals. For example, the introduction of digital tools can reduce CO2 emissions by 15% in various industries, which in absolute terms is as much as the United States and the European Union emit together [30]. According to the Global Enabling Sustainability Initiative (GeSI), the average possible acceleration of achieving sustainable development goals through the use of digital technologies is at the level of 22% [16]. According to the World Economic Forum and PwC, the use of modern technologies can accelerate the achievement of at least 10 of 17 Sustainable Development Goals [30]. Consequently, 70% of 169 indicators aimed at ending poverty, fighting inequality, promoting the prosperity of society, and protecting the environment by 2030 can be attained using the existing digital tools. However, along with the opportunities, digitalization also creates challenges for sustainable development. Sustainable digital transformation is the concept that refers to the process of digitalizing the economy in a long-lasting, green, and organic way. Sustainable digitalization includes three fundamental aspects: sustainable digitalization, green technologies, and a circular economy, and an innovation-enabling policy and regulatory framework [10].

The digital potential mainly determines the quality of development of all enterprise subsystems integrating its resources with the opportunities for open innovations [39]. Digital transformations contribute to the growth of labor productivity [6, 14], and enhance the environmental component of the sustainable development of an enterprise [25, 26]. A case study of a power tool factory in Mexico showed that the use of Wi-Fi RFID tags resulted in a 10% increase in work efficiency and an 80%–90% increase in the utilization rate of the most in-demand workforce [8]. Digital transformations in the production process reduce losses from errors and equipment downtime by 5–15% [22]. The use of digital technologies also lowers energy consumption, which has been reduced by 40% in the case of a multinational company providing equipment and services to the plastics industry [32].

The efficiency of digital transformations is directly determined by the efficiency of their management processes. The management of Russian industrial companies reveals an increased willingness for digital changes. Seventy-two percent of managers of Russian companies from 14 industries consider the introduction of digital technologies to be strategically important [28]. At the same time, the existence of a strategic plan is regarded as the main success factor [36].

The industry 4.0 market is projected to grow by an average of 20.7% over the next 5 years [24]. The rashness and unpredictability of digital technologies' development lead to significant challenges in determining long-term planning horizons. Accordingly, traditional strategic planning approaches to managing an enterprise's digital potential turn out to be ineffective. At the same time, approaches that go beyond traditional management procedures and involve greater flexibility in decision-making are extremely rare.

Concerning the identified issue, the goal of the article is to substantiate the advantages of the incremental approach to managing the digital potential development of an industrial enterprise over traditional strategic planning approaches.

2 Literature Review

"The digital potential of an enterprise" is a relatively new economic category, so discussions about the essence of digital potential and its components are still ongoing.

In the Russian scientific literature, when defining the term "the digital potential of an enterprise," the special emphasis is put on resources (a set of data, software and hardware for creating, storing, processing data, etc.) and the possibilities of using them with maximum efficiency [19, 27].

In foreign research publications on digital transformation in industrial enterprises, we have found no mention of the term "digital potential". The object of digital development management is digital values as the combined resources and opportunities in the creation of digital systems [35]; digital technologies integrated into all production systems and business systems [11]; and digital innovations in production processes [31]. However, these terms are essentially similar to the term "digital potential" used in Russian studies.

The number of scientific publications on the processes of industry digitalization is constantly increasing. Current studies are focused on understanding the logic of managerial decision-making [37], identifying key managerial actions and functional roles of a manager [12], and assessing the impact of the enterprise digital maturity on decision-making about managerial influences [20]. However, management approaches and technologies are almost unexplored as success factors for managerial decisions in the field of the digital potential development of an enterprise, and the existing literature in this area mainly focuses on involving employees in controlling digital transformations [18, 38].

Therefore, exploring the possible relevance of the incremental approach applied to manage the digital potential of an enterprise can contribute important theoretical ideas to the development of a mechanism for implementing digital transformations in industry.

3 Material and Methods

The selected methodology consists of the following main stages. At the first stage, the incremental approach is described based on the analysis of literary sources. To that end, we scrutinize scientific articles indexed in the international databases Web of Science and Scopus. At the second stage, we substantiate the advantages of using the incremental approach to form a mechanism for managing the digital potential development of an industrial enterprise over traditional strategic planning approaches. We also consider the possibility of using the approach to solve strategic and tactical objectives of developing the digital potential in the mechanism for managing digitalization processes in industry. Our reasoning is based on the comprehension of scientific publications about using the context-oriented approach. At the third stage, in the Discussion section, we compare our conclusions with those in relevant studies on managing the digital potential development of an enterprise. In Conclusion, we discuss the limitations of the study and the prospects for its development.

4 Results

4.1 The Essence and Advantages of the Incremental Approach to Management

Traditional approaches to strategic planning are expressed in more than 10 schools of strategic planning. The most popular approach is the Harvard Business School model [33]. It consists in ensuring the correspondence between the external capabilities and the internal potential of the enterprise in accordance with a SWOT analysis. The principles of this school are becoming obsolete and its key disadvantage is the inability to work in the conditions of complexity and multifactoriality of the modern market.

Ansoff's model—another traditional approach—differs from the previous one by deepening concretization in setting goals and considering feedback, which ensures the interactivity of the planning procedure [1]. The main disadvantage of this model is the complexity of its application because the process is highly formalized, it involves examining factors that are prioritized by calculation of weight coefficients, as well as various diagrams and rules for choosing an alternative.

Mintzberg [23] notes that all the schools are based on one theoretical construction, or basic model, i.e., a formalized sequence of choosing alternatives, setting goals and objectives, and differ from each other in details more than in the fundamental principles. In such approaches, planning based on the top-down strategy does not correspond to today's highly turbulent environment. Often, central planning departments do not receive sufficient information about the constantly changing daily market realities and, finally, about the experience of front-line employees interacting directly with customers. Consequently, staff members are forced to execute plans that do not correspond to the environment and the needs of customers.

The concept of incrementalism was first introduced in political science by Charles Lindblom in his work "The Science of Muddling Through" [21]. He opposes the incremental approach to strategic planning: incrementalism allows concentrating resources on tackling the most pressing current problems, while strategic planning involves significant time and other costs to design a plan that risks being unrealized due to the high mobility of the environment. Lindblom argues that incrementalism providing even a minor positive gain moves the system forward.

In economics, the incremental approach initially found application in budgeting, when in the mid-1960s, American researchers wondered how the fund distribution mechanism in the formation of the federal budget operated. If in political science incrementalism was presented descriptively, then in budgeting the theory of incrementalism was aimed to explain the process of making managerial decisions. Moreover, based on statistical analysis, there was built a model with the empirical evidence of its reliability.

The incremental approach was further developed by Quinn, who considered it as a technological method that allowed improving and integrating the analytical and behavioral aspects in the formation of a company's development strategy [29]. Quinn believes that the incremental approach is effective in practice, does not ignore the limited rationality of the individual and the environment's unbearable uncertainty, and turns the imperfections of human decisions into the science of achieving success.

Since the beginning of the twenty-first century, the incremental approach has been supported by an increasing number of researchers. For example, Edelman and Benning define the incremental approach as the foundation for large-scale changes, when transformations result from non-stop small adjustments, rather than a time-limited stage of directed activity [7]. The effectiveness of the incremental approach in management is also confirmed by Russian researchers. Thus, Balatsky and Ekimova [3] note that traditional approaches based on the need to compile labor-intensive extensive reports with statistical information depreciate over time under the conditions of accelerating changes.

In this way, most researchers highlight that the major disadvantage of traditional strategic planning approaches is the impossibility to correctly assess the potential implications of specific decisions with significant financial, time, and labor costs for their development and justification. Involving a continuous sequence of quick solutions, the incremental approach allows concentrating on simple but most pressing problems. In this case, great progress comes through small increments.

4.2 Incremental Approach in the Management Mechanism of Digital Potential Development

The mechanism for managing the digital potential development of an industrial enterprise based on the principles of the incremental approach has the following specific features:

- permanence of digital transformations, since there is no certain level of digital potential, which, if reached, implies that its development is completed;
- interdependence of decisions in the field of an enterprise's digital potential development, when some changes cause others according to the principle of a chain reaction;
- digital transformation processes synchronized in time and space at all stages of the value-added chain;
- constant adjustment of the goals and objectives of the digital potential development based on feedback and monitoring.

There are distinguished the following blocks in the structure of this mechanism: organizational and managerial, procedural, and instrumental.

The organizational and managerial block is designed to ensure the process of making management decisions and their successful implementation based on monitoring information about the digital potential performance of the enterprise, as well as considering the characteristics of the environment. Changes in the environment are regarded as opportunities to improve production efficiency through the use of modern information technologies.

The procedural block is designed to ensure the endless process of the digital potential development of an enterprise and its constant adjustment in accordance with changing environmental conditions. This process includes the following main stages: collecting information about the state of the environment and the digital potential of the enterprise; analyzing this information; identifying threats and opportunities; setting goals and objectives for development; devising a plan to implement the objectives; taking actions in accordance with the plan; evaluating the results and effects; gathering feedback.

The instrumental block is designed to provide a systematic assessment of the digital potential of the enterprise and monitor the indicators aimed to characterize its state with the identification of an incremental surplus. Note that the instrument itself may also be adjusted following the development of digital technologies, and, consequently, the emergence of new aspects of assessment and/or abolition of the old ones.

In general, the use of the incremental approach in the mechanism for managing the digital potential development of an industrial enterprise provides the following advantages compared to the traditional strategic planning approaches:

- since each subsequent step is based on previous experience, the decisions are more reliable, and their possible implications (effects) are more predictable;
- not performing "big" actions focused on the fundamental solution to the problem, managers avoid "big" mistakes related to the fact that, when making their decisions, they relied on forecasts that might have not come true;
- "small" solutions allow promptly verifying their effectiveness and quickly neutralizing the negative consequences, if occur.

4.3 *Incrementality in Tactical and Strategic Objectives of the Digital Potential Development of an Industrial Enterprise*

Even though the incremental approach to managing the digital potential development of an industrial enterprise is expressed in the implementation of "small" steps, the set of these steps should ensure the achievement of "big" goals. Thus, the incremental approach to management is designed to guarantee the achievement of both tactical and strategic development objectives.

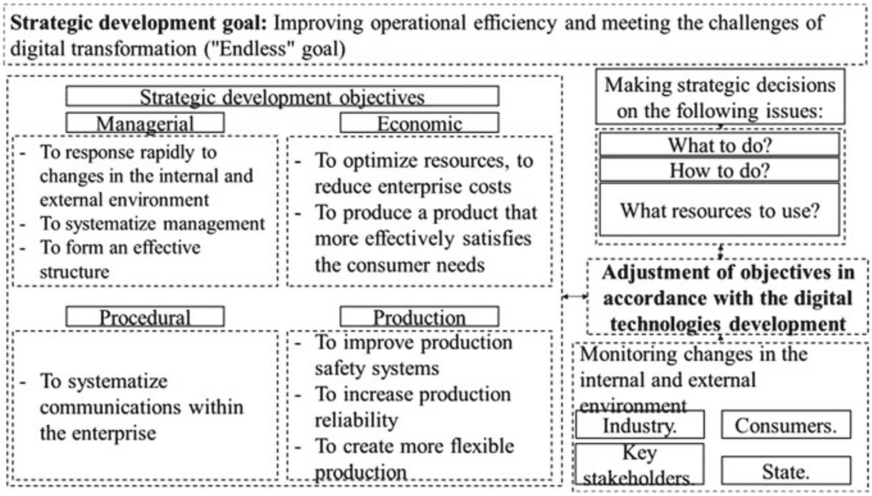

Fig. 1 Opportunities for using the incremental approach in strategic objectives of the digital potential development of an industrial enterprise

Opportunities for using the incremental approach in strategic objectives of the digital potential development of an industrial enterprise are shown in Fig. 1.

All the "small" steps focus on achieving some strategic development goal. Such a strategic goal, if exists, is fundamentally important, since it makes it possible to avoid the "slippery slope" error, when multiple consecutive particular decisions lead to undesirable results.

There are four groups of strategic objectives for developing the digital potential of an enterprise:

– managerial—improving the enterprise management system based on the benefits provided by the integration of digital technologies;
– economic—the more rational use of the enterprise's resources through digital technologies; improving the efficiency of the enterprise's business and production processes;
– procedural—increasing the efficiency of the interaction system within the enterprise and with the environment;
– production—improving labor safety; ensuring production processes to be reliable and uninterrupted, as well as raising the level of adaptive capabilities of production.

It is important to emphasize that strategic goals are "endless", consequently, the enterprise is not expected to ever reach such a level of digital potential, where it is fulfilled: the goals are achieved and there is no need for further development of the digital potential. Strategic goal is a sort of a development vector, the direction of which is set by technological frontiers. Strategic goals determine the content of tactical objectives of the digital potential development of an industrial enterprise. In fact, tactical decisions detail the directions for strategic objectives and determine their time frames.

For example, the strategic "endless" objective of improving the reliability of production in the current year is provided by solving such tactical objectives as selection, acquisition, installation, and maintenance of specialized sensors to reflect the digital model of production, as well as computers capable of generating this model; purchase of specialized software for digital production modeling; training employees to work with new equipment and software, etc. Thus, the implementation of a strategic objective implies tactical objectives to be formed in the areas of digital development, which are expressed in creating a group of projects designed to bring incremental growth.

Opportunities for using the incremental approach in tactical objectives of the digital potential development of an industrial enterprise are shown in Fig. 2.

The implementation of tactical objectives for managing the digital potential development of an industrial enterprise is based on the use of a project approach. The set and content of projects will be determined on the grounds of the information about the state of the company's digital potential.

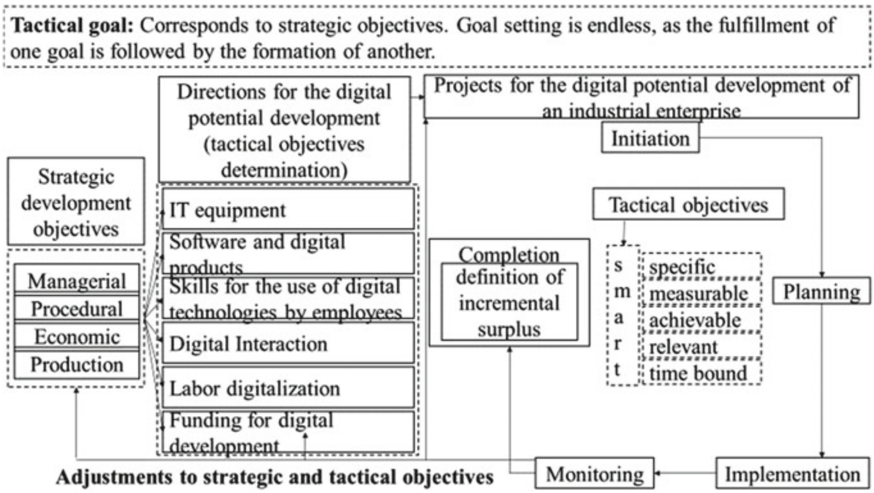

Fig. 2 Opportunities for using the incremental approach in tactical objectives of the digital potential development of an industrial enterprise

5 Discussion

The experience of using the incremental approach in the modernization transformation management at foreign enterprises of various industries and fields of activity demonstrates its advantages over the traditional approaches in terms of greater flexibility in decision-making. For example, Franco et al. [13] substantiate the expediency of using the incremental approach to regulate the process of studying the risks of using nanomaterials. The benefits of this approach to managing innovation in manufacturing are justified by Gärtner et al. [15]. However, Escrig-Tena et al. [9] find that the use of the incremental approach in quality management helps to enhance the innovative capabilities of an enterprise. Staniškis and Katiliūtė [34] note that the incremental approach to innovation management ensures an increase in the sustainability of an enterprise's development. Berggren [5] adheres to a similar viewpoint demonstrating that the implementation of innovative projects requires a combination of traditional and incremental approaches. The incremental approach has proved its significance in the field of managing the transformational processes of a company. In one of the latest studies, the benefits of its use in the implementation of the modernization process have been empirically demonstrated. An analysis of observational data from US firms between 1983 and 2007 using databases such as Compustat, CRSP, and USPTO found that firms that adopted hopping change outperformed those that favored gradual, continuous, incremental change [17].

However, in Russia, the incremental approach is less known to national business. A small number of publications on the opportunities of using this approach in management are related to the strategic planning of the regional [2] or municipal development [4]. As for the opportunities of applying the incremental approach to managing the development of industrial enterprises, no studies have been discovered. Nevertheless, considering that all researchers emphasize that the incremental approach to management demonstrates significant advantages over the traditional approaches in a high variability in the environment, as well as in the implementation of innovative transformations (which, in particular, include digitalization projects), it can be argued that it will have the same advantages in resolving the problems of the digital potential development of industrial enterprises. Moreover, in the current conditions of great uncertainty in the environment, there is a strong probability of adverse events and situations that require flexible adjustment of the existing digital development plans. The above confirms the expediency of using the incremental approach in dealing with the digitalization problems in the national industry.

6 Conclusion

In the given research, we substantiate the advantages of the incremental approach to managing the digital potential development of an industrial enterprise over the traditional strategic planning approaches. Considering that in modern literature there is almost no attention paid to the implementation of the incremental approach at the micro level, our research helps to fill the gaps in understanding how this approach can be used as part of a mechanism for implementing digital transformations in the national industry. The article establishes the main components of this mechanism and demonstrates the relationship between strategic and tactical tasks of incremental control.

The main limitation of our study is that it considers the issue of managing the digital potential development of an enterprise at the strategic level. For a deeper understanding of this process, it is necessary to investigate the industry and the regional context of the issue with access to relevant detailed information. Our future research will take into account this limitation to improve the understanding of how to effectively implement digital transformations in specific industries.

References

1. Ansoff, I. (1989). Strategic management. *Economics*, 519.
2. Antipin, I. A., & Vlasova, N. Y. (2020). Incremental approach to regional strategy: Theory, methodology, practices. *Journal of New Economy, 21*(3), 73–90. https://doi.org/10.29141/2658-5081-2020-21-3-4
3. Balatsky, E. V., & Ekimova, N. A. (2021). Public administration tools: Forecasting vs Designing. *The Manager, 12*(1), 18–31. https://doi.org/10.29141/2218-5003-2021-12-1-2
4. Belousova, E. A., & Kaibicheva, E. I. (2022). Prospects for an incremental approach in strategic planning of socio-economic development of rural municipalities. *The Manager, 13*(1), 49–67. https://doi.org/10.29141/2218-5003-2022-13-1-4
5. Ch., & Berggren. (2019). The cumulative power of incremental innovation and the role of project sequence management. *International Journal of Project Management, 37*(3), 461–472. https://doi.org/10.1016/j.ijproman.2019.01.014
6. Du, X., & Jiang, K. (2022). Promoting enterprise productivity: The role of digital transformation. *Borsa Istanbul Review, 22*(6), 1165–1181. https://doi.org/10.1016/j.bir.2022.08.005
7. Edelman, L., & Benning, A. L. (2004). Incremental revolution: Organizational change in highly turbulent environments. *Comportamento organizacional e gestão, 10*, 107–122.
8. Enterprise insights. (2018). Three smart manufacturing case studies. https://enterpriseiotinsights.com/20180102/smart-factory/three-smart-manufacturing-case-studies-tag23-tag99
9. Escrig-Tena, A., Segarra-Ciprés, M., & García-Juan, B. (2021). Incremental and radical product innovation capabilities in a quality management context: Exploring the moderating effects of control mechanisms. *International Journal of Production Economics, 232*, 107994. https://doi.org/10.1016/j.ijpe.2020.107994
10. European Digital SME Alliance. (2022). Sustainable digitalization. https://www.digitalsme.eu/what-is-sustainable-digitalisation
11. Facchini, F., Digiesi, S., Fernando, L., & Pinto, R. (2022). Implementation of I4.0 technologies in production systems: Opportunities and limits in the digital transformation. *Procedia Computer Science, 200*, 1705–1714. https://doi.org/10.1016/j.procs.2022.01.371
12. Fernandez-Vidal, J., Perotti, F., Gonzalez, R., & Gasco, J. (2022). Managing digital transformation: The view from the top. *Journal of Business Research, 152*, 29–41. https://doi.org/10.1016/j.jbusres.2022.07.020
13. Franco, A., Hansen, S., Olsen, S., & Butti, L. (2007). Limits and prospects of the "incremental approach" and the European legislation on the management of risks related to nanomaterials. *Regulatory Toxicology and Pharmacology, 48*(2), 171–183. https://doi.org/10.1016/j.yrtph.2007.03.0/

14. Gaglio, C., Kraemer-Mbula, E., & Lorenz, E. (2022). The effects of digital transformation on innovation and productivity: Firm-level evidence of South African manufacturing micro and small enterprises. *Technological Forecasting and Social Change, 182*, 121785. https://doi.org/10.1016/j.techfore.2022.121785
15. Gärtner, Q., Dorth, A., & Reinhart, G. (2022). Concept for ambidextrous management of incremental and radical innovation in manufacturing. *Procedia CIRP, 107*, 475–480. https://doi.org/10.1016/j.procir.2022.05.011
16. GeSI, Deloitte. (2019). Digital with purpose: Delivering a smarter 2030. https://gesi.org/research/download/36
17. Kang, J., & Kim, S.-J. (2020). Performance implications of incremental transition and discontinuous jump between exploration and exploitation. *Strategic Management Journal, 41*(6), 1083–1111. https://doi.org/10.1002/smj.3119
18. Kıyıklık, A., Kuşakc, A., & Mbowe, B. (2022). A digital transformation maturity model for the airline industry with a self-assessment tool. *Decision Analytics Journal, 3*, 100055. https://doi.org/10.1016/j.dajour.2022.100055
19. Kozlov, A. V., & Teslya, A. B. (2019). Digital potential of industrial enterprises: essence, definition and methods of calculation. *Bulletin of the Transbaikal State University, 25*(6), 101–110. https://doi.org/10.21209/2227-9245-2019-25-6-101-110
20. Kryukov, V., Shakhgeldyan, K., Kiykova, E., Kiykova, D., & Saychuk, D. (2022). Assessment of transport enterprise readiness for digital transformation. *Transportation Research Procedia, 63*, 2710–2718. https://doi.org/10.1016/j.trpro.2022.06.313
21. Lindblom, C. E. (1959). The science of "muddling through." *Public Administration Review, 19*(2), 79–88. https://doi.org/10.2307/973677
22. McKinsey & Company. (2018). Digitally enabled reliability: Beyond predictive maintenance. https://www.mckinsey.com/capabilities/operations/our-insights/digitally-enabled-reliability-beyond-predictive-maintenance
23. Mintzberg, H. (1994). *The rise and fall of strategic planning*. Free Press.
24. Mordor intelligence. (2022). Industry 4.0 Market. https://www.mordorintelligence.com/industry-reports/industry-4-0-market
25. Nikitaeva, A. Y., Chernova, O. A., & Molapisi, L. (2022). Smart territories as a driver for the transition to sustainable regional development and green economy. *R-Economy, 8*(2), 120–134. https://doi.org/10.15826/recon.2022.8.2.010
26. Pauliuk, S., Koslowski, M., Madhu, K., Schulte, S., & Kilchert, S. (2022). Co-design of digital transformation and sustainable development strategies - What socio-metabolic and industrial ecology research can contribute. *Journal of Cleaner Production, 343*, 130997. https://doi.org/10.1016/j.jclepro.2022.130997
27. Popov, E. V., Semyachkov, K. A., & Moskalenko, Y. A. (2019). Digital potential of the enterprise. *Economic Analysis: Theory and Practice*, *18*(12–495), 2223–2236. https://doi.org/10.24891/ea.18.12.2223
28. PwC. (2018). Corporate management of digital technologies. Survey of members of the boards of directors of Russian companies. https://media.rbcdn.ru/media/reports/russian-boards-survey-pwc-2018-r.pdf
29. Quinn, J. B. (1978). Strategic change: Logical Incrementalism. *Sloan Management Review, 20*(1), 7–21.
30. RAEC. (2020). Russia and sustainable digital development. https://raec.ru/upload/files/rus-digital-dev.pdf
31. Rahnama, H., Johansen, K., Larsson, L., & Rönnbäck, A. (2021). Exploring digital innovation in the production process: A suggested framework for automation technology solution providers. *Procedia CIRP, 104*, 803–808. https://doi.org/10.1016/j.procir.2021.11.135
32. Resolutions and Decisions Adopted by the General Assembly During its Seventy-fifth Session: Resolutions, 15 September – 31 December 2020. (2021). New York: United Nations Publications, 1388. http://digital.casalini.it/9789210011488
33. Spirina, A. M. (2012) Characteristics of theoretical approaches to strategic planning at the enterprise. *Young Scientist, 1*(36), 144–150. https://moluch.ru/archive/36/4183

34. Staniškis, J., & Katiliūtė, E. (2019). Unsustainability reduction in enterprises by incremental innovations implementation and management. *Journal of Cleaner Production, 236*, 117542. https://doi.org/10.1016/j.jclepro.2019.07.017
35. Trabert, T., Beiner, S., Lehmann, C., & Kinkel, S. (2022). Digital value creation in sociotechnical systems: Identification of challenges and recommendations for human work in manufacturing SMEs. *Procedia Computer Science, 200*, 471–481. https://doi.org/10.1016/j.procs.2022.01.24
36. Veselovsky, M. Y., & Khoroshavina, N. S. (2021). *Digital transformation of industrial enterprises in an innovative economy*. Moscow: Mir nauki, https://izdmn.com/PDF/06MNNPM21.pdf
37. Vial, G. (2019). Understanding digital transformation: A review and a research agenda. *Journal of Strategic Information Systems, 28*(2), 118–144. https://doi.org/10.1016/j.jsis.2019.01.003
38. Weber, E., Büttgen, M., & Bartsch, S. (2022). How to take employees on the digital transformation journey: An experimental study on complementary leadership behaviors in managing organizational change. *Journal of Business Research, 143*, 225–238. https://doi.org/10.1016/j.jbusres.2022.01.036
39. Wu, L., Sun, L., Chang, Q., Zhang, D., & Qi, P. (2022). How do digitalization capabilities enable open innovation in manufacturing enterprises? A multiple case study based on resource integration perspective. *Technological Forecasting and Social Change, 184*, 122019. https://doi.org/10.1016/j.techfore.2022.122019

Digital Transformation and Human Capital

Has Digitalisation Alleviated the Impact of the COVID-19 on Manufacturing Sectors? Evidence from Sectoral-Level and Cross-Country Data

Tien-Ming Yip, Wee-Yeap Lau, and Shankaran Nambiar

Abstract This study is motivated by the repeated call from international organisations on the potential role of digitalisation in alleviating the adverse impact of the COVID-19 pandemic on the manufacturing sector's performance. Using a balanced panel data of 24 sub-sectors in Malaysia's manufacturing sector from January 2020 to December 2020, the empirical result shows that the COVID-19 pandemic significantly and adversely impacts manufacturing sales performance if digitalisation is low. However, the negative effect diminishes with a rising level of digitalisation. Further analysis using cross-country datasets from 79 countries documents similar results. This implies that the key finding of a mitigating effect of digitalisation is not confined to Malaysia but widespread across countries worldwide. Overall, the empirical results indicate that digitalisation is the key to the sustainable growth of the manufacturing sector during a health crisis.

Keywords Digitalisation · COVID-19 pandemic · Manufacturing sector

1 Introduction

The outbreak of the COVID-19 pandemic brought conventional economic activities, such as manufacturing activities, to a standstill. Global manufacturing production growth has decreased since 2019 due to the ongoing trade dispute between the United States and China [35]. However, the slowdown is exacerbated by the outbreak of

T.-M. Yip · W.-Y. Lau (✉)
Faculty of Business and Economics, Universiti Malaya, 50603 Kuala Lumpur, Malaysia
e-mail: wylau@um.edu.my

T.-M. Yip
e-mail: yiptienming@um.edu.my

S. Nambiar
Malaysian Institute of Economic Research, JKR 606, Jalan Bukit Petaling, Bukit Petaling, 50460 Kuala Lumpur, Malaysia
e-mail: nambiar@mier.org.my

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_31

the COVID-19 pandemic in the year 2020. Based on the UNIDO statistics, global manufacturing production recorded a negative 4.1% growth in 2020 [35].

Across the regions, European industrialised countries recorded the highest fall in manufacturing production (−7.6%), followed by Latin America (−7.3%), North America (−6.7%), Africa (−5.4%) and East Asia (−4.7%). Implementing a national lockdown policy to curb COVID-19 transmission has halted manufacturing activity, whereby factories are prohibited from operating during the lockdown period.

Consequently, this negatively affects the output and sales performance of the manufacturing industry. The adverse impact of the COVID-19 pandemic on manufacturing sector performance has been widely documented in the existing literature [2, 6, 7, 17, 21, 30, 37, 40]. According to [19] in a report from Future Development, the COVID-19 pandemic affected most businesses across Central Europe [19]. Different countries implemented diverse policies to alleviate the shock to the firms based on the information collected by the World Bank [39].

Implementing a national lockdown policy to curb COVID-19 transmission has halted manufacturing activity, whereby factories are prohibited from operating during the lockdown period. Consequently, this negatively affects the output and sales performance of the manufacturing industry. The adverse impact of the COVID-19 pandemic on manufacturing sector performance has been widely documented in the existing literature [2, 6, 7, 17, 21, 30, 37, 40].

International organisations such as the World Bank [38], UNCTAD [34] and International Monetary Fund [24] suggest that digitalisation is the solution to mitigate the negative impact of the COVID-19 pandemic on sectoral performance. Practically, digital technologies such as digital payments, e-commerce and robots would help businesses cope with national lockdown measures, ensuring business continuity and offsetting the adverse impact of the pandemic. The theoretical argument for the mitigating role of digitalisation is proposed by [15]. Specifically, digitalisation would offset the adverse impact of the COVID-19 pandemic on firms' performance by providing effective crisis response strategies to cope with the pandemic.

As such, highly digitalised firms tend to have greater dynamic capabilities in sensing the crisis, seizing new opportunities and reconfiguring resources to cope with the crisis. This strategy would result in effective crisis response strategies and offset the pandemic's adverse impact on firms' performance. Notably, the mitigating role of digitalisation is further highlighted in the empirical study, in which digital adoption is essential in helping firms overcome the challenges imposed by the COVID-19 pandemic and subsequently sustain their business operation [3].

Malaysia is one of the countries seriously affected by the COVID-19 pandemic. As of 31 December 2020, Malaysia has recorded a total of 3491 COVID-19 cases per million population, far surpassing the neighbouring countries, such as Thailand (102 cases per million population), Brunei (358 cases per million population), Vietnam (15 cases per million population) and Indonesia (2717 cases per million population). The COVID-19 figures are obtained from the Our World In Data database. The spike in COVID-19 cases has disturbed Malaysia's economic performance, as shown by the 5.6% contraction in the annual GDP growth rate in 2020.

As indicated above, international organisations have repeatedly emphasised digitalisation as the key to coping with the challenges imposed by the pandemic. However, to the best of the authors, there is no empirical study quantifying digitalisation's mitigating effect in Malaysia's context. The finding is important as it would provide alternative policy options to the Malaysian government in helping the local manufacturers to cope with the COVID-19 pandemic. Moreover, for the manufacturers, the finding would suggest alternative crisis response strategies to help them to sustain their business operations during the pandemic. Accordingly, this study investigates whether digitalisation mitigates the negative impact of the COVID-19 pandemic on Malaysia's manufacturing sector performance. The COVID-19 pandemic is a global health crisis. It negatively impacted the manufacturing sector performance in countries around the world. Therefore, it is also important to investigate whether digitalisation can help to offset the adverse impact of the pandemic on the manufacturing sector performance in other countries. Thus, apart from providing the sectoral-level analysis for the Malaysian context, this study expands the scope of analysis by providing a cross-country analysis for the mitigating effect of digitalisation.

Based on a balanced panel data of 24 sub-sectors in Malaysia's manufacturing sector from January 2020 to December 2020, the empirical result shows that the manufacturing sales performance is negatively associated with the COVID-19 pandemic. Digitalisation is essential in mitigating the negative relationship. Specifically, the COVID-19 pandemic significantly and adversely impacts manufacturing sales performance if digitalisation is low. However, the negative effect diminishes with a rising level of digitalisation. Further analysis using cross-country datasets from 79 countries documents similar results. This implies that the key finding of a mitigating effect of digitalisation is not confined to Malaysia but widespread across countries around the world.

For the manufacturers, this study proposes an alternative crisis response strategy to help them to sustain their operations during the COVID-19 pandemic. The result indicates that manufacturers should actively pursue digitalisation in the workplace. For instance, adopting digital technology such as remote robots allows manufacturers to operate remotely following a national lockdown, thereby ensuring the continuation of manufacturing production. Furthermore, e-commerce provides manufacturers alternative platforms to market their products and services, preserving sales performance. Digitalisation can be regarded as the universal crisis response strategy for effectively helping manufacturers from Malaysia and countries worldwide cope with the COVID-19 pandemic.

This study is arranged as follows. Section 2 reviews the theoretical argument on digitalisation in mitigating the effect of the pandemic. Section 3 describes the data, model and methodology used. Section 4 presents baseline estimation results followed by the robustness checks in Sect. 4.1. Section 5 concludes the study and makes policy recommendations.

2 Theoretical Review

The theoretical argument on the mitigating role of digitalisation is based on the study by [15]. Digitalisation would offset the adverse impact of the COVID-19 pandemic on firms' performance by providing effective crisis response strategies to cope with the pandemic. Specifically, highly digitalised firms are associated with greater dynamic capabilities in sensing the crisis, seizing new opportunities and reconfiguring resources to cope with the crisis. This digitalisation would result in effective crisis response strategies and offset the adverse impact on firm performance due to the pandemic.

Dynamic capabilities refer to the firms' capability to build, integrate and reconfigure resources when coping with a rapidly changing environment [31–33]. This perspective is the key to formulating effective crisis response strategies for firms. Firms with dynamic capabilities are more likely to adapt to the changing environment and sustain company operations during a crisis [10, 22].

Meanwhile, digitalisation refers to organisational transformation through adopting digital technologies [15, 27, 36]. Digitalisation has been widely perceived as the key to sustainable development for business enterprises [25]. Digitalisation, particularly the application of big data analysis, enables firms to predict the changing environment to some extent, thereby better gauging the country's future economic prospects. This digital application assists the firm in designing short- and long-term strategies to sustain the company amid future economic uncertainty. Moreover, digitalisation allows firms to expand their consumer market to venture into a new business model, such as the digital business. Furthermore, digitalisation enables robots in the production process, improving production efficiency and allowing firms to achieve greater economies of scale.

Digitalisation interferes with all the firms' dynamic capabilities dimensions. In particular, digitalisation enhances firms' dynamic capabilities by responding better to the COVID-19 pandemic and subsequently preserving firms' performance [15]. In other words, digitalisation is expected to offset the adverse impact of the COVID-19 pandemic on firms' performance.

Digitalisation would enhance firms' capability to sense the crisis for the first dimension in dynamic capabilities. Digitalisation enables firms to identify the spread of COVID-19, thereby providing an early indication of the possible implication of the pandemic on firms' performance. Subsequently, early preparation can be conducted to cope with the pandemic. For instance, big data analysis would help firms predict environmental changes to some extent and allow them to perceive the pandemic better [14]. The analysis will enable the firms to formulate strategies to cope with the pandemic.

As indicated by the above theoretical arguments, it can be argued that digitalisation plays an important role in the relationship between the COVID-19 pandemic and firms' performance. In particular, the COVID-19 pandemic is conjectured to depress firms' performance by reducing output produced and purchase orders. Digitalisation would mitigate this adverse effect by providing effective crisis response strategies to cope with the pandemic. Specifically, highly digitalised firms are associated with greater dynamic capabilities in sensing the crisis, seizing new opportunities in the crisis period and reconfiguring resources to cope with the crisis. This digitalisation process would result in effective crisis response strategies and offset the pandemic's adverse impact on firms' performance and vice versa.

3 Data and Empirical Model

3.1 Data

This study utilises two sets of data to examine the mitigating effect of digitalisation. The first data set contains balanced panel data of 24 sub-sector (as shown in Appendix 1) in the Malaysian manufacturing industry from January 2020 to December 2020. The main dependent variable in this study is the monthly growth rate of manufacturing sales (SALESMoM), a proxy for the Malaysian manufacturing sector performance. The monthly manufacturing sales (SALES) are obtained from the Department of Statistics Malaysia (DOSM) and subsequently transformed into a monthly growth rate by using the following formula:

$$\text{SALESMoM}_{\text{it}} = \frac{\text{SALES}_{\text{it}} - \text{SALES}_{\text{it}-1}}{\text{SALES}_{\text{it}-1}} * 100 \tag{1}$$

Next, the COVID-19 pandemic is a proxy by the total COVID-19 cases per million population (COVID) and digital adoption (DIGITAL) is a proxy by the number of fixed broadband subscribers of Telekom Malaysia.

There are two reasons for choosing this proxy. First, Telekom Malaysia is the major internet service provider in Malaysia. Therefore, the number of fixed broadband subscribers will likely capture a broad range of internet users than other internet services providers such as Maxis, Digi, Celcom and U Mobile. Hence, it can be expected that Telekom Malaysia's fixed broadband subscribers will likely capture the pace of digitalisation in Malaysia. Second, broadband penetration has been recognised by the World Bank as an important source of growth for a country [23]. As such, broadband enables services such as cloud computing and mobile apps, facilitating innovation across various sectors of the economy. In application to this study, the broadband internet would facilitate innovation and productivity in the manufacturing sector by digitalising the production process. Digitalisation enables robots and facilitates the production, allowing projects to move faster and manufacturers to receive more orders. As a result, digitalisation enables manufacturers to practice economies of scale, improving output and company performance. However, the number of fixed broadband subscribers of Telekom Malaysia is available on a quarterly frequency.

Hence, this study employs the cubic spline interpolation method to convert the quarterly subscribers into monthly frequency. This interpolation method is detailed in [16] and is widely adopted in empirical studies to overcome data unavailability [1, 20, 28].

Next, alternative measures for the manufacturing sales, namely the yearly growth rate of the manufacturing sales (SALESYoY), are included in the model.

The second data set contains cross-country information on the manufacturing sector performance, COVID-19 cases and adoption of digitalisation from 79 countries (as shown in Appendix 2) in the year 2020. For country-level, the manufacturing sector performance is measured by the value added of the manufacturing and industry sectors.

Next, country-level digitalisation is measured by the global connectivity index (GCI). Huawei created this index, which can be used for cross-country comparisons on the level of digital adoption [18]. Based on the global connectivity report published by Huawei, the global connectivity index is used to analyse a broad spectrum of ICT Infrastructure and digital transformation indicators to provide a comprehensive map of the global digital economy. The index benchmarked 79 countries according to their performance in 40 indicators that track the impact of ICT on a nation's economy, digital competitiveness and future growth. Combining these countries account for 95% of global GDP. The 40 indicators can be analysed both vertically (Supply, Demand, Experience, Potential) and horizontally (Broadband, Cloud, IoT and AI). The global connectivity index is a unique quantitative assessment that comprehensively and objectively evaluates connectivity from a national and industrial perspective. The total COVID-19 cases per 100 million population are used to proxy for the COVID-19 pandemic.

The selection of sampled countries and periods is based on the availability of the global connectivity index and COVID-19 data. As indicated earlier, the index was created for 79 countries from 2015 to 2020. However, the COVID-19 cases data is only available from 2020 onwards. Thus, this limits the estimation to cross-sectional instead of panel data analysis. All the variables from both data sets are shown in Table 1.

3.2 Empirical Model

This study employs two empirical models to examine the mitigating effect of digitalisation. The first empirical model is applied to the sectoral-level data obtained from Malaysia's manufacturing sector, as such:

$$\begin{aligned} \text{SALESMoM}_{\text{it}} = {} & \beta_0 + \beta_1 \text{COVIDMSIA}_t + \beta_2 \text{DIGITAL}_t \\ & + \beta_3 \text{COVIDMSIA}_t * \text{DIGITAL}_t + v_i + \varepsilon_{\text{it}} \end{aligned} \quad (2)$$

where i is the sectoral index, t is the monthly index, SALESMoM represents the monthly growth rate of the manufacturing sub-sector sales value and COVIDMSIA

Table 1 List of variables

Variables	Description	Unit of measurement	Source
Variables used in the sectoral-level analysis			
SALESMoM	Monthly growth rate of manufacturing sales	Month-on-month %	DOSM
SALESYoY	Yearly growth rate of manufacturing sales	Year-on-year %	DOSM
COVIDMSIA	Total COVID-19 cases in Malaysia	Per million population	OWID
DIGITAL	Telekom Malaysia's fixed broadband subscriber	Thousands	TM
Variables used in cross-country analysis			
MANUVA	Value added of the manufacturing sector	Constant 2015 USD	WDI
INDUSTRYVA	Value added of the industry sector	Constant 2015 USD	WDI
GCI	Global connectivity index	Index	Huawei
COVID	Total COVID-19 cases	Per 100 million population	OWID

Note
1. DOSM denotes the Department of Statistics Malaysia
2. OWDI denotes Our World In Data database
3. TM denotes Telekom Malaysia
4. WDI denotes the World Development Indicators database

represents the total COVID-19 cases per million population in Malaysia. DIGITAL denotes digital adoption, proxy by the number of fixed broadband subscribers of Telekom Malaysia. The v_i represents the sector-specific effect and ε_{it} represents the error term.

Both COVID-19 and digital adoption measures are unavailable at the sectoral level, so the aggregate value is included in the model. However, using aggregate value can capture the impact of COVID-19 and digital adoption on manufacturing sales performance. For instance, higher COVID-19 cases induce the Malaysian government to implement a national lockdown policy to curb virus transmission. Consequently, this halts manufacturing activity, whereby factories cannot operate during the lockdown period. This, in turn, negatively affects the sales performance of the manufacturing industry.

For the digital adoption measure, the higher number of fixed broadband subscribers indicates a greater degree of internet penetration rate in the country, thereby facilitating manufacturing sales performance. From the consumer perspective, internet use allows them to purchase through e-commerce. This online system ensures consistent demand for manufacturers' goods amid the closure of the physical store.

The internet allows manufacturers to venture into a digital business model by providing an online platform to market their products and services. This approach would expand the consumer market and provide a constant revenue stream to the company, thereby offsetting the revenue loss due to the closure of physical stores during the pandemic. More importantly, the use of the internet, particularly high-speed internet, such as a 5G network, allows firms to deploy remote robots in the factory. Remote robots enable employees to perform their daily routine in the factory, thereby ensuring the continuation of manufacturing activity despite the plant's closure. This approach facilitates the output produced and sales performance of the manufacturing sector.

Including the interaction term, COVIDMSIA*DIGITAL enables identifying the impact of COVID-19 on manufacturing sales at the varying pace of digital adoption in Malaysia. The marginal effect of COVID-19 on manufacturing sales depends on β_3, that is:

$$\frac{\partial \mathrm{SALESMoM_{it}}}{\partial \mathrm{COVIDMSIA}_t} = \beta_1 + \beta_3 \mathrm{DIGITAL}_t \tag{3}$$

The Fixed Effect (FE) estimator was used to estimate Eq. (2). There are two reasons for choosing this estimator. First, the FE estimator includes the sector-specific effect in the estimation to control for heterogeneity across different manufacturing sub-sectors. The Pooled OLS (POLS) estimator assumes homogeneity across the cross-section unit. This homogeneity is a strict assumption, given that the sales value will likely differ across the sub-sectors. Hence, the FE estimator is deemed to provide an unbiased estimate compared to the POLS estimator. Second, compared to the Random Effect (RE) estimator, the FE estimator is consistent and efficient in the presence of a non-zero correlation between explanatory variables and the sector-specific effect. Robust standard error was computed for the Fixed effect estimator to preclude heteroscedasticity and autocorrelation in the error term.

Equation (2) provides evidence of the role of digitalisation in mitigating the adverse impact of the COVID-19 pandemic on Malaysian manufacturing sector performance. An immediate question is whether the findings from Malaysia can be generalised to a broad range of countries worldwide. To provide an answer to this question, this study estimates the second empirical model for cross-country analysis as below:

$$\mathrm{LnMANUVA}_i = \beta_0 + \beta_1 \mathrm{COVID}_i + \beta_2 \mathrm{GCI}_i + \beta_3 \mathrm{COVID}_i * \mathrm{GCI}_i + \varepsilon_i \tag{4}$$

where i is the country index, MANUVA represents the value added of the manufacturing sector (constant 2015 USD), a proxy for the manufacturing sector performance. Equation (4) will be re-estimated to ensure the robustness of the finding using an alternative measure for the manufacturing sector performance, namely the value added of the industry sector (INDUSTRYVA). *GCI* represents the global connectivity index, a proxy for digitalisation for cross-country analysis. Next, COVID represents the total COVID-19 cases per 100 million population. The marginal effect of COVID-19 on the value added of the manufacturing sector depends on β_3, that is:

$$\frac{\partial \text{MANUVA}_i}{\partial \text{COVID}_i} = \beta_1 + \beta_3 \text{GCI}_i \tag{5}$$

Given that Eq. (4) is specified as a cross-sectional model, therefore the Ordinary Least Square (OLS) estimator will be used to estimate Eq. (4). Moreover, the robust standard error is computed to control for heteroscedasticity in the error term.

4 Empirical Results

4.1 Descriptive Statistics

Table 2 shows the descriptive statistics for all the variables used in this study. The manufacturing sector in Malaysia experienced a positive average monthly sales growth rate of 0.183% in the year 2020. However, the yearly growth rate of manufacturing sales was negative 7.3%, indicating that the outbreak of the COVID-19 pandemic has halted the manufacturing sector's performance compared to the preceding year. Next, on average, the total COVID-19 cases stood at 682 cases per million population, far surpassing neighbouring countries, such as Thailand (41 total COVID-19 cases per million population), Brunei (328 total COVID-19 cases per million population) and Vietnam (6 total COVID-19 cases per million population). Meanwhile, the average number of Telekom Malaysia's fixed broadband subscribers stood at 2253 thousand in 2020.

4.2 Estimation Results for Sectoral-Level Analysis (Eq. (2))

This section shows the estimation results for the sectoral-level analysis of Eq. (2). By focusing on column 1, it can be observed that the estimated coefficients for COVID-19 cases (COVIDMSIA) are negative and statistically significant at a 1% level. As observed, an additional 1 case increase in the total COVID-19 cases per million Malaysian population is associated with a 0.013% reduction in the manufacturing sales performance. The effect is substantial, given that Malaysia recorded 3491 COVID-19 cases per million of the population in December 2020. The results indicate that the COVID-19 pandemic suppresses the manufacturing sales performance in Malaysia.

The result is consistent with the empirical finding in other countries, such as South Africa [30], Bangladesh [7], Pakistan [21], China [6, 37], the United Kingdom [17, 26], Japan [40], New Zealand [29] and the United States [2]. These studies found that the COVID-19 pandemic has a dampening impact on the country's manufacturing sector performance.

Table 2 Descriptive statistics

Variable	Mean	Std. dev	Obs
Variables used for sectoral-level analysis			
SALESMoM	0.183	51.506	264
SALESYoY	−7.309	23.660	288
COVIDMSIA	682.439	1006.935	288
DIGITAL	2253.260	56.916	288
Variables used for cross-country analysis			
LnMANUVA	24.265	1.569	76
LnINDUSTRYVA	24.964	1.544	78
GCI	51.430	16.297	79
COVID	226.098	194.461	79

Note

1. The sample period for sectoral-level analysis: January 2020-December 2020
2. Given that the manufacturing sales (SALESMoM) are measured in monthly growth rate. Hence, the data point for January 2020 effectively drops out for all 24 sub-sectors
3. Ln denotes natural logarithm
4. The data used for cross-country analysis is based on the year 2020

Besides, the finding is in line with the survey results published by the Federation of Malaysian Manufacturers (FMM). As such, the Federation of Malaysian Manufacturers (FMM)-Malaysian Institute of Economic Research (MIER) Business Conditions Index recorded a slump in manufacturing activity and local and export sales in the first half of 2020 [12]. Furthermore, the industry survey found that almost all businesses saw revenue drop in the first half of 2020, with 82% of the respondents surveyed reporting a decrease in income while 80% said their profitability plunged. Similarly, in the second half of 2020, most of the indicators under the Business Conditions Index remained below the 100-point threshold level of optimism, indicating that the overall business condition in the Malaysian manufacturing sector had remained subdued [13].

Next, digital adoption (DIGITAL) positively and significantly influences manufacturing sales performance. The result indicates the importance of digital adoption in facilitating manufacturing sales performance. Notably, the finding is in line with the empirical literature [5, 8, 9, 11], which argued that digital adoption is the key to improving manufacturing sector performance. Moreover, the finding supports the numerous policy measures undertaken by the Malaysian government under the Malaysia Digital Economic Blueprint to accelerate digital adoption in the country.

Turning to the focus of this study. Column 2 of Table 3 shows the mitigating effect of digital adoption. As noted by [4], it is inappropriate to interpret the coefficients of COVID-19 (COVIDMSIA) and digital adoption (DIGITAL) if the model contains an interaction term (COVIDMSIAxDIGITAL), as the former captures the effect of

Table 3 Estimation results for Eq. (2)

Dependent variable	SALESMoM		SALESYoY
	1	2	3
COVIDMSIA	−0.013*** (0.002)	−0.606*** (0.164)	−1.019*** (0.109)
DIGITAL	0.311*** (0.058)	0.437*** (0.090)	0.297*** (0.045)
COVIDMSIA × DIGITAL	–	0.0001*** (0.0000)	0.0004*** (0.0000)
CONSTANT	−692.582*** (128.422)	−965.333*** (197.423)	−658.428*** (99.460)
Marginal effect			
Minimum	–	−0.065*** (0.016)	−0.089*** (0.009)
Mean	–	−0.047*** (0.011)	−0.058*** (0.006)
Maximum	–	−0.019*** (0.004)	−0.009*** (0.002)
No. Subsector	24	24	24
Observation	264	264	288

Note
1. *, ** and *** denotes statistically significant at 10, 5 and 1% level, respectively
2. Values in parentheses are robust standard errors. Ln denotes the natural logarithm

COVID-19 pandemic on sales performance only if the digital adoption is equal to zero. The latter provides the effect of digital adoption on sales performance only if the COVID-19 cases are equal to zero. The interaction term (COVIDMSIAxDIGITAL) is positive and significant at the 1% level, implying that digital adoption mitigates the negative effect of the COVID-19 pandemic on manufacturing sales performance.

Following the suggestion by [4], the marginal effect of the COVID-19 pandemic on manufacturing sales performance is computed at different levels of digital adoption to exhibit its mitigating effect. The marginal effect diagram shows the role of digital adoption in mitigating the adverse effect of the COVID-19 pandemic on manufacturing sales performance (Fig. 1). As observed, the COVID-19 pandemic has a negative and significant impact on sales performance if the digital adoption is at the minimum level (2182 thousand of Telekom Malaysia's fixed broadband subscribers). The negative effect corresponds to the intercept of the solid marginal effect line (−0.065%). However, the negative impact of the COVID-19 pandemic on manufacturing sales performance diminishes with the rising level of digital adoption. When digital adoption is at the maximum level (2366 thousand Telekom Malaysia's fixed broadband subscribers), the negative impact is reduced to −0.019%. This outcome is equivalent to a 3.5 times reduction in the sales-deteriorating effect of the COVID-19 pandemic. The substantial effect highlights the important role of digitalisation in offsetting the sales-deteriorating effect of the COVID-19 pandemic.

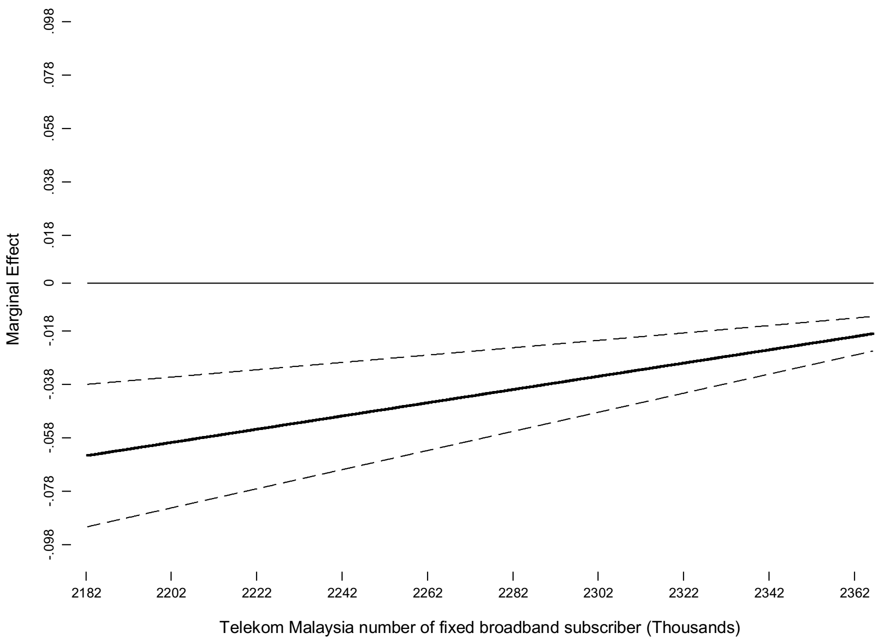

Fig. 1 Marginal effect of the COVID-19 cases on manufacturing sales. *Notes* 1. The figure provides the marginal effect (solid line) and its 90% confidence interval (dotted lines)
2. The above marginal effect diagram is plotted based on FE robust estimator in Table 3, column 2

The finding of the mitigating effect of digital adoption is in line with the theoretical argument by [15], whereby digitalisation is essential in improving firms' dynamic capabilities and providing effective response strategies to cope with the COVID-19 pandemic. Thus, this mitigates the adverse impact of the COVID-19 pandemic and preserves firms' performance. Empirically, the finding concurs with [3], in which digital adoption is essential in helping firms overcome the challenges imposed by the COVID-19 pandemic and sustain their business operation.

Similar results are obtained in column 3, where the manufacturing sector performance is measured by the yearly growth of manufacturing sales (*SALESYoY*). Thus, the key finding of a mitigating effect of digitalisation is robust and not influenced by the choice of the dependent variable in the model.

4.3 Estimation Results for Cross-Country Analysis (Eq. (3))

To ensure the findings from Malaysia can be generalised to a broad range of countries, this section shows the estimation results for the cross-country analysis of Eq. (3). By focusing on column 1 of Table 4, the estimated coefficient of the global connectivity index (GCI) is positive and statistically significant at a 1% level, suggesting that digitalisation increases the value added of the manufacturing sector in the 79 countries. The finding aligns with the estimation results obtained from Malaysia, whereby digitalisation plays an imperative role in enhancing the manufacturing sector's performance. In contrast, the estimated coefficient of COVID-19 cases (COVID) is negative and statistically significant at a 5% level, implying that the COVID-19 pandemic suppresses the manufacturing sector performance in the 79 countries.

Turning to the focus of this study. Column 2 of Table 4 shows the mitigating effect of digitalisation. Consistent with the above results in Malaysia, the marginal effect estimate shows the important role of digitalisation in mitigating the adverse effect of the COVID-19 pandemic on manufacturing sector performance in the 79 countries. As observed, the COVID-19 pandemic has a negative and significant impact on the value-added of the manufacturing sector if the global connectivity index is at the minimum level. However, the negative impact of the COVID-19 pandemic diminishes with the rising level of the global connectivity index. When the global connectivity index is at the maximum level, the COVID-19 pandemic has an insignificant impact on the value added of the manufacturing sector. Similar results are obtained in column 3, whereby the value added by the manufacturing sector is replaced with the value added by industry sector. This implies that the key finding of a mitigating effect of digitalisation is not confined to Malaysia but widespread across countries worldwide.

Table 4 Estimation results for Eq. (3)

Dependent variable	LnMANUVA		LnINDUSTRYVA
	1	2	3
GCI	0.059*** (0.011)	0.047*** (0.015)	0.048*** (0.014)
COVID	−0.002** (0.001)	−0.006** (0.003)	-0.006** (0.003)
GCI × COVID	–	0.001 (0.001)	0.001 (0.001)
CONSTANT	21.733*** (0.531)	22.348*** (0.709)	23.105*** (0.640)
Marginal effect			
Minimum	–	−0.005** (0.002)	−0.005*** (0.002)
Mean	–	−0.002*** (0.000)	−0.003*** (0.001)
Maximum	–	−0.000 (0.002)	−0.001 (0.002)
R-squared	0.313	0.331	0.339
F-statistics	14.96***	12.16***	11.53***

Note
1. *, ** and *** denotes statistically significant at 10, 5 and 1% level, respectively
2. Values in parentheses are robust standard errors. Ln denotes the natural logarithm

5 Conclusion and Policy Recommendation

In Malaysia, the outbreak of the COVID-19 pandemic brought conventional economic activities, such as manufacturing, to a standstill. The observation is reflected by the negative 2.6% year-on-year growth in the manufacturing sector in 2020. On the other hand, the pandemic accelerated the growth of digital adoption due to an abrupt increase in work from home, a surge in video-based content consumption, e-commerce and internet banking.

Based on the above discussion, digitalisation can be expected to play an important role in reducing the sales-deteriorating effect of the COVID-19 pandemic on the manufacturing sector. Accordingly, this study aims to provide an empirical investigation on whether digitalisation mitigates the negative impact of COVID-19 on manufacturing sales performance in Malaysia.

Based on the finding, this study offers three important policy recommendations to raise the degree of digital adoption in the Malaysian manufacturing sector. First, the Malaysian government could provide a tax incentive to encourage manufacturers to adopt digital technologies such as remote robots in the production process. Tax incentive plays an important role in providing additional cash flows to firms, thereby lessening their financial constraint and promoting greater investment. As a result, a tax credit would facilitate firms' investment behaviour and accelerate the pace of digitalisation in the manufacturing sector.

Second, the Malaysian government could provide public capital to support digital adoption among manufacturers. Public capital, such as providing a public grant programme, can address the financial constraint among small manufacturers, particularly Small and Medium Enterprises (SMEs). Generally, research and development activity is costly. Therefore financial support from the government is essential in helping small manufacturers to develop and adopt a digital solution in their production process.

Third, the Malaysian government should speed up the deployment of the 5G network in the country. Despite the introduction of Malaysia's Digital Economic Blueprint, Malaysia is relatively slow in deploying the 5G network compared to neighbouring countries such as Thailand. The term 5G indicates the 5th generation of mobile networks, which enables the application of big data, the Internet of Things (IoT) and Artificial Intelligence (AI) in various sectors of the economy.

The empirical analysis of this study shows that the mitigating effect of digitalisation is not confined to Malaysia but is widespread across countries worldwide. Thus, the above policy recommendations can be applied to other countries to uplift digital adoption and subsequently offset the adverse impact of the COVID-19 pandemic on the manufacturing sector's performance.

Table 5 Sub-sector in the Malaysian manufacturing sector

No.	Sub-sector
1	Manufacture of food products
2	Manufacture of beverages
3	Manufacture of tobacco products
4	Manufacture of textiles
5	Manufacture of wearing apparel
6	Manufacture of leather and related products
7	Manufacture of wood and products of wood and cork
8	Manufacture of paper and paper products
9	Printing and reproduction of recorded media
10	Manufacture of furniture
11	Manufacture of cake and refined petroleum products
12	Manufacture of chemicals and chemical products
13	Manufacture of basic pharmaceutical products
14	Manufacture of rubber and plastic products
15	Manufacture of other non-metallic mineral products
16	Manufacture of basic metals
17	Manufacture of fabricated metal products
18	Manufacture of computers, electronics and optical
19	Manufacture of electrical equipment
20	Manufacture of machinery and equipment
21	Manufacture of motor vehicles, trailers and semi-trailers
22	Manufacture of other transport equipment
23	Other manufacturing
24	Repair and installation of machinery and equipment

Source Department of Statistics Malaysia (DOSM)

Appendix 1

See Table 5.

Appendix 2

See Table 6.

Table 6 List of the country (79 countries)

Algeria, Argentina, Australia, Austria, Bahrain, Bangladesh, Belarus, Belgium, Bolivia, Botswana, Brazil, Bulgaria, Canada, Chile, China, Colombia, Croatia, Czech Republic, Denmark, Ecuador, Egypt, Estonia, Ethiopia, Finland, France, Germany, Ghana, Greece, Hungary, India, Indonesia, Ireland, Italy, Japan, Jordan, Kazakhstan, Kenya, Kuwait, Lebanon, Lithuania, Luxembourg, Malaysia, Mexico, Morocco, Namibia, Netherlands, New Zealand, Nigeria, Norway, Oman, Pakistan, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Russia, Saudi Arabia, Serbia, Singapore, Slovakia, Slovenia, South Africa, South Korea, Spain, Sweden, Switzerland, Tanzania, Thailand, Turkey, Uganda, Ukraine, United Arab Emirates, United Kingdom, United States, Uruguay, Venezuela, Vietnam

Note Country selection is based on the data availability of the global connectivity index by Huawei. See https://www.huawei.com/minisite/gci/en/

References

1. Bathia, D., & Bredin, D. (2013). An examination of investor sentiment effect on G7 stock market returns. *The European Journal of Finance, 19*(9), 909–937.
2. Bauer, L., Broady, K., Edelberg, W, & O'Donnell, J. (2020). *Ten facts about COVID-19 and the U.S. Economy.* The Hamilton Project. Brookings Institution.
3. Belhadi, A., Kamble, S., Jabbour, C. J. C., Gunasekaran, A., Ndubisi, N. O., & Venkatesh, M. (2021). Manufacturing and service supply chain resilience to the COVID-19 outbreak: Lessons learned from the automobile and airline industries. *Technological Forecasting & Social Change, 163*.https://doi.org/10.1016/j.techfore.2020.120447
4. Brambor, T., Clark, W. M., & Golder, M. (2006). Understanding interaction models: Improving empirical analyses. *Political Analysis, 14*, 63–82.
5. Buchi, G., Cugno, M., & Castagnoli, R. (2020). Smart factory performance and Industry 4.0. *Technological Forecasting & Social Change, 150*. https://doi.org/10.1016/j.techfore.2019.119790.
6. Cai, M., & Luo, J. (2020). Influence of COVID-19 on manufacturing industry and corresponding countermeasures from a supply chain perspective. *Journal of Shanghai Jiaotong University (Science), 25*, 409–416.
7. Chakraborty, S., & Biswas, M. C. (2020). Impact of COVID-19 on the textile, apparel and fashion manufacturing industry supply chain: Case study on a ready-made garment manufacturing industry. *Journal of Supply Chain Management, Logistics and Procurement, 3*(2), 181–199.
8. Chauhan, C., Singh, A., & Luthra, S. (2021). Barriers to industry 4.0 adoption and its performance implications: An empirical investigation of emerging economy. *Journal of Cleaner Production, 285*. https://doi.org/10.1016/j.jclepro.2020.124809
9. Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of Production Economics, 204*, 383–394.
10. Eisenhardt, M., & Jeffrey, A. M. (2000). Dynamic capabilities: What are they? *Strategic Management Journal, 21*(10–11), 1105–1121.
11. Falentina, A. T., Resosudarmo, B. P., Darmawan, D., & Sulistyaningrum, E. (2020). Digitalisation and the performance of micro and small enterprises in Yogyakarta, Indonesia. *Bulletin of Indonesian Economic Studie.* https://doi.org/10.1080/00074918.2020.1803210
12. Federation of Malaysian Manufacturers. (2020). *Pandemic-hit Malaysian manufacturers post record slump in first half.* https://www.fmm.org.my/FMM_In_The_News-@-Pandemic-hit_Malaysian_manufacturers_post_record_slump_in_first_half.aspx
13. Federation of Malaysian Manufacturers. (2020). *FMM–MIER Business Conditions Survey 2H2020 (GI/04/2021).* https://www.fmm.org.my/General_Information-@-FMM_%E2%80%93_MIER_Business_Conditions_Survey_2H2020_(GI-s-04-s-2021).aspx

14. George, G., Haas, M. R., & Pentland, A. (2014). Big data and management. *Academy Management Journal, 57*(2), 321–326.
15. Guo, H., Yang, Z., Huang, R., & Guo, A. (2020). The digitalisation and public crisis response of small and medium enterprises: Implications from the COVID-19 survey. *Frontiers of Business Research in China.*https://doi.org/10.1186/s11782-020-00087-1
16. Granville, S. (2005). *Application: Cubic spline interpolation, computational methods of linear algebra*. Wiley-Interscience.
17. Harris, J. L., Sunley, P., Evenhuis, E., Martin, R., Pike, A., & Harris, R. (2020). The Covid-19 crisis and manufacturing: How should national and local industrial strategies respond? *Local Economy, 35*(4), 403–415.
18. Huawei. (2020). Shaping the New Normal with Intelligent Connectivity. https://www.huawei.com/minisite/gci/en/
19. Iacovone, L., Kapil, N., Marc, L. M., Marcolongo, G., Skamnelos, I., & Vincelette, G. A. (2021). *How COVID-19 policy responses differed in Central Europe*. https://www.brookings.edu/blog/future-development/2021/10/11/how-covid-19-policy-responses-differed-in-central-europe/
20. Isabel, V. (2017). Did the crisis permanently scar the Portuguese labour market? Evidence from a Markov-switching Beveridge curve analysis. Working Papers No. 2043. European Central Bank.
21. Kaur, K. (2021). The early impact of COVID-19 on textile industry: An empirical analysis. *Management and Labour Studies.*https://doi.org/10.1177/0258042X21991018
22. Lin, Y., & Wu, L. Y. (2014). Exploring the role of dynamic capabilities in firm performance under the resource-based view framework. *Journal of Business Research, 67*(3), 407–413.
23. Minges, M. (2016). Exploring the relationship between broadband and economic growth. World Development Report No. 102955. World Bank.
24. Njoroge, P., & Pazarbasioglu, C. (2020). *Bridging the digital divide to scale up the COVID-19 recovery*. https://blogs.imf.org/2020/11/05/bridging-the-digital-divide-to-scale-up-the-covid-19-recovery/
25. OECD. (2014). The digital economy, new business models and key features. In *Addressing the tax challenges of the digital economy* (pp. 69–97). OECD Publishing.
26. OECD. (2020). *Economic outlook: The world economy on a tightrope*. OECD.
27. Sebastian, I., Ross, J., Beath, C., Mocker, M., Moloney, K., & Fonstad, N. (2017). How big old companies navigate digital transformation. *MIS Quarterly, 16*(3), 197–213.
28. Shaharuddin, S. S., Lau, W. Y., & Ahamd, R. (2018). Is the Fama French Three-Factor model relevant? Evidence from Islamic unit trust funds. *Journal of Asian Finance, Economics and Business, 5*(4), 21–34.
29. Stats, NZ. (2020). *Manufacturing sales shrink during COVID-19 lockdown*. https://www.stats.govt.nz/news/manufacturing-sales-shrink-during-covid-19-lockdown
30. Telukdarie, A., Munsamy, M., & Mohlala, P. (2020). Analysis of the impact of COVID-19 on the Food and Beverages Manufacturing Sector. *Sustainability, 12*(22). https://doi.org/10.3390/su12229331
31. Treece, D. J. (2007). Explicating dynamic capabilities: The nature and micro foundation of (sustainable) enterprise performance. *Strategic Management Journal, 28*(13), 1319–1350.
32. Treece, D. J. (2012). Dynamic capabilities: Routines versus entrepreneurial action. *Journal of Management Studies, 49*(8), 1395–1401.
33. Treece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal, 18*(7), 509–533.
34. UNCTAD. (2021). *How COVID-19 triggered the digital and e-commerce turning point.* https://unctad.org/news/how-covid-19-triggered-digital-and-e-commerce-turning-point
35. UNIDO. (2020). *World Manufacturing Production, Quarter 4-2020*.
36. Vial, G. (2019). Understanding digital transformation: A review and a research agenda. *The Journal of Strategic Information Systems, 28*(2), 118–144.
37. Wen, W., Yang, S., Zhou, P., & Gao, S. Z. (2021). Impacts of COVID-19 on the electric vehicle industry: Evidence from China. *Renewable and Sustainable Energy Reviews, 144.*https://doi.org/10.1016/j.rser.2021.111024

38. World Bank. (2020). *Philippines digital economy report 2020*. The World Bank.
39. World Bank. (2022). *Global Guide: Measures adopted to support distressed businesses through the COVID-19 crisis.* https://thedocs.worldbank.org/en/doc/194131592248086470-0090022020/original/globalguide.pdf
40. Zhang, H. (2021). The impact of COVID-19 on global production networks: Evidence from Japanese multinational firms. Discussion Papers NO. 364. Economic Research Institute for ASEAN and East Asia (ERIA).

Impact of Electronic Government on Human Capital: Dynamics of Interaction

Utsav Kumar Singh and Maxim Vlasov

Abstract In the modern economy, there is an increased interest in the electronic state, and its role in the socio-economic development of human capital and society. This paper examines the results of previous studies on the analysis of the e-government's significance in order to assess its current level of activity and what value it should bring to society. The object of research is e-government and its social value. The information base of the study was the statistical data of the Federal State Statistics Service on the dynamics of digital economy indicators characterizing the development of the electronic state and human capital indicators in the Russian Federation. The study period is 2010–2019. Analysis of the development of e-government was carried out at the country level. During the study, the authors sought to answer the following two questions. To what extent is the issue of assessing the importance of e-government for society developed in modern economic science? How does increasing the value of e-government for society affect the development of human capital? The subjects of the study are six discovered values of e-government: quality services from the state; administrative efficiency; open government; enhancing ethical behavior and professionalism; trusting relationship with the government; social value and well-being, and the identified correlations between certain factors of human capital and the digital economy, and how they together form what we call e-government today. As a research methodology, the authors used a literature analysis of works on the value of e-government, and correlation analysis was applied to assess the dependencies. The findings of the study were divided into three dimensions of societal value: improved public services, improved administration, and increased social value. The obtained

U. K. Singh
Shaheed Bhagat Singh College, University of Delhi, Sheikh Sarai Phase II, New Delhi 110017, India

M. Vlasov (✉)
Ural Federal University, 19 Mira Street, 620002 Ekaterinburg, Russian Federation
e-mail: mvlassov@mail.ru

Institute of Economics of the Ural Branch of the Russian Academy of Sciences, 29 Moskovskaya Street, 620014 Ekaterinburg, Russian Federation

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_32

negative and positive correlations lead to conclusions that can improve our understanding of the social value of e-government from different points of view, as well as the intersection between them in real projects and e-government implementations.

Keywords E-government · Information and communication technologies · Human capital · Digital economy · Digital state · Value of e-government

1 Introduction

The formation of an effective e-government makes it possible to increase the competitiveness of the country's economy [1, 2]. In turn, the acceleration of economic development and GDP growth provides an increase in the level of the country's human capital [3].

E-government is usually understood as a process of using digital economy tools by the state aimed at improving organizational structures and state operations [4]. In addition, it is expected that the introduction of e-government helps states provide services and transform relations with citizens, enterprises, and other government structures [5].

At present, in contrast to developed countries where e-government quality is at a high level, in developing nations e-government faces many challenges. These problems include, among other things, the digital divide, inadequate electronic infrastructure, and lack of skills and competencies for the development, implementation, and use of e-government systems and managing them. A high percentage of electrical failures in the least developed countries was determined based on estimates, according to which 35% of projects are complete failures, 50% are partial failures, and only 15% are successful [6]. Failure of e-government entails many negative consequences, such as loss of time and money, loss of a good image of the actors involved, and an increase in future costs. For example, unsuccessful electronic governments hinder future projects due to the loss of confidence in them as a tool for modernizing the public sector. Despite the high failure rate, interest in this topic has grown significantly in recent years [7].

The purpose of this work is to analyze the existing studies of the social value of e-government to explore the current state and what value the electronic state should bring, and using the data of the Russian Federation as an example reveals the relationship between the factors of digital economy in the context of the electronic state and human capital factors.

Among the research questions are (1) to what extent is the issue of assessing the importance of e-government for society developed in modern economic science? and (2) how does increasing the value of e-government for society affect the development of human capital?

The authors answer these questions based on the data of the existing works exploring the concepts of the values of electronic states that can serve as a guide for research and practice in the government bodies and also reveal correlations between the main factors of the digital economy involved in e-government and human capital factors.

2 Literature Review

2.1 Definition of E-government

There are various interpretations of the concept of e-government. Table 1 presents the most popular of them.

Having analyzed the interpretations of the term "e-government" in Table 1, we have come to the following conclusions. First, today there are several different approaches to understanding this concept. In the first, the narrowest, approach, the concept of electronic government is considered only as digitized information necessary for government work or only as a tool that allows digital interactions with citizens in the provision of public services. The second approach, the definition of "electronic state" is considered more broadly and in detail, as a set of innovative

Table 1 Approaches to defining the concept of e-government

Authors	Definition of the term "e-government"
Tyushnyakov [8]	Transformation of relations emerging in the public sector, aimed at improving the quality and efficiency of public services, through the introduction of information and communication technologies and network operations
Shkurat and Sidorenko [9]	Organization of the activities of government bodies using the Internet, ensuring the internal unity of advanced information technologies with legal and legal norms, and external interactions of state information and communication systems and technologies with tax residents of the state
World Bank [10]	A set of state systems built on the basis of information and communication technologies that ensure the transformation of interaction with citizens, private business structures, as well as government agencies and organizations, in order to empower citizens, improve the quality of services provided, strengthen control and accountability, cut off the maximum transparency and efficiency of functioning of public administration bodies
Mamay [11]	The introduction of advanced information and communication technologies into the activities of state bodies aimed at improving the quality of services provided to citizens, increasing the reliability of information protection, organizing public administration functions in the most efficient way, and stimulating civil and social activity of citizens
Artyomova et al. [12]	Organization of interaction between public authorities and the public in digital form

information and communication technologies that allow providing citizens with the highest quality public services. In the third approach [8], an attempt is made to consider e-government as a tool built on the basis of digital technologies to ensure internal and external relations of the state. The advantage of these definitions is that they are highly specialized and can help more accurately define the problems that electronic software solves. However, this narrow focus in these definitions is at the same time their minus, because there are limited opportunities that can be offered to e-government [4, 13, 14]. The narrow definition and misunderstanding of the general concept of e-government lead to frequent failures of government initiatives in the implementation of ICT and transition from regular government to e-government. The authors of this article believe that e-government is a complex concept with many variables, which requires a deep understanding to develop and implement successful e-states, which, of course, includes the use of ICT, on the one hand, for more efficient functioning of the e-state itself, and on the other hand, to provide better services to citizens and all structural units of a particular country.

Thus, in this study, we propose the following definition of the term "e-government": this is the use by the public sector of innovative ICT that transform relations with citizens, the private sector, and/or other government institutions, with the aim of providing all citizens with improved services, reliable information, and deeper knowledge in order to facilitate access to the governance process and encourage greater citizen participation.

2.2 *Public Value E-government*

Comprehending e-government and its value requires understanding and experience in process management at the state level. When dividing organizations into private and public, their main goal remains the same, which is in the service people, but each group does it in different ways [15]. Private organizations serve people as customers and strive to maximize profits, while public sector organizations consider each person as a citizen of a particular state. As a result, we get organizations of the state sectors that, on the one hand, operate in order to earn money for their stability, and on the other hand, experience additional concerns about social value [16]. This article describes the concept of general intrinsic value, which is based on the theory of Moore [17]. This theory is inextricably linked with public administration, its main focus is the creation of value but of public administration, which includes performance criteria borrowed from private organizations. The main concept of social value is contributing to public welfare through entrepreneurial activity. According to Castelnovo [18], when considering the individual components of the general value, special attention is needed to focus on specific groups of people who somehow participate in the social value chain. The author argues that it is wrong to consider a citizen as a separate unit, it makes sense to consider citizens divided into subgroups according to various criteria, citizens involved in the public sector, citizens involved in politics, citizens with direct attitude towards the private sector, etc. In their scientific study, Pazmiño-Sarango et al.

[19] prove that public organizations are the main driver that has the most significant impact on the development and generation of social value. Organizations to some extent contribute to the development of values in society. The term "social value" is a kind of description of ways to solve complex problems. The structure of social value includes the ability of e-government systems to provide increased efficiency of government agencies, improved services for citizens, and the protection of social values, such as freedom, democracy, equality, and the consequences of these changes will depend on the current socio-economic context [16].

The effectiveness of e-government can be judged on the basis of its ability to create societal value not just for all citizens, but also for those who can be considered as consumers, as well as citizens who influence government policy. In the context of public sector reforms with the help of ICT, the theory of public value [17, 20], either initially or because of its adaptation, is increasingly used to study these reforms. When creating public value of the state, we primarily take into account the goals that are economically unprofitable, but fall into the category of social goals, e.g., the effectiveness of the state's actions, equality, social interaction, relative independence, transparency, the welfare of society, etc. [21]. Pang et al. [22] describe in detail how the state can create social value through ICT for only five areas: access to public services, the availability of open interaction with society, the potential for joint production, accumulation and multiplication of resources, and innovative component in public administration. Thus, the authors conclude that the creation of social value and bringing it to a qualitative level within the framework of the electronic state must be understood as the ability of effective interaction of individual e-government units between themselves and outside their borders while maintaining social values, such as freedom, democracy, and equality.

2.3 Structure of the Electronic State

The structure of the electronic state, according to Ndou [21], is detailed and includes all major components. According to this framework, the existing network of e-government definitions lends itself to three main components that characterize the structure of e-government, namely: (1) areas of transformation; (2) users, stakeholders, and their relationships; (3) scope. The following areas of e-government transformation can be distinguished: internal, external, and relative. Domestic refers to the use of advanced technologies within government structures aimed at increasing performance indicators. For example, using technologies in such a structure, it is easy to connect individual departments and divisions with each other by introducing internal workflow, which significantly speeds up the exchange of information [23].

As for the external area of transformation, here we can include the processes associated with external players of this structure within one state, namely, providing more efficient and transparent communication with citizens and businesses in the private sector. Relative areas tell how the introduction of ICT can lead to fundamental changes in relationships between citizens and the state, with implications for the democratic process and structuring government. According to the structure of e-government Ndou, the component "Users, Stakeholders and their relationships" includes four fundamental components: citizens of this state, private organizations, government organizations, and employees of private and public organizations. Accordingly, the government interacts separately with each of these four groups: G2C (government to citizens) is a state with citizens, G2B (government to business) is a state with private organizations, G2G (government to government) is a state with a state organization, and G2E (government to employees) is a state with employees of private and public organizations.

According to the e-government framework proposed by Ndou, the full use and implementation of the complex networks of interconnections described in the second component (users, stakeholders, and their relationships), entails three main areas of application and dissemination for e-government: e-administration, e-citizens, and e-services, and electronic society. As a result of theoretical research, the authors have changed the above application areas of e-government. Following the methodology of Gill [24], the author separated the concepts of e-citizens and e-services to make e-services independent, and in connection with their closeness in volume e-citizens now merged with the electronic society, to become a separate unit, which includes the whole society. Thus, the authors came to the following applied areas of e-government. E-administration is digitization of all internal tasks of the state by automating processes between individual components of state structures. E-services are the digitization of connections and provision services between government agencies, citizens, and private organizations. E-citizens and e-society imply establishing relationships and interactions between government institutions, citizens, and civil society as a whole.

2.4 Human Capital

To correctly operate with the concept of human capital, it is necessary to determine the interpretation of this term. Arvanitis and Loukis [25] refer human capital as a whole to factors of production. Chu et al. [26] refer human capital to knowledge, experience, level of mobility, skills, experience of employees, and leadership of the entire organization. Huff [27] classifies human capital as the intangible resources of individuals and groups of people, such as intelligence, knowledge, skills, etc. In this study, the authors interpret human capital as the skills and knowledge acquired by a person in the process of education and training, which are used to create new knowledge and skills, as well as to ensure that human needs are met.

3 Methodology

To identify the significance of the impact of digital technologies used in public authorities on the factors of human capital indicators, digital technologies and factors of human capital were analyzed. Among digital technologies are the share of public authorities and local governments using the Internet; the share of government authorities and local governments having a data transfer rate over the Internet of at least 2 Mbps; the share of placed orders for the supply of goods, performance of work and provision of services for state and municipal needs using electronic trading platforms; the share of electronic document flow between public authorities. Among the factors of human capital are the average per capita cash income of the population in the Russian Federation; the share of domestic expenditures on research and development of the ICT sector in the total volume of domestic research and development costs; the number of researchers performing scientific research and development, per 10,000 employed in economy. To determine the relationship between digital technology factors and human capital factors, the authors carried out a correlation analysis. It reveals the relationship between two or more independent quantities, while changes in the values of one or more of these quantities are accompanied by a systematic change in the values of another or other quantities. The author analyzed independent statistical data on the development of digital technologies and e-government, which justifies the choice of correlation analysis as the main research method [28]. The information base of the study was statistical data on the values of the factors of the digital economy, directly related to the electronic state and factors characterizing the development of human capital, presented by the Federal State Statistics Service (Rosstat, https://rosstat.gov.ru/), the study period was 2010–2019.

4 Results

To conduct the study, the authors selected the factors of the digital economy that are directly related to the e-government, namely the share of state authorities (OGV) and local government bodies (LSG) that used the Internet in the total number of surveyed organizations of OGV and LSG; the proportion of OGVs and LSG that had a data transfer rate over the Internet of at least 2 Mbps; the share of placed orders for the supply of goods, performance of work and provision of services for state and municipal needs using electronic trading platforms in the total volume of orders placed, by the number of auctions; the share of electronic document circulation between public authorities in the total volume of interdepartmental document circulation. Also considered are three factors related to human capital, namely, the average per capita cash income of the population in the Russian Federation (rubles per month); the share of domestic R&D expenditures in the ICT sector in total domestic R&D expenditures; and the number of researchers in R&D, per 10,000 employed in the economy. In the example of the Russian Federation and eight federal districts of the

RF, correlations between the above factors were calculated. Table 2 shows that with a positive change in the share of OGV and CHI in the use of ICT, in particular the Internet, there is a positive correlation with such a human capital factor as household income, but it is worth noting here that in the period from 2012 to 2018, the change in the first factor was insignificant (1.5% per year). Thus, we can conclude that the increase in the first factor does not directly affect the increase in the second. Further in Table 2, such factors of the digital economy as the share of OGVs and LSG that had a data transfer rate over the Internet of at least 2 Mbps, which also applies to ICT, and to the Internet, in particular. There is also a positive correlation (0.9) in relation to the monetary income of the population. Here it can be argued that the first factor affects the second, because the first changes by 4% every year. In other words, the speed of the Internet in OGV and CHI has a positive effect on the income of the population. According to Table 2, it is worth noting that such a human capital factor as "The number of researchers in R&D" has negative correlations everywhere (from −0.5 to −0.99), except for the format "the share of electronic document circulation between public authorities." According to the authors, this has nothing to do with the speed of the Internet in government institutions and with the share of government organizations that carry out transactions through electronic trading platforms; most likely, one or more other factors that are not directly related to the electronic state play a role here.

When considering such a factor of the digital economy as "the share of electronic document circulation between public authorities," we can conclude that there is a positive correlation with such a factor of human capital as the number of researchers in R&D.

5 Discussion

According to Jansen [29], the concept of an open e-government means that the actions and policies of the state should be developed and implemented in conditions of openness, transparency, equality, and cooperation. Particular attention will be paid to the conceptualization of e-government, that is, in practice, the state, using digital technologies, aims to improve internal relationships, namely, the relationship between various authorities and their employees, and external relationships, namely, with citizens of the state and private organizations. In the course of the correlation analysis, it was possible to find both positive and negative dependencies, which in the future, when developing the concept of introducing certain ICTs in the public sector, will help to choose the most effective tools. The results also showed the dominance of the government's desire to use ICT to improve relations between citizens and the state, which will ultimately lead to improved human capital indicators at the country level.

Table 2 Correlation coefficients of digital e-government factors and human capital factors

Factors	Average per capita cash income of the population in the RF (rubles per month)	Share of domestic spending on R&D in the ICT sector in total domestic spending on research and development (%)	Number of researchers in R&S, per 10,000 employed in the economy (persons)
The share of public authorities and local governments using the Internet in the total number of surveyed organizations of public authorities and local governments	0.465	−0.023	−0.552
The share of public authorities and local governments that had a data transfer rate over the Internet of at least 2 Mbps, in the total number of surveyed organizations of public authorities and local governments	0.927	−0.060	−0.949
The share of placed orders for the supply of goods, performance of work, and provision of services for state and municipal needs using electronic trading platforms, in the total volume of orders placed, by the number of auctions	−1	−0.292	−0.999
The share of electronic document circulation between public authorities, in the total volume of interdepartmental document circulation	−0.476	−0.742	0.604

6 Conclusion

The theoretical significance of the study lies in identifying, based on the results of the correlation analysis, the relationship between the factors of the digital economy and the factors that ensure the development of the electronic state, which are drivers of the development of human capital, which can serve as a theoretical basis for further research on the impact of digitalization of government structures on the level of development of human capital.

The practical significance of the study is the ability to form predictive models for the development of e-government based on innovative ICTs in order to improve the efficiency and quality of public services provided to the population.

References

1. Belokurova, E. V., Pizikov, S. V., Petrenko, E. S., & Koshebayeva, G. K. (2019). The institutional model of building the digital economy in modern Russia. In *Digital economy: Complexity and variety vs. rationality* (pp. 64–70). https://doi.org/10.1007/978-3-030-29586-8_8.
2. Koskinen, J., Vermanen, M., Rantanen, M., & Hyrynsalmi, S. (2020). Ethical governance of eGovernment ecosystems. In *BLED 2020 Proceedings* (No. 29).
3. Singh, U. K. (2022). Quantitative analysis of human development in India. In *Human development in Bihar, India* (pp. 91–97). https://doi.org/10.1007/978-981-19-3624-1_4.
4. Pavlyutenkova, M. Yu. (2015). Electronic government of Russia in new conditions. *PolitBook*, *2*, 6–32.
5. Grönlund, Å., & Horan, T. A. (2005). Introducing e-gov: History, definitions, and issues. *Communications of the Association for Information Systems, 15*. https://doi.org/10.17705/1cais.01539.
6. Heeks, R. (2002). Information systems and developing countries: Failure, success, and local improvisations. *The Information Society, 18*(2), 101–112. https://doi.org/10.1080/01972240290075039.
7. Nkohkwo, Q., & Islam, M. S. (2013). Challenges to the successful implementation of e-government initiatives in Sub-Saharan Africa: A literature review. *Electronic Journal of e-Government, 11*(2), 253–267.
8. Tyushnyakov, V. N. (2012). Technologies of interdepartmental electronic interaction in state and municipal management. *Bulletin of the Southern Federal University. Technical Science, 133*(8), 195–200.
9. Shkurat, I. V., & Sidorenko, N. O. (2014). Using indicators of the e-government development index in public administration: Calculation methodology and statistical accounting. *Philosophical Problems of Information Technologies and Cyberspace, 2*, 7–19.
10. e-Government: Information resource of WorldBank. https://www.worldbank.org/en/topic/digitaldevelopment/brief/e-government.
11. Mamay, Ye. A. (2018). E-government in Russia: The problem of determining efficiency criteria and achieving indicators. *Legal Concept*, *17*(4), 35–44.
12. Artyomova, P. V., Kamolov, S. G., & Konstantinova, A. N. (2019). E-government: Dynamics of mutual actions of the state and Russian society in the XXI century. *Power, 27*(3), 57–62.
13. Pavlyutenkova, M. Yu. (2016). Electronic ruler STVO as a vector of innovative state transformations in Russia. *Bulletin of the Russian Peoples' Friendship University. Series: Political Science, 4*, 121–129.
14. Polozhikhina, M. A. (2017). Electronic government: The experience of the West and Russia. *Russia and the Modern World, 1*(94), 182–196.

15. Laizah, S. M., & Tiko, L. (2021). Conceptualizing the integration of eHealth with eGovernance in a developing country. *Information Resources Management Journal, 34*(3), 64–78.
16. Kamau, G., & Wausi, A. (2015). Evaluating the public value of eGovernment services. In *2015 IST-Africa Conference*. https://doi.org/10.1109/istafrica.2015.7190554.
17. Moore, M. H. (2021). Creating public value: The core idea of strategic management in government. *International Journal of Professional Business Review, 6*(1), 219. https://doi.org/10.26668/businessreview/2021.v6i1.219.
18. Castelnovo, W. (2013). A stakeholder-based approach to public value. *Paper Presented at the 13th European Conference on eGovernment ECEG 2013.*
19. Pazmiño-Sarango, M., Naranjo-Zolotov, M., & Cruz-Jesus, F. (2021). Assessing the drivers of the regional digital divide and their impact on eGovernment services: Evidence from a South American country. *Information Technology and People*. https://doi.org/10.1108/ITP-09-2020-0628.
20. Scott, M., DeLone, W., & Golden, W. (2016). Measuring eGovernment success: A public value approach. *European Journal of Information Systems, 25*(3), 187–208. https://doi.org/10.1057/ejis.2015.11.
21. Ndou, V. (2004). E-government for developing countries: Opportunities and challenges. *The Electronic Journal of Information Systems in Developing Countries, 18*. http://akgul.bilkent.edu.tr/unpan/UNPAN018634.pdf.
22. Pang, M.-S., Lee, G., & Delone, W. H. (2014). IT resources, organizational capabilities, and value creation in public sector organisations: A public-value management perspective. *Journal of Information Technology, 29*(3), 187–205.
23. Sánchez-Bayón, A., & Trincado Aznar, E. (2021). Rise and fall of human research and the improvement of talent development in digital economy. *Studies in Business and Economics, 16*(3), 200–214. https://doi.org/10.2478/sbe-2021-0055.
24. Gill, S. (2020). Future framework of eGovernance architecture: A structural equitation modeling perspective. *Indian Journal of Science and Technology, 13*(36), 3754–3761. https://doi.org/10.17485/ijst/v13i36.1596.
25. Arvanitis, S., & Loukis, E. N. (2009). Information and communication technologies, human capital, workplace organization and labour productivity: A comparative study based on firm-level data for Greece and Switzerland. *Information Economics and Policy, 21*(1), 43–61. https://doi.org/10.1016/j.infoecopol.2008.09.002.
26. Chu, P. Y., Lin, Y. L., Hsiung, H. H., & Liu, T. Y. (2006). Intellectual capital: An empirical study of ITRI. *Technological Forecasting and Social Change, 73*(7), 886–902. https://doi.org/10.1016/j.techfore.2005.11.001.
27. Huff, R. F. (2011). Measuring performance in US municipalities: Do personnel policies predict system level outcomes? *Journal of Comparative Policy Analysis: Research and Practice, 13*(1), 11–33. https://doi.org/10.1080/13876988.2011.538535.
28. Vogt, W. P., & Johnson, B. (2016). *The Sage dictionary of statistics & methodology: A nontechnical guide for the social sciences*. SAGE.
29. Jansen, A. (2012). The understanding of ICTs in public sector and its impact on governance. In *Lecture Notes in Computer Science* (pp. 174–186). https://doi.org/10.1007/978-3-642-33489-4_15.

Open Engineering Education Tools in the Context of Education 4.0

Karim Ismagilov, Andrey Vlasov, Alexey Karpunin, Alexey Kurnosenko, and Anastasia Strukova

Abstract The article examines the impact of Open Engineering Education on the digital transformation of the social sphere. We focus on the methods of Open Engineering Education as a tool to eliminate interregional inequality and provide universal access to educational resources through its digitalization. The paper analyzes how the trends in the digitalization of education affect the development of its infrastructure within Education 4.0. We propose the concept of Open Engineering Education, which implements individual learning paths, and formulate recommendations on adapting teaching practice to changing requirements in the context of Education 4.0.

Keywords Industry 4.0 · Education 4.0 · Engineering education · Digitalization

1 Introduction

Digital transformation of the economy implies both industrial and social changes. High labor mobility and regional inequality as the context for the modern labor market formation underlie the new requirements in education [1]. Challenges of Industry

K. Ismagilov
Carleton University, 1125 Colonel By Drive, Ottawa, ON K1S 5B6, Canada
e-mail: karimismagilov@cmail.carleton.ca

A. Vlasov (✉) · A. Karpunin · A. Kurnosenko
Bauman Moscow State Technical University, 5 2-Baymanskaya Street, Moscow 105005, Russian Federation
e-mail: vlasov@iu4.ru

A. Karpunin
e-mail: alexk811@yandex.ru

A. Kurnosenko
e-mail: akurn@bmstu.ru

A. Strukova
Moscow State Linguistic University, 38/1 Ostozhenka Street, Moscow 119034, Russian Federation
e-mail: anastrand14@yandex.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_33

4.0 [2] have resulted in the emergence of a new educational concept, i.e., Education 4.0. Today's model of Education 4.0 is based on such components as personalization of learning, expanding open education opportunities, the use of digital educational tools, project-based learning and mentoring, simple, accurate and adequate evaluation, availability of analytical data and information resources, etc. [3, 4]. Amid digital transformation, it is of high necessity to alter the teaching practice in terms of creativity, communications and end-to-end informatization considering the individual characteristics of students and demands of the industry.

Open education is one having no strict academic requirements for admission to educational institutions, but with flexible individual learning paths adopted online [5, 6].

To ensure the effective functioning of open education tools as components of digital transformation of the social sphere, a number of prerequisites need to be met [7, 8], including an appropriate level of IT literacy and supranational language expertise (communication tool) among students. In addition, a wide range of potential users should have access to the Internet. As a result, the dynamic development of the regional digital environment requires the unity of communication means (linguistic), an accessible digital infrastructure for data transmission, and a sufficient level of IT literacy among users. The current digital eco-environment suggests encapsulating the methods of ecology, social policy and state and corporate governance into a single digital living space. Equal access to information, technology and infrastructure throughout the country and through them to educational resources is a necessary condition for successful development in the context of digital transformation.

The purpose of the article is to systematize and generalize the trends in digital transformation of education and, on this basis, to form the concept and tools of an open system for training engineering personnel.

The objectives of the study are to formulate the concept and approach to the implementation of tools that ensure the effective functioning of a multiservice information-educational environment for Open Engineering Education.

The proposed concept establishes the general functional features of a typical system of Open Engineering Education: *accessibility*, that is the ability to identify and access educational components from one remote location and deliver them to many others; *adaptability*, that is the ability to adapt training to individual and corporate needs; *cost-effectiveness*, that is the ability to increase efficiency and productivity by reducing the cost and time required to provide distance learning; *durability*, that is the ability to withstand technological developments and changes without extra costs incurred in redesigning, reconfiguring and changing the source code; *compatibility*, that is the possibility to take an educational component developed in one system with one set of tools and platforms and use it in another system with a different set of tools and platforms; *reusability*, that is the flexibility to attach an educational component multiple times in different applications and contexts.

The toolkit of Open Engineering Education systems aims to provide delivery, tracking and reporting on educational program management, management of user learning progress and user actions.

The first part of the work provides an overview of solutions in the field of Open Engineering Education and analyzes the trends in the development of educational technologies starting from Education 1.0 to Education 4.0. We demonstrate the relationship between the elements of Education 4.0 and the trends in Industry 4.0 and investigate the key methods and technological tools of digitalization of education. Based on the results of systematization and generalization, we develop a problem-modular approach to the implementation of the main tools and services of Education 4.0, which deals with technological and methodological aspects of modern education. In conclusion, the paper analyzes the experience of implementing Education 4.0 technologies on the basis of a technical university and gives recommendations for further development of the components of the digital educational environment, both from the standpoint of the use of modern digital technologies and modern teaching methods and techniques aimed at shaping 'creative' personal growth.

2 Literature Review

In the context of digital transformation of the economy, it is worth noting a number of trends, such as the growing need of rapidly developing digital industries for engineering specialists and providing parallel advanced training programs for the staff of educational institutions capable of working in the context of the end-to-end application of digital technologies [9]. Under Industry 4.0, social transformation leads to a decrease in the total number of jobs and changes their nature [1]. Currently, professional requirements for specialists are increasingly affecting the IT sphere and digital literacy is becoming a mandatory criterion for professional development [7]. All this poses new challenges to the workplace skills and competencies of the digital production staff.

Education 4.0 [4, 10] is another social component of the overall digital transformation, along with Medicine 4.0, Business 4.0, etc. Interpretations of the term 'Education 4.0' vary significantly: from basic educational components (educational content, didactics, pragmatics, teaching methods) presented in the form of a 'cube of opportunities' to direct comparison with the methods and tools of the Fourth Industrial Revolution. Many researchers believe this concept covers not only new technological opportunities, but also methodological and educational tools. It is still difficult to judge the completeness and correctness of certain approaches. Typically, Education 4.0 is a kind of 'philosophy of the future' that stimulates practical learning and teamwork, as well as the use of distributed sources of data, cloud storage and other advanced digital technologies. All this is combined into the so-called learning factories [10].

Education 4.0 involves not just cybertechnologies integrated into the learning process, but the formation of a unified social-educational cyberenvironment focused on solving both educational and social problems of society [11]. Cybertechnologies (technologies that combine computing (sensor networks, the Internet, social networks, cloud services, etc.) and physical components) form new global value chains with an emphasis on individualization, product digitalization and production flexibility [7].

On the one hand, Education 4.0 corresponds to new methodological approaches, and on the other, it implies new technological opportunities [11–13]. It is difficult to say which is primary and which is secondary. New technologies create new opportunities, but their effectiveness is dependent on new methodological techniques used. It can be stated that the core of the open education system at the present stage is the digital learning environment (DLE), which has experienced an active development since Education 2.0. Such an environment is an information and software complex for vocational training of specialists, in which knowledge and skills are formed through general access to distributed knowledge resources [11, 14].

The cornerstone of Education 3.0 was student-centered learning technologies [15]. Their implementation was based on online technologies and services accessed by the general public, which underlay the creation of distributed tools for implementing personalized learning technologies. Through these technologies, students were able not only to access the resources of university clusters, but also independently construct self-education routes, thereby creating a personal mobile learning environment.

In the era of the digital economy, engineers should have practical skills in using research and technological equipment, as well as be experienced in independent design and production activities, which is attained by introducing project-oriented learning methods [16–21].

DLEs can be categorized into two groups: open environments (without feedback) and closed environments (with feedback) [22, 23]. The delivery of educational content in the first group does not depend on the degree it is assimilated. A significant event in this approach is the adherence to a given algorithm for completing the educational module. In closed DLEs, a significant event is the level of knowledge obtained at a certain step of the learning algorithm. Upon completion of every educational stage, students are supposed to assess their knowledge by passing control tests that can consist of both open-ended and closed-ended (multiple choice) questions. All test results are recorded and an assessment is formed, which is part of a comprehensive evaluation of the knowledge gained.

Simulation modeling tools [24] make it possible to widely use the opportunities of modeling real situations in various subject areas. In addition to solving model problems, students can have an opportunity to use various training systems. Such tools allow for actively using various business games and project-based methods in the distributed learning process [25]. Such adaptive DLEs implement a comprehensive interactive approach to learning. For example, *BridgetoEnglish* is one of the digital tools forming language skills adequate for communication. Created in the UK for professional use, it has proven itself over the years. The product contains listening exercises, crossword puzzles, dialogues, spelling tests, classical grammar and vocabulary exercises, pronunciation and grammar guides, dictionaries, etc. All texts are provided with native speaker's pronunciation, and nearly every sound is recorded in both male and female voices. Classes are built on a modular basis. There exist other similar systems that, owing to numerous methodological techniques and a strict

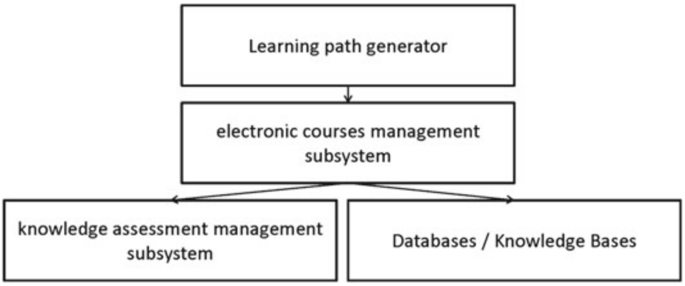

Fig. 1 Typical structure of a problem-modular DLE

performance assessment system, have proven to be effective for learning Romance languages [26].

Given the modern requirements for DLEs, it is obvious that closed learning systems offer the best opportunities. Let us scrutinize the principles of implementing a typical closed DLE with elements of problem-modular learning for the purposes of Open Engineering Education [16, 22].

DLEs can be classified according to their algorithmic structure. When using linear DLE algorithms, a student is provided with DLE in-built blocks. The advantage of such DLEs is their relative simplicity. Among their disadvantages are difficulties with covering complex topics with wide semantic links and problems with building a complex route with a guarantee of studying all individual sections of the subject area.

Non-linear DLEs give an opportunity to dynamically adjust the path for studying individual sections based on student's reaction, which is recorded by feedback tools. In these systems, the main situational element is the student's decision made in a particular node of the learning algorithm. Non-linear educational algorithms are divided into directed, cyclic, and combined.

Figure 1 presents a typical structure of a problem-modular DLE and its components.

An e-learning course is a set of didactic units that provide information and content of the learning course (lectures, reference books, class assignments) [16].

Computer testing subsystems are software modules evaluating the current level of user competence through pedagogical computer tests [12].

Databases/knowledge databases are sets of user data, learning strategies, e-learning course structures, etc. stored in e-learning systems [14].

The learning path generator is a subsystem that corrects (adapts) the DLE work to guarantee the best learning effect and create an individual learning route [13].

Such a modular structure of modern DLEs allows one to forge problem-oriented learning paths (including individual ones). These learning systems have a certain structure based on a conceptual unity that allows revealing new knowledge through the existing one, forming semantic links between them and, as a result, formulating an idea of the whole subject area under study.

It can be stated that the main goal of global digitalization of the eco-environment is to accelerate production relations and reduce overall labor intensity. The formation of a global digital space blurs national boundaries, accelerates innovation, allows the exchange of new technologies and, consequently, changes the structure of the labor market [1, 9, 11]. In such an environment, highly qualified IT-specialists come to the fore [7].

Recently, there has emerged a large number of different educational systems acting as the basis for distributed e-learning. However, despite certain achievements, the development of open education methodological tools remains an urgent task. There is a need for a unified, comprehensive concept of Open Engineering Education adapted to regional characteristics and individual learning paths and aimed at the implementation of problem-modular and project-based technologies. A new conceptual form of problem-modular learning organization needs to be established that expands, supplements and increases the effectiveness of traditional open education forms. Resolving this problem is of crucial importance since today's negative challenges (international restrictions, pandemics, underdevelopment of communications, etc.) lead to stagnation and interregional inequality. The widespread use of e-learning systems implementing open education systems and engineering education, in particular, as the most project-intensive one, is aimed at achieving the goals of The Same Country—the Same Opportunities trend.

One of the fundamental components in the formation of a modern and effective open system for training engineers is the material-technical and technological (instrumental) infrastructure of the learning process and problem-modular training model based on it.

3 Material and Methods

Consider the main methods and models for implementing DLEs. A classical DLE is constructed using network, interactive and multimedia technologies [14, 23] that allow applying various communication means and techniques (verbal and non-verbal). This combination affects the special manner of information perception by all participants in the open education process, taking into account the emotional coloring and all sensory channels: auditory, visual, kinesthetic, etc. This makes the learning materials as visual as possible and, therefore, easily understandable and memorable. In addition, one of the most important advantages of DLEs is interactivity, which allows one to keep working in an interactive mode.

Among the significant parameters of DLEs are communicativeness, accessibility, distribution, and modernity of the knowledge component. Modern DLEs include distance research workshops and simulation modeling modules, including through the use of Digital Twins technologies [24]. DLEs also cover control subsystems, such as adaptive ones, which combine periodic control and learning from simple to complex [12, 13].

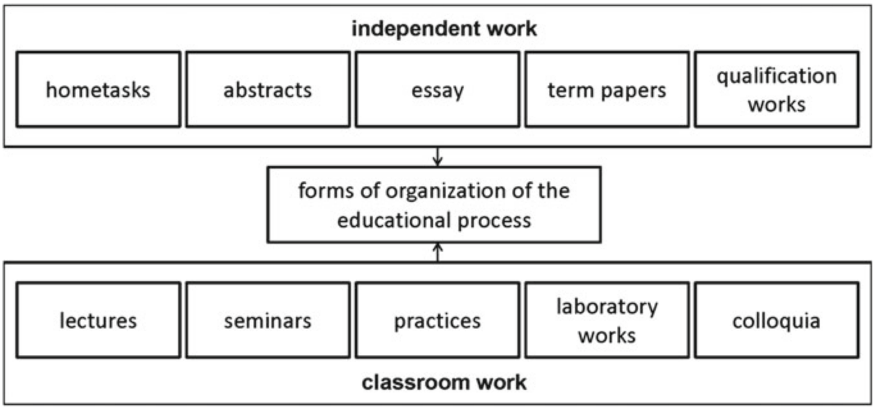

Fig. 2 Organizational forms of the educational process

With the introduction of digital transformation elements, learning management systems (LMSs) have become the predominant systems of open education, where the emphasis is put on managing the content of learning programs and administrative support (lectures, chats, task management, etc.). Blackboard [27] and Moodle [14] are some of the most popular platforms.

Using the Blackboard learning system, educators can post learning materials, course information, reference books, and home tasks. The system also provides features for student–teacher communication and other collaboration tools. The Moodle system (Modular Object-Oriented Dynamic Learning Environment) is an open source learning management system designed to provide the best experience for learners and an unparalleled level of data security. Moodle users can use the system in the cloud or on a server. The cloud platform MoodleCloud is quick to set up, easy to scale, and has many standard features available for instant use. The structure of the learning process on this platform is shown in Fig. 2.

All learning materials are a single knowledge database, which stores all the information on different courses. It also encompasses the elements indirectly related to educational materials, such as style requirements, tests, a full set of questions and answers to independent tasks, etc. The special features of the learning system make it possible to differentiate one educational material from another and not change the overall structure of the course.

To assess the effectiveness of these technologies and tools in the implementation of DLEs, statistics on the implementation of corporate training for a distributed group of specialists (electronics manufacturers) at the training center of Bauman Moscow State Technical University are summarized. Statistical data were obtained as a result of testing study groups at various stages of the educational process and surveying students. The resulting sample is subjected to further processing using statistical methods, the Delphi method, etc.

The capabilities of the LMS model allow one to fine-tune the architecture of the learning course to the needs of the educational process. The availability of materials can be controlled by the role-based access model, have date and time limits, as well as be restricted once a particular task is done. For instance, the access to the second lecture may be limited until the student has studied the first one and completed the corresponding tasks. It instills discipline and compels students to study the course materials.

The implementation of Open Engineering Education based on the above solutions covers a wide range of potential users. Such solutions are intrinsic to modern engineering education, distributed corporate learning systems and local professional development activities. Modern digital technologies blur boundaries and make knowledge accessible regardless of the user's location or other restrictions.

4 Results

The educational system, viewed as Education 4.0, requires a constant connection to the data transmission medium, human participation and decentralized decision-making. The major tools of Education 4.0 are cyber-physical systems (CPSs), virtual and augmented reality, cloud computing, big data analysis, etc. [28–30]. Digital tool manufacturing technologies in Industry 4.0 create a new type of factory of the future, namely smart factories [9]. Such factories pose new challenges for the training of specialists, their regional distribution and independence. It can be stated that it is human resources that are becoming the main resource of digital transformation [15].

Modern educational technologies are transforming and changing. They are becoming increasingly important for overcoming social and regional inequality and for creating a single distributed professional eco-environment.

Problem-modular project-based learning is a learning system in which teachers create problem situations and encourage students to be active and independent in resolving them, thereby creatively acquiring knowledge, skills and abilities [19, 22]. At that, at all stages of the educational process, students receive information in accordance with a certain route-module.

Analyze the main tools of problem-modular project-based engineering education that implement the provisions of Education 4.0. They are divided into organizational, methodological, and technical. In problem-modular learning, a module is a relatively integral structural unit of information, activity, process or organizational-methodological structure that make up the discipline.

To ensure the accessibility of open education in the context of a problem-modular learning system, the modules need to be divided into discipline submodules. The proposed hierarchical structure of the learning materials is presented in Fig. 3.

A small amount of learning materials in the discipline submodule gives students the impression of a simple task that can be solved without spending a lot of time. This encourages them to study the next submodules. Discipline submodules are arranged in a logical sequence, and the previous submodules serve as a source of initial data

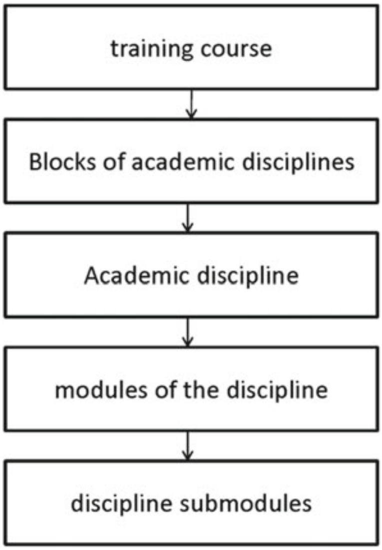

Fig. 3 Hierarchical structure of the learning materials

for the subsequent ones. Routing of initial data combined with the elements of adaptive testing ensures the continuity of educational materials and the assimilation of accumulated knowledge by students [13, 15].

Submodules are filled with multiplicative resources for collective use, developed using information technology and providing not only accessibility, but also variability. Such resources include visualized thematic dictionaries of terms and definitions based on the individual perception of ideas [16], educational software with user-friendly interfaces that do not need prior user training [23], libraries, video libraries, databases and search subsystems with direct navigators, etc. [5, 27, 30].

The predominance of laboratory and practical classes and project activities is typical of engineering education [15]. Project-based methods for performing practical work using social communication tools make it possible to effectively apply group (team) forms of training to technical disciplines, in which the process of fulfilling production tasks models and the system of industrial relations are impossible to explain to students using only oral presentation of the course material [15–21]. Figure 4 shows the methodology of the traditional approach to the implementation of practical term paper. Unlike the traditional one, the implementation of project-module training creates an industrial atmosphere, implements teamwork, situational decision-making, collective distribution of roles, simulated production situations that are as close as possible to real ones [25]. This approach creates conditions for the development of individual and leadership qualities of all participants in the project activity. To create teams, random or specifically selected methods are used. Students can be divided into teams by mentors or form a team independently based on their interpersonal relationships, group leaders or areas in which they better understand each other's ideas about terms and definitions of the subject-specific vocabulary. Teamwork produces the greatest effect when students from different countries are

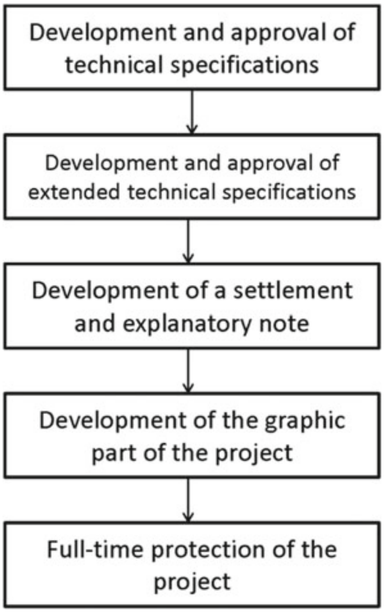

Fig. 4 Schematic representation of the traditional approach to writing and defending course papers

involved in it. Through joint activities, they form a common supranational worldview and project-related culture.

One of the main elements of modular education is a system for monitoring and evaluating student performance [12]. Practical work is evaluated according to the criteria of effectiveness and readiness of the practical object. Learning outcomes are assessed using various educational standards and pedagogical evaluation systems; measurement scales are recalculated. Course papers are evaluated using complex criteria.

Generally, when implementing open education technologies, the methods of adaptive testing demonstrate the greatest effectiveness. While forming a learning route, adaptive testing is aimed at dealing with training objectives in the first place, and only then evaluation ones. This approach helps students absorb information and is less related to disciplinary functions, i.e., is more humane. Knowledge evaluation in DLEs is performed for various purposes. The relationship between knowledge assessment methods in DLEs is shown in Fig. 5.

To create a learning profile, students should pass an entry assessment in order to determine the incoming level of their competence and choose a path that will correspond to their abilities and be comfortable in learning. Pre-testing is carried out once individual sections (modules) for identifying the incoming knowledge level are completed. Current assessment provides control in the process of performing current assignments. Intermediate testing is usually undertaken to assess knowledge during intermediate performance reviews (modules). The final assessment (performance review, external testing, exam) is carried out after the completion of the discipline.

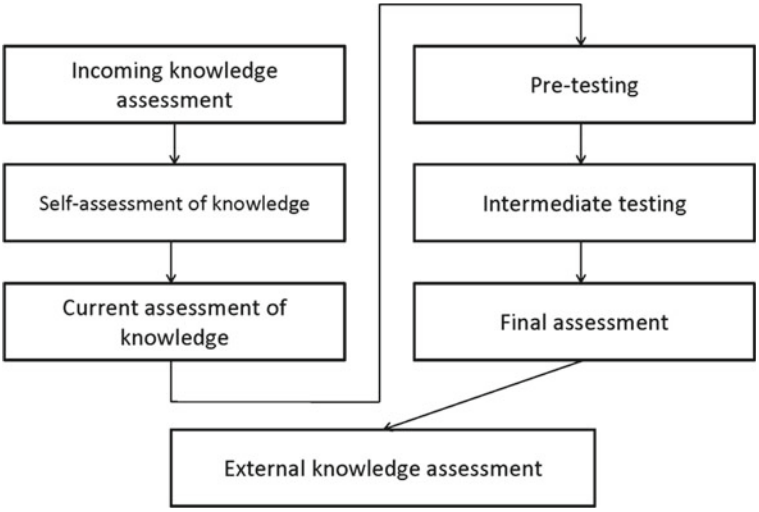

Fig. 5 Knowledge assessment methods in DLEs

To check the adequacy of mastering educational programs, it is highly advisable to conduct an external assessment of learning outcomes (mastering a block of disciplines, etc.), for example, evaluation procedures in internationally recognized organizations, such as Thomson Prometric, VUE, CatGlobal-Promissor, etc. As a result, upon graduation, the student will have not only a diploma, but also a number of recognized international certificates in certain specialities. This approach allows assessing both the quality of mastering educational programs by students and the quality of the entire educational process. The more certified specialists graduate from an educational institution, the better it is adapted to rapidly changing market conditions and industry demands.

The main element of project activities is course projects. Within the open education system, their implementation is unconventional. However, this project activity can also be effectively realized through modern systems of project management and version control including in the framework of group projects. The traditional method of writing and defending a course paper lies in consulting with the research advisor and designing the sections of the work. Once the paper is completed, the advisor looks it through and gives corrective advice, checks the corrected version and, if necessary, writes additional recommendations. After that the student defends the course paper in front of the examination board. With this form of training, it is difficult to distinguish between the contribution of the student and the teacher to the work performed and objectively assess the level of the student's knowledge and skills. In essence, it is assessed how the student defends their work and answers to the questions. The traditional approach to writing and defending course papers is shown in Fig. 4.

When implementing project-based methods in open education, practical work is evaluated according to five main criteria: topic complexity (three levels of complexity), completion period of the course paper, the content of the engineering analysis notes in accordance with the guidelines, the compliance of the engineering analysis notes with style recommendations, the compliance of graphic elements with requirements, defense of the course paper. At that, it is defended 'invertedly'. The student writes all parts of the course paper based on the advisor's recommendations and in accordance with the writing and style guidelines. During the defense, the examination board evaluates the student's ability to present their work, the content and correctness of answers to the questions, and the research advisor assesses the content and compliance with the guidelines' requirements.

The analyzed methodological tools of open education are impossible to realize without an effective management environment. Lately, the SCORM (Sharable Content Object Reference Model) standard—a set of rules for organizing work with educational materials—has become widespread in the construction of integrated learning systems. The developed generalized architecture of a SCORM-based learning system is shown in Fig. 6.

The SCORM standard determines what types of service functions should be present in order to handle a certain problem of organizing learning materials, how these functions can be interconnected and how they can be used. The SCORM core is the learning management module. Its architecture is a set of services, each of which has a specific functionality aimed at delivering, tracking and reporting on the management of the educational process and materials, tracing learning progress and user actions.

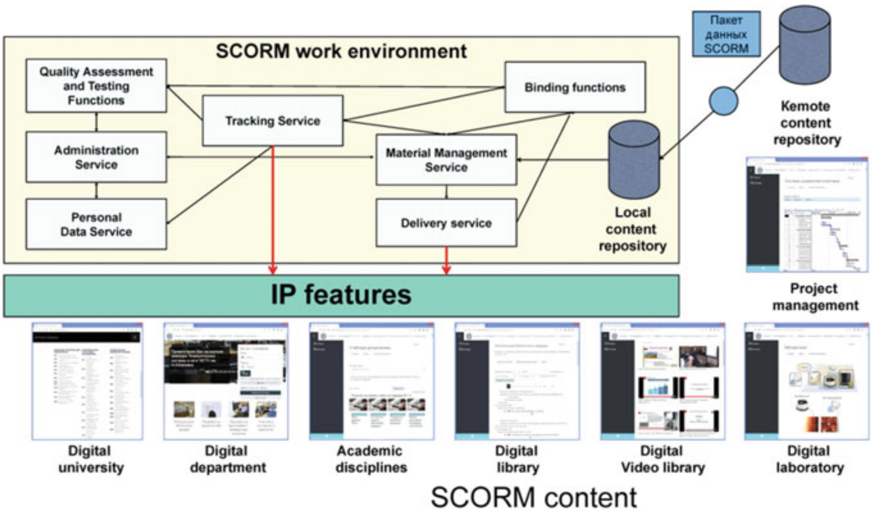

Fig. 6 Generalized learning management architecture in a DLE

The SCORM standard allows focusing on the mechanisms of interaction (interfaces) between the learning materials and the functional work environment. This makes it possible to create a set of one's own learning management services with unique competitive implementation. At that, the requirement that SCORM modules from different developers should be compatible is preserved.

In SCORM, the learning process is managed through the client–server architecture, which provides an opportunity to operate and deliver material to the user. According to SCORM, the DLE core determines what to deliver and at what time, and tracks the progress and performance of the user while they are learning.

Based on the results of research, a concept and approach to the implementation of distributed DLE tools are proposed, which differ from the existing alternatives in the problem-modular paradigm of educational services and personalized learning paths with the elements of adaptive testing and predictive analysis, which ensure the effective functioning of the multiservice information-educational environment of Open Engineering Education.

5 Discussion

Open Engineering Education tools have a significant effect on digital transformation of the social sphere as a whole. In the context of digital transformation, the combination of a problem-modular approach and modern digital tools allows forming a new type of educational technology, that is, smart education [3]. Smart education carries a high social connotation. It implies free access to knowledge, an individual approach to every student, and cross-learning of vocational communities.

To evaluate the effectiveness of the proposed DLE technologies and tools and implement them, the results of corporate training for a distributed group of specialists (electronics manufacturers) were qualitatively analyzed. The survey results were processed using statistical data processing procedures. At the initial stage, incoming competence evaluation tests were used. Three independent groups of students (with varying sizes and from different companies) were tested. 60–70% of the participants from the first group (8 people) gave correct answers to the questions of the basic tests (basic knowledge of the subject area). In the second (15 people) and the third (6 people) groups, the share of correct answers amounted to 70–80% and 80–90%, respectively. The results are given in Fig. 7.

Among the main characteristics of DLE implementation are labor intensity, complexity, novelty, level of methodological support, and consistency. The characteristics were assessed in relative units on a scale from 1 to 5, depending on the students' incoming competence in each individual group (Fig. 8).

To assess how dependent the labor intensity of learning materials is on the incoming competence, each group were tested independently.

Figure 9 presents the correlation between the complexity of learning materials and the incoming competence, and Fig. 10 shows the correlation between the novelty of learning materials and the incoming competence.

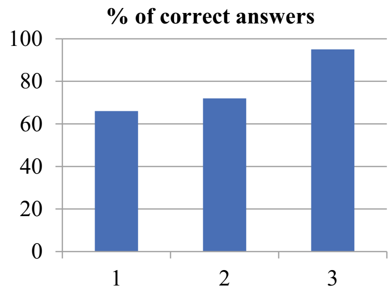

Fig. 7 Results of incoming competence evaluation tests for the three groups of students

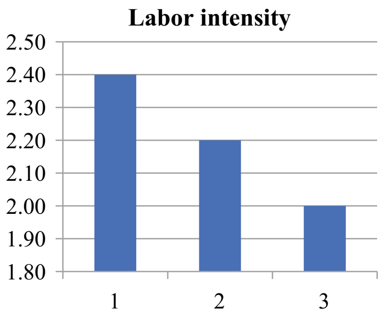

Fig. 8 Correlation between the labor intensity of learning materials and students' incoming competence

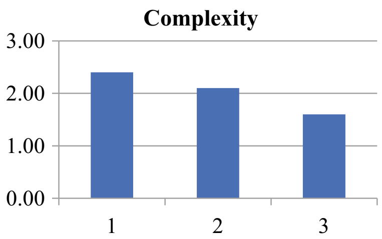

Fig. 9 Correlation between the complexity of the learning materials and the groups' incoming competence

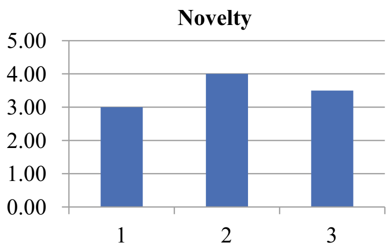

Fig. 10 Correlation between the novelty of the learning materials and the groups' incoming competence

The dependence of the methodological support level on the incoming competence is shown in Fig. 11, and the dependence of the consistency of learning materials on the incoming competence is shown in Fig. 12.

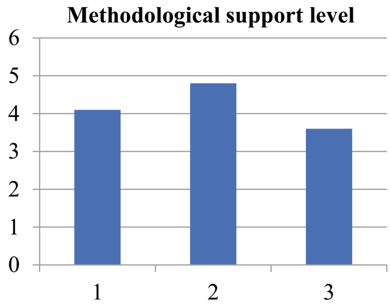

Fig. 11 Correlation between the methodological support level and the incoming competence

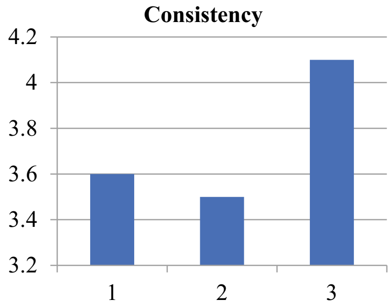

Fig. 12 Correlation between the consistency of learning materials and the incoming competence

In order to make the most of the DLE functionality and improve the learning process when integrating courses into DLEs, it is necessary to use a variety of types of educational materials and methods of their presentation (interactive lectures, business games, team tasks, etc.). The integration outcome also depends on the correct use of various open education tools, both technological and methodological, as well as the way the curriculum is formalized.

The formalization method chosen correctly allows one to comprehensively analyze the training course for the subsequent integration of its learning materials into the DLE and to use the DLE functionality to the maximum.

6 Conclusion

The ever-increasing requirements for labor mobility in the context of digital transformation determine the need to introduce new digital technologies for knowledge transfer. Open education technologies and tools, along with smart factories, digital twins, smart social environment, etc., are the basis for dealing with digital transformation problems holistically.

Creating a unified learning environment is crucial for an effective digital living space, whether it is a region, a municipality or an enterprise. It underlies the sustainable development of production activities, which implies a responsible environmental attitude, high social responsibility and highly skilled human resources. When adopting investment plans, world industrial leaders account for the state of the training sector and its impact on the regional social environment in the first place. Education is among the fields having the greatest influence on the trends in the sustainable development of the social environment. The trends of 'ubiquitous learning and end-to-end knowledge exchange', testing and predictive formation of routes for each student taking into account the principles of sustainable development of their professional activity form a knowledge-based eco-environment. The evolution of any region should meet development standards in three categories—social, managerial and environmental—both in industry and education.

The proposed solution for creating a SCORM-based multiservice educational platform using the methodological and technological tools of Open Engineering Education allows one to track the unfolding digital transformation. The developed generalized architecture of educational management in the DLE can be used to prepare, analyze and enhance the unity of the educational environment, reduce interregional inequality and increase labor mobility. The effective methodological and technological tools of Open Engineering Education applied within Industry 4.0 make it possible to create prerequisites and forecast the development paths of the industrial digital revolution.

Acknowledgements The results were partially obtained within the project «U2U» under the Development Program of Bauman Moscow State Technical University as part of the Priority-2030 federal academic leadership program.

References

1. Akberdina, V. V., Tretyakova, O. V., & Vlasov, A. I. (2017). A methodological approach to forecasting spatial distribution of workplaces in an industrial metropolis. *Problems and Perspectives in Management, 15*(4), 50–61.
2. Ovinova, L. N., & Shraiber, E. G. (2019). Pedagogical model to train specialists for Industry 4.0 at university. *Perspectives of Science & Education, 39*(4), 448–461. https://doi.org/10.32744/pse.2019.4.34.
3. Selyanskaya, G. N. (2015). SMART university as the response to challenges of the new industrial revolution. *Creative Economics, 9*(9), 1151–1164. https://doi.org/10.18334/ce.9.9.1928.
4. Smolyaninova, O. G., & Bezyzvestnykh, E. A. (2019). Professional training of Teacher 4.0: Developing digital competency by means of ePortfolio. *Journal of Siberian Federal University. Humanities & Social Sciences, 12*(9), 1714–1732. https://doi.org/10.17516/1997-1370-0478.
5. Hooshyar, D., Pedaste, M., Saks, K., Leijen, Ä., Bardone, E., & Wang, M. (2020). Open learner models in supporting self-regulated learning in higher education: A systematic literature review. *Computers & Education, 154*, 103878.
6. Mkrttchian, V., & Brandt, D. (2005). Open distance education: A technological approach within social perspective. In *IFAC Proceedings Volumes (IFAC-PapersOnline)*, IFAC 2005 (pp. 178–181).

7. Aleksandrov, A. A., Fang, K., Proletarsky, A. V., & Neusypin, K. A. (2012). Conception of complex continuous education with innovative information technologies. In *Proceedings of the 2nd International Conference on Education and Education Management. S. "Advances in Education Research"* (pp. 374–378). Academic Press.
8. Cao, Y., Kirilova, G. I., & Grunis, M. L. (2017). Cooperative research projects of master's students (education programs) in the open informational educational environment. *Eurasia Journal of Mathematics, Science and Technology Education, 13*(7), 2859–2868.
9. Juravleva, L. V., Kurnosenko, A. E., Lysenko, O. A., & Vlasov, A. I. (2021). Trend analysis in the development of factories of the future, taking into account digital transformation of active systems. In *ACM International Conference Proceeding Series, DEFIN 2021* (Vol. 4). https://doi.org/10.1145/3487757.3490881.
10. Chaka, C. (2022). Is Education 4.0 a sufficient innovative, and disruptive educational trend to promote sustainable open education for higher education institutions? A review of literature trends. *Frontiers in Education, 7*, 824976. https://doi.org/10.3389/feduc.2022.824976.
11. Aleksandrov, A. A., Neusipin, K. A., Proletarsky, A. V., & Fang, K. (2012). Innovation development trends of modern management systems of educational organizations. In *Proceeding of 2012 International Conference on Information Management, Innovation Management and Industrial Engineering*, Sanya, China, 25 October 2012 (pp. 187–189). IEEE, Sanya, China.
12. Drobyshev, D. V., Neusypin, K. A., & Tsibizova, T. Y. (2019). Distance education in the training system of highly qualified personnel. In *AIP Conference Proceedings. International Scientific and Practical Conference "Modeling in Education 2019"*.
13. Tsarev, R. Y., Yamskikh, T. N., Evdokimov, I. V., Prokopenko, A. V., Rutskaya, K. A., Everstova, V. N., & Zhigalov, K. Y. (2019). An approach to developing adaptive electronic educational course. *Advances in Intelligent Systems and Computing, 986*, 332–341. https://doi.org/10.1007/978-3-030-19813-8_34.
14. Pisarev, A. V. (2011). Possibilities of the educational platform Moodle in teaching information technology. *Science Journal of Volgograd State University. Series 6. University Education, 13*, 70–73.
15. Juravleva, L. V., Shakhnov, V. A., & Vlasov, A. I. (2020). Adaptation of professional engineering training to the challenges of modern digital production. In *Advances in intelligent systems and computing* (Vol. 1134, pp. 623–633). https://doi.org/10.1007/978-3-030-40274-7_59.
16. Juravleva, L. V., Shakhnov, V. A., & Vlasov, A. I. (2019). Visual environment of cognitive graphics for end-to-end engineering project-based education. *Journal of Applied Engineering Science, 17*(1), 99–106.
17. Yudin, A., Kolesnikov, M., Vlasov, A., & Salmina, M. (2017). Project oriented approach in educational robotics: From robotic competition to practical appliance. In M. Merdan, W. Lepuschitz, G. Koppensteiner, & R. Balogh (Eds.), *Robotics in education. Advances in intelligent systems and computing* (Vol. 457, pp. 83–94). https://doi.org/10.1007/978-3-319-42975-5_8.
18. Yudin, A., Salmina, M., Sukhotskiy, V., & Vlasov, A. (2019). Challenging intensive project-based education: Short-term class on mobile robotics with mechatronic elements. *Advances in Intelligent Systems and Computing, 829*, 79–84.
19. Yudin, A., Vlasov, A., Salmina, M., & Sukhotskiy, V. (2022). Educational robotics: Methodological considerations and practice of mechatronics. In *Lecture notes in networks and systems* (Vol. 515, pp. 63–77).
20. Yudin, A., Vlasov, A., Shalashova, M., & Salmina, M. (2020). Evolution of educational robotics in supplementary education of children. *Advances in Intelligent Systems and Computing, 1023*, 336–343. https://doi.org/10.1007/978-3-030-26945-6_30.
21. Yudin, A., Zatekin, D., Lapshinov, S., & Vlasov, A. (2021). Educational robotics: School to university, examples of interconnected longitudinal individual student routes. *Studies in Computational Intelligence, 982*, 202–215. https://doi.org/10.1007/978-3-030-77022-8_18.
22. Juravleva, L. V., Shakhnov, V. A., & Vlasov, A. I. (2019). Concept of automated support to problem: Modular vocational training. In E. Smirnova & R. Clark (Eds.), *Handbook of research on engineering education in a global context* (pp. 101–114). IGI Global. https://doi.org/10.4018/978-1-5225-3395-5.ch010.

23. Smirnova, E., & Titov, I. (2013). Network architectures of remote laboratories proposal of a new solution and comparative analysis with existing ones. *International Journal of Online Engineering, 9*(6), 41–44.
24. Shakhnov, V. A., Kurnosenko, A. E., Demin, A. A., & Vlasov, A. I. (2020). Industry 4.0 visual tools for digital twin system design. *Software Engineering Perspectives in Intelligent Systems, 2*, 864–875. https://doi.org/10.1007/978-3-030-63319-6_80.
25. Aleksandrov, A. A., Kapyrin, P. A., Meshkov, N. A., Neusypin, K. A., Popovich, A. E., & Proletarsky, A. V. (2018). Gamification in the advanced higher professional education: Fundamentals of theory and experience of use. *International Journal of Civil Engineering and Technology, 9*(11), 1800–1808.
26. Strukova, A. A. (2019). Linguocultural glossaries as a tool of developing sociocultural competence. *Bulletin of the Moscow State Linguistic University. Education and Pedagogical Sciences*, *4*(833), 159–170.
27. Rutskaya, K. A., Aronov, A. M., Rutskiy, V. N., Tsarev, R. Yu., Titovskaia, N. V., Zhigalov, K. Y., Bystrova, N. V., & El Amrani, Y. (2020). An activity-based approach to up-skilling teachers who teach engineering of software products. *Journal of Physics: Conference Series, 1515*(2), 022089. https://doi.org/10.1088/1742-6596/1515/2/022089.
28. Da Motta Reis, J. S., Ferreira Costa, A. C., Espuny, M., Batista, W. J., Francisco, F. E., Gonçalves, G. S., Tasinaffo, P. M., Vieira Dias, L. A., da Cunha, A. M., & de Oliveira, O. J. (2020). Education 4.0: Gaps research between school formation and technological development. *Advances in Intelligent Systems and Computing, 1134*, 415–420. https://doi.org/10.1007/978-3-030-43020-7_55.
29. Wallner, T., & Wagner, G. (2016). Academic education 4.0. In *Proceedings of the International Conference on Education and New Developments*, Ljubljana, Slovenia (pp. 155–159).
30. Zimin, V. N., Proletarskiy, A. V., & Sergeev, D. A. (2017). Training of digital economy personnel. *Scientist's Notes, 7*(23), 15–20.

Employee Engagement and Soft Skills in the Digitalization of the Economy. Preliminary Study Results

Aleksandra Revina, Elena Kalabina, and Olga Belyak

Abstract The fast-paced digitalization and automation make hard skills acquired by employees in their academic study programs outdated and irrelevant very fast. Hence, researchers and practitioners have recently demonstrated a growing interest in studying soft skills in various settings, including leadership, education, and training. Additionally, in times of digital transformation, businesses are promoting employee engagement evermore, particularly in the present context of crises and instability. The research intends to investigate this issue from the viewpoint of employee soft skills. We specifically look into the link between employees' soft skills and workplace engagement. While doing our research in two different countries, we distinguish between commercial and non-commercial organizations as well as add an international perspective. Based on an acknowledged European skills framework, we focus our study on such soft skills as teamwork, communication, and conflict management and use recognized surveys to quantify them. We use a well-known Gallup methodology to evaluate employee engagement. Using correlation analysis, we investigate the impact of the three selected skills on employee engagement while considering the organization type and country, factors that may play an important role in the digital transformation of businesses and companies.

Keywords Soft skills · Teamwork · Conflict management · Communication · Employee engagement

A. Revina (✉)
Brandenburg University of Applied Sciences, 50 Magdeburger str., 14770 Brandenburg an der Havel, Germany
e-mail: revina@th-brandenburg.de

E. Kalabina · O. Belyak (✉)
Ural State University of Economics, 62/45 8-Marta/Narodnoy Voli Street, Ekaterinburg 620144, Russian Federation

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_34

1 Introduction

Due to the times of crisis, the global economy is experiencing and the dramatically declining population's purchasing power worldwide, organizations have to search for new ways to stay competitive and survive in the market. At the same time, in the fast-changing market, technology advancements and penetrating digitalization have established themselves as primary drivers of business growth [1]. However, these technologies shape not only businesses but also the workplace, triggering its change. As the new workplace encompasses individuals from different cultural backgrounds, interpersonal communication skills become a must to be able to work efficiently. The workforce's demographics are likewise changing. People of various nationalities, gender identities, and ages, including those close to retirement, actively participate in the work processes. Due to such changes, businesses pay increased attention to soft skills [2].

We further observe that digitalization and automation are increasingly penetrating all sectors of the economy. For example, recently, the so-called Robotic Process Automation (RPA) topic has been rather trendy in research, and at present, it is a daily practice for many businesses. Hereby, robots, commonly known as "bots", interact with software systems by imitating user behaviors, reducing the workload of the human workforce [3] or, in other terms, making many hard skills or even jobs obsolete in many sectors [4]. Predictably, such hard skills as programming have also undergone automation [5, 6]. Hence, relying solely on the skills acquired within an academic qualification is not sustainable.

It becomes natural that scholars and practitioners started to show an increased interest in the research of soft skills in different contexts, for example, information systems (IS) [7], education programs at universities [8], leadership training programs [9], comparative analyzes of the demand in hard and soft skills [10] to name a few. Hereby, the topic of employee engagement, i.e., energy, involvement, and willingness to contribute to organizational success [11, 12], is mentioned in several limited contexts, such as leadership soft skills advantageous for engaging employees [13–15]. Employee engagement can also potentially positively influence the imbalance in the hard skills due to the mentioned job automation. Further, [16] recommends increasing employee engagement by developing soft skills such as leadership, communication, and teamwork. Albeit this seemingly natural relation between the soft skills of employees and their willingness to engage in organizational work, the literature lacks empirical studies investigating the direct relation between employee skills and their engagement.

Thus, motivated by this gap, in our preliminary study, we aim to select and empirically measure soft skills and study their relation to employee engagement, taking into account such factors as the type of organization and different countries. Hence, we pose the following main research question (MRQ): *do employee soft skills influence their engagement in organizations?* Based on this MRQ, we define the following RQs:

RQ1: *how do selected soft skills influence employee engagement*?

RQ2: *does organization type (commercial, non-commercial) influence employee engagement?*

RQ3: *does a country context influence employee engagement?*

In previous studies, soft skills have been suggested as an instrument to increase employee engagement which is also named as a key to corporate success, i.e., higher employee retention, productivity, better customer service, satisfaction, and loyalty, and, as a result, faster growth and higher profits [13–16]. In this study, we also consider which soft skills can potentially influence employee engagement to offer a functioning instrument in Human Resources (HR) management as one of the main success factors in dynamically changing environments.

Accordingly, the scientific contribution of the research is empirical evidence of the relation between selected soft skills and employee engagement which is limited in the existing literature. Several studies mention soft skills among those factors likely influencing engagement. However, they lack detailed theoretically and methodologically grounded empirical research to analyze specific soft skills as factors for employee engagement increase. The practical contribution of the work consists of the following. Organizations can use this knowledge on soft skills to develop targeted training programs for existing employees and include specific questions in interviews and assessment tests in the selection process of potential candidates.

The remainder of the paper is structured as follows. Section 2 provides background information and related work on soft skills and employee engagement research, including theoretical and empirical works. Section 3 presents the methodology of the research. It includes the review of evaluation methods of employee engagement and soft skills. Further, the methods and set of soft skills selected for this study are presented. Afterward, the survey set-up is described. Section 4 presents the data sample and survey results, followed by the discussion and reflection on the research questions. Key conclusions and outlook are provided in Sect. 5.

2 Background

In this section, we provide the theoretical background necessary to understand soft skills and employee engagement research in general and related work serving to identify the gaps in the intersection of these two topics.

2.1 Soft Skills: Definitions and Main Research Directions

Soft skills, a notion getting much traction in recent years, describe personal transversal skills such as social aptitudes, language and communication ability, friendliness and teamwork ability, and other personality attributes that characterize interpersonal connections. As a rule, soft skills complement hard skills or competencies to accomplish a specific task or activity [17]. In contrast to hard skills, i.e., content expertise, soft skills are historically related to managing people. Whereas hard skills have always been a primary focus of HR managers, soft skills as a competence essential for individual, team, and organizational success [18] have been increasingly getting the attention of researchers and practitioners [19]. Addressing such personal characteristics as teamwork, self-awareness, conflict management, effective communication, and soft skills significantly impacts the quality of products, services, organizational processes, and workers' lives [17]. Hard skills are task-specific, and soft skills are applied in various situations.

Unlike hard skills, soft skills are intangible and, thus, difficult to measure and quantify. Further, there is no unified definition of soft skills in the literature due to their abstract and vague character. According to [20], soft skills are a broad concept encompassing many aspects of personality, including emotional, behavioral, and cognitive components. This indicates the difficulty of defining what needs to be included or excluded from the definition.

Legitimately, a large number of studies are devoted to systematic analysis and mapping studies aiming to define soft skills [21]. We refer to [20, 22], consolidating more than 30 soft skills definitions. These research works [21] highlight three main approaches to determining the concept of soft skills: (1) providing an explicit definition, (2) providing examples of specific soft skills, and (3) focusing on the comparison of soft and hard skills.

Similar to these approaches, other literature on soft skills can be grouped into the following categories: (1) research and practical efforts on the classification approaches, i.e., development of various skills frameworks such as European Skills, Competences and Occupations classification (ESCO) [23], (2) research on soft skills in specific subject areas like soft skills in Information Systems and Software Engineering [7, 24], (3) research aimed at the approaches to training soft skills such as educational games [20] or project-based learning [25], (4) both hard and soft skills research directions focused on the skill sets for various purposes, for example, information security managers profiles [26].

In line with the first point, literature evidences a number of various frameworks devoted to the classification of skills in general and in a particular area. For example, the e-Competence Framework (e-CF) is a competency reference framework for the Information and Communication Technology (ICT) industry [27]. It can be used by ICT practitioners, managers, human resources departments, the public sector, and educational and social partners across Europe [28]. Another popular framework related to the ICT sector is the Skills Framework for the Information Age (SFIA), which has been gradually developed over the last few decades to help individuals and organizations manage their skills [29]. Further, ESCO is a generic European Commission-promoted official labor classification that European Union employment agencies will implement in the near future. The primary goal of the ESCO framework is to assist in bridging the gap between education and training and the labor market. As a result, the mismatch between employees' skills and company demands might be addressed [28]. Another differentiation to be mentioned here is country specificity. Whereas ESCO is focused on job profiles in Europe, the Occupational Information Network (O*NET) is a publicly available online database developed to describe occupational features across US job titles [30]. Additionally, several other overarching frameworks, such as project management, address the topic of skills classification, among others [31].

Research on soft skills in specific subject areas has emerged triggered by certain trends. Accordingly, with the ongoing digitization and growing attention and demand on technical job profiles, soft skills, naturally not lying in the focus of these job profiles, have started to get increasing attention of research and practice in this relation. For example, [32] analyzed 500 advertisements for IT positions, focusing on the soft skills mentioned in these advertisements to determine which soft skills are in high demand for software development jobs and which soft skills are neglected despite their importance. In a recent research effort, [19] presents an analysis of the perceived importance and existing gap of soft skills for new entrants in the information technology sector. Florea and Stray [24] investigate the job advertisements for testers from the perspective of soft skills.

Another group of research works deals with the approaches to training soft skills. While some studies are targeted at designing and developing training programs [33], others aim to evaluate their effectiveness [34].

2.2 Soft Skills and Employee Engagement

The harsh rivalry and global economic recession have recently increased the value of employee engagement, which has been of interest to managers for years. The relationship between employee engagement and performance has traditionally received much attention in study and practice, in addition to several literature reviews [35]. The study diversity has increased along with the demand. Currently, one can identify the following major research trends: (1) defining engagement, for instance, as a distinct and particular concept consisting of knowledge, emotion, and behavior [36], (2) measuring engagement, like an approach by Gallup [37], (3) factors influencing engagement [38]. The latter can be further split into (i) organization-related factors, such as already mentioned performance [35], (ii) personality-related factors, like various personality traits [39], and (iii) specific factors, for example, Covid [40] or different countries context [41].

When considering engagement and soft skills together, a number of studies can be cited, including [13–15], which looked into the soft leadership skills beneficial for motivating employees. Further, [16] suggests strengthening soft skills like leadership, communication, and teamwork to raise employee engagement. Young et al. [39] perform a study to determine the workers most likely interested in their work. The eight personality qualities such as conscientiousness, neuroticism, extraversion, agreeableness, openness to experience, proactive personality, and positive and negative affectivity, are highlighted. However, despite a variety of studies related to employees' soft skills and their connection with other organizational and personal characteristics, the research lacks empirical studies investigating the direct relation between employee soft skills and their engagement.

3 Methodology

As indicated in the work's title, this is a preliminary study that tests the research questions and approach while taking a minimal set of soft skills mostly highlighted by other researchers. Hence, as the first step in our survey design, we focused on scoping and selecting soft skills. Motivated by the research [16] and taking the already mentioned ESCO framework soft skills classification as a basis, we bring teamwork, communication, and conflict management soft skills into the study focus.

Afterward, the related empirical research studies and relevant surveys were reviewed for the three selected soft skills. Accordingly, several studies were analyzed for measuring communication skills and adaptions of prominent surveys in specific domains like sports [42]. For example, the study by [43] considers several communication-related factors in an organization, including the standard of corporate information, the degree of information support, barriers to interpersonal contact, and an analysis of distinct business communication styles. With this, the author uses different question types and scales, which makes the usage of such a survey rather challenging. Another questionnaire was developed by [44] to collect data on the communication skills of project teams in the automotive industry. However, we encountered the same challenge of different question types and scales. Hence, further surveys more relevant to our research goal were identified [45, 46]. Finally, to assess the level of communication in the team, V. F. Ryakhovsky's test was used with necessary adjustments in the wording to fit the topic and objectives of the study.

For teamwork and conflict management, a similar search process was performed. To measure conflict management, the intra-group conflict analysis questionnaire presented by Lehmann-Willenbrock et al. [47], adapted to the topic and objectives of the study, was implemented.

To measure the respondents' team orientation, the "Teamwork" scale was adapted based on the standardized German questionnaire "Bochumer Inventar für berufsbezogene Beschreibung (BIP)" [48]. Team orientation means a high appreciation of teamwork and cooperation and a willingness to support team processes. In addition, the willingness to give up one's interests and position in favor of the team is measured. Moreover, teamwork is associated with accepting responsibility for cooperation and a willingness to support team decisions. The scale includes 13 items, e.g., "I am convinced that almost all current problems can only be solved in a team", and "I can fully develop my abilities, especially in collaboration with others." The response format consisted of four items ranging from "not at all" to "completely".

A well-known Gallup approach of 12 yes/no questions was used to measure engagement [49]. The final socio-demographic part of the questionnaire addressed questions about the demographic characteristics of the respondents. For all scales used in this study, Cronbach's alpha coefficient was calculated to assess their internal reliability. The obtained data are higher than the recommended Cronbach's $\alpha \geq 0.7$.

The questionnaire was implemented in Google Forms and translated into two languages: Russian and German for Russian and German participants correspondingly. In both countries, participants from commercial and non-commercial organizations were involved in the survey. The main dependent variable was employee engagement. The study was conducted in the period of April–May 2022.

4 Survey Results and Discussion

IBM SPSS Statistics data processing program was used to analyze the collected data. Average values with standard deviation were calculated for the variables. A paired Student's t-test was used to evaluate the influence of employee soft skills on the main dependent variable. Spearman's rank correlation method was used to estimate correlation links between employee soft skills and engagement. The differences were considered statistically significant at $p < 0.05$. As a statistical method, correlation analysis, using correlation coefficients, allows determining whether a relationship exists between variables and how strong it is.

The main characteristics of the two groups are summarized in Table 1.

Table 1 Characteristics of the groups of the study

Characteristics	Russia	Germany
Gender distribution, number of respondents		
Men	24	21
Women	40	41
Age distribution, number of respondents		
20–24 years old	7	1
25–29 years old	6	9
30–34 years old	5	17
35–39 years old	16	10
40–49 years old	9	17
50–59 years old	11	5
Over 60 years old	10	3
Level of education, number of respondents		
Academic degree	2	15
Higher (specialist, master)	37	32
Bachelor degree	12	6
Secondary education and other	13	9
Form of business activities of the organization in which the respondent is employed		
Commercial	46	20
Non-commercial (social, cultural, educational, spiritual, charity, etc.)	18	42

In the course of the analysis, statistically, significant differences were found in the influence of employee soft skills on their engagement between groups in Russia and Germany ($p \leq 0.05$) (see Table 2). This allows us to answer RQ1 and RQ3. An observable influence of the soft skill "Teamwork" on employee engagement in both countries was demonstrated. For the Russian organizations, the influence was identified as "moderate" ($k = 0.43$, $p = 0.021$) on the Cheddock scale, and, for Germany, as "noticeable" ($k = 0.61$, $p = 0.050$). A moderate influence of the soft skill "Communication" on the employee engagement was observed for both Russia ($k = 0.41$, $p = 0.001$) and Germany ($k = 0.34$, $p = 0.030$). A discrepancy was identified in the influence of the "Conflict management" skill on engagement: although the correlation coefficients are weak for both countries, there is a negative influence in the case of Russian employees ($k = -0.15$, $p = 0.040$), in contrast to German employees ($k = 0.13$, $p = 0.025$).

The next step was to analyze the influence of the form of business activities of the organization in which the respondent is employed (commercial and non-commercial) and their engagement. Accordingly, it was found that the analysis results of the two countries are relatively similar for the employee engagement of non-commercial but different for commercial organizations (see Table 3).

Further, following RQ2 and RQ3, the correlation between employee soft skills and their engagement in commercial and non-commercial organizations has been calculated. The results are presented in Figs. 1 and 2.

According to the obtained profiles of employee soft skills influence on their engagement in commercial and non-commercial organizations (Figs. 1 and 2), it can be stated that in non-commercial organizations of both Russia and Germany, the employee soft skill "Teamwork" has the most significant influence on their engagement ($k = 0.71$, $p = 0.014$ and $k = 0.57$, $p = 0.041$, respectively). The employee soft

Table 2 Correlation analysis results of the influence of employee soft skills on their engagement

Employee soft skills	Correlation with engagement			
	Russia		Germany	
	Correlation coefficient	p	Correlation coefficient	p
Teamwork	0.43	0.021	0.61	0.050
Conflict management	−0.15	0.040	0.13	0.025
Communication	0.41	0.001	0.34	0.030

Table 3 Employee engagement in Russia and Germany in relation to the form of business activities

Form of business activities	Average value of employee engagement	
	Russia	Germany
Commercial organizations	7.06 ± 3.74	8.67 ± 2.25
Non-commercial (social, cultural, educational, spiritual, charity, etc. organizations)	8.94 ± 3.08	8.77 ± 2.48

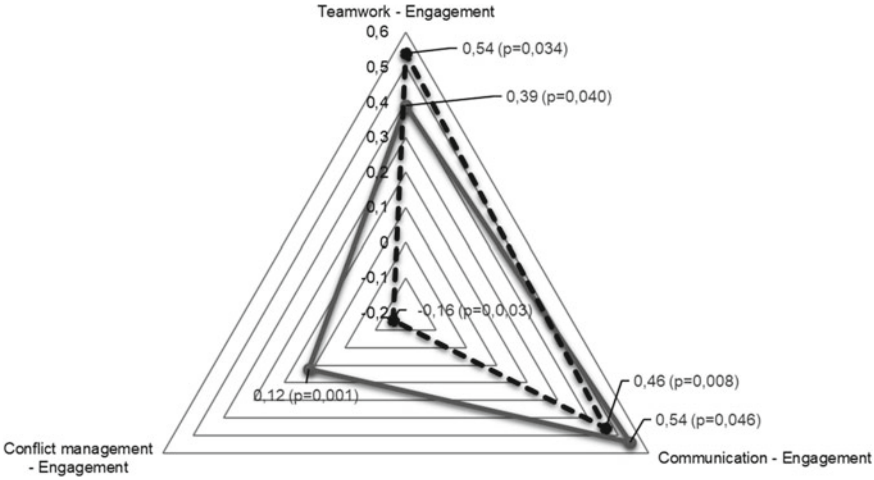

Fig. 1 Correlation analysis results of employee soft skills influence on their engagement in *commercial* organizations in Russia (solid line) and Germany (dashed line)

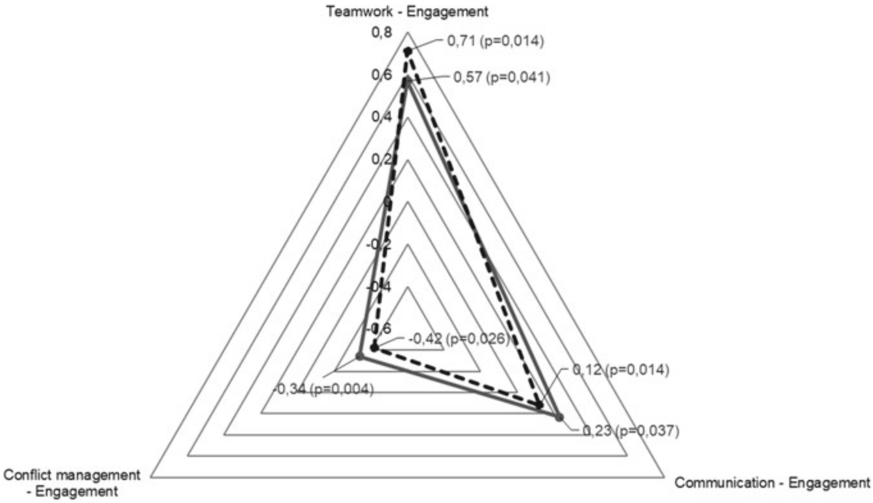

Fig. 2 Correlation analysis results of employee soft skills influence on their engagement in *non-commercial* organizations in Russia (solid line) and Germany (dashed line)

skill "Conflict management" has shown a negative influence on their engagement in organizations of both countries ($k = -0.34$, $p = 0.004$ and $k = -0.42$, $p = 0.026$, respectively).

In the case of commercial organizations, the analysis results slightly change. For Russia, "Communication" has demonstrated the greatest influence on engagement ($k = 0.54$, $p = 0.046$), whereas less significant effects are identified for "Teamwork" and "Conflict management" ($k = 0.46, p = 0.008$ and $k = 0.039, p = 0.040$, respectively). In Germany, the employee soft skill "Teamwork" ($k = 0.54, p = 0.034$) has been shown to be important for their engagement, similarly to the values of non-commercial organizations. If compared to non-commercial organizations, "Communication" appears to be more significant for engagement ($k = 0.46, p = 0.008$), and "Conflict management" has a weak but negative influence ($k = -0.16, p = 0.003$).

We assume that the observed differences in soft skills influencing employee engagement are due to various reasons. In fact, we are confronted with different cultural and historical employment backgrounds, which may be reflected in different profiles of soft skills demanded in organizations and consciously developed by employees. As a result, this has an impact on their engagement.

Further, soft skills profiles obtained for non-commercial organizations engaged in educational, spiritual, social, and other activities have similarities for both countries, while they vary, albeit partially, for commercial organizations. Commercial organizations are likely to create different requirements for their employees, reflecting the specifics of doing business in a particular country. This way, various soft skill profiles for an effective worker engaged in the work process are established. In the case of non-commercial organizations, we detected similarities in the influence of soft skills on engagement in both countries. We suggest that this is due to a similar set of values in the employees' work performance in these organizations.

5 Conclusion and Outlook

To sum up, this preliminary study aimed to identify the influence of employee soft skills on their engagement in organizations. This way, the work contributes to a better understanding of those factors influencing engagement. Such knowledge can be used as a basis for training programs to increase employee motivation in the companies and, in this way, support digital transformation efforts of different levels. A comparative analysis of the survey results from the two countries showed the similarities and differences in the profiles of employee engagement as related to their soft skills.

As follows from the title, this work serves as a starting point for a more extensive study implying a larger sample size, which will allow applying more accurate analysis methods, and considering other soft skills like time and stress management as well as critical thinking.

References

1. Leite, M. P., Mihajlovski, T., Heppner, L., Branco, F., & Au-Yong-Oliveira, M. (2019). The impact of the digital economy on the skill set of high potentials. *Advances in Intelligent Systems and Computing, 931*, 726–736. https://doi.org/10.1007/978-3-030-16184-2_69/COVER.

2. Schislyaeva, E. R., & Saychenko, O. A. (2022). Labor market soft skills in the context of digitalization of the economy. *Social Sciences*, *11*(3), 91. https://doi.org/10.3390/SOCSCI11030091.
3. Syed, R., Suriadi, S., Adams, M., Bandara, W., Leemans, S. J. J., Ouyang, C., ter Hofstede, A. H. M., van de Weerd, I., Wynn, M. T., & Reijers, H. A. (2020). Robotic process automation: Contemporary themes and challenges. *Computers in Industry, 115*, 103162.
4. Lewicki, P., Tochowicz, J., & Van Genuchten, J. (2019). Are robots taking our jobs? A Robo-Platform at a bank. *IEEE Software, 36*(3), 101–104. https://doi.org/10.1109/MS.2019.2897337.
5. Sahinaslan, E., Sahinaslan, O., & Sabancioglu, M. (2021). Low-code application platform in meeting increasing software demands quickly: SetXRM. *AIP Conference Proceedings, 2334*(1), 070007. https://doi.org/10.1063/5.0042213.
6. Villegas-Ch, W., García-Ortiz, J., & Sánchez-Viteri, S. (2021). Identification of the factors that influence university learning with low-code/no-code artificial intelligence techniques. *Electronics, 10*(10), 1192. https://doi.org/10.3390/ELECTRONICS10101192.
7. Pospelova, V., Baldominos, I. L., Sanz, L. F., & Castillo-Martinez, A. (2021, August 10). Big data and skills frameworks to determine recommended profiled of soft skills for IS development. In *29th International Conference on Information Systems Development (ISD 2021)*. https://aisel.aisnet.org/isd2014/proceedings2021/currenttopics/5.
8. Gruzdev, M. V., Kuznetsova, I. V., Tarkhanova, I. Y., & Kazakova, E. I. (2018). University graduates' soft skills: The Employers' opinion. *European Journal of Contemporary Education*, *7*(4), 690–698. https://doi.org/10.13187/ejced.2018.4.690.
9. AbuJbara, N. K., & Worley, J. A. (2018). Leading toward new horizons with soft skills. *On the Horizon, 26*(3), 247–259. https://doi.org/10.1108/OTH-10-2017-0085/FULL/PDF.
10. Sopa, A., Asbari, M., Purwanto, A., Budi Santoso, P., Hutagalung, D., Maesaroh, S., Ramdan, M., & Primahendra, R. (2020). Hard skills versus soft skills: Which are more important for Indonesian employees innovation capability. *International Journal of Control and Automation*, *13*(02), 156–175. http://sersc.org/journals/index.php/IJCA/article/view/7626.
11. Albrecht, S. L., Bakker, A. B., Gruman, J. A., Macey, W. H., & Saks, A. M. (2015). Employee engagement, human resource management practices and competitive advantage: An integrated approach. *Journal of Organizational Effectiveness, 2*(1), 7–35. https://doi.org/10.1108/JOEPP-08-2014-0042.
12. Saks, A. M. (2022). Caring human resources management and employee engagement. *Human Resource Management Review*, *32*(3). https://doi.org/10.1016/J.HRMR.2021.100835.
13. Bloch Jensen, O. (2012). The engagement of employees as a key to corporate success. *Dynamic Relationships Management Journal*, *1*(2), 45–56. https://doi.org/10.17708/DRMJ.2012.V01N02A05.
14. McGonegal, L. (2020). *Employee engagement during organizational changes to reduce turnover*. Colorado Technical University.
15. Rao, M. S. (2016). Hard versus soft leadership? Examples and illustrations. *Strategic HR Review, 15*(4), 174–179. https://doi.org/10.1108/SHR-02-2016-0016.
16. Haas, E. (2020). Employee engagement: Establishing and using safety committees at work. Rock Products, 32–38.
17. Cimatti, B. (2016). Definition, development, assessment of soft skills and their role for the quality of organizations and enterprises. *International Journal for Quality Research*, *10*(1), 97–130. https://doi.org/10.18421/IJQR10.01-05.
18. Parlamis, J., & Monnot, M. J. (2018). Getting to the CORE: Putting an end to the term "soft skills". *28*(2), 225–227. https://doi.org/10.1177/1056492618818023.
19. Singh Dubey, R., & Tiwari, V. (2020). Operationalisation of soft skill attributes and determining the existing gap in novice ICT professionals. *International Journal of Information Management, 50*, 375–386. https://doi.org/10.1016/J.IJINFOMGT.2019.09.006.
20. Dell'Aquila, E., Marocco, D., Ponticorvo, M., Di Ferdinando, A., Schembri, M., & Miglino, O. (2017). Educational games for soft-skills training in digital environments. *Educational Games for Soft-Skills Training in Digital Environments*. https://doi.org/10.1007/978-3-319-06311-9.

21. Matturro, G., Raschetti, F., & Fontán, C. (2019). A systematic mapping study on soft skills in software engineering. *Journal of Universal Computer Science, 25*(1), 16–41. https://doi.org/10.3217/JUCS-025-01-0016.
22. Matteson, M. L., Anderson, L., & Boyden, C. (2016). "Soft skills": A phrase in search of meaning. *Portal: Libraries and the Academy*, *16*(1), 71–88. https://doi.org/10.1353/PLA.2016.0009.
23. European Commission. (2022). *ESCO*. https://ec.europa.eu/esco/portal.
24. Florea, R., & Stray, V. (2018). Software tester, we want to hire you! An analysis of the demand for soft skills. *Lecture Notes in Business Information Processing, 314*, 54–67. https://doi.org/10.1007/978-3-319-91602-6_4.
25. Vogler, J. S., Thompson, P., Davis, D. W., Mayfield, B. E., Finley, P. M., & Yasseri, D. (2018). The hard work of soft skills: Augmenting the project-based learning experience with interdisciplinary teamwork. *Instructional Science, 46*(3), 457–488. https://doi.org/10.1007/S11251-017-9438-9/TABLES/5.
26. Haqaf, H., & Koyuncu, M. (2018). Understanding key skills for information security managers. *International Journal of Information Management, 43*, 165–172. https://doi.org/10.1016/J.IJINFOMGT.2018.07.013.
27. European Committee for Standardization (CEN). (2016, April). *EN 16234-1:2016, European e-Competence Framework 2.0—Part 1: A common European framework for ICT Professionals in all industry sectors*. https://joinup.ec.europa.eu/collection/european-committee-standardization-cen/solution/european-e-competence-framework-20-part-1-common-european-framework-ict-professionals-all-industry.
28. Fernández-Sanz, L., Gómez-Pérez, J., & Castillo-Martínez, A. (2017). e-Skills Match: A framework for mapping and integrating the main skills, knowledge and competence standards and models for ICT occupations. *Computer Standards & Interfaces, 51*, 30–42. https://doi.org/10.1016/J.CSI.2016.11.004.
29. Brown, J. (2020). An examination of the Skills Framework for the Information Age (SFIA) version 7. *International Journal of Information Management, 51*, 102058. https://doi.org/10.1016/J.IJINFOMGT.2019.102058.
30. Cifuentes, M., Boyer, J., Lombardi, D. A., & Punnett, L. (2010). Use of O*NET as a job exposure matrix: A literature review. *American Journal of Industrial Medicine, 53*(9), 898–914. https://doi.org/10.1002/AJIM.20846.
31. Cerezo-Narváez, A., Ceca, M. J. B., & Blanco, J. L. Y. (2018). Traceability of intra- and interpersonal skills: From education to labor market. In *Human capital and competences in project management*. InTech. https://doi.org/10.5772/INTECHOPEN.71275.
32. Ahmed, F., Capretz, L. F., & Campbell, P. (2012). Evaluating the demand for soft skills in software development. *IT Professional, 14*(1), 44–49. https://doi.org/10.1109/MITP.2012.7.
33. Lucía Sutil-Martín, D., Javier Otamendi, F., Medina, M., & Luis Gutiérrez Vela, F. (2021). Soft skills training program based on serious games. *Sustainability*, *13*(15), 8582. https://doi.org/10.3390/SU13158582.
34. Succi, C., & Wieandt, M. (2019). Walk the talk: Soft skills' assessment of graduates. *European Journal of Management and Business Economics, 28*(2), 114–125. https://doi.org/10.1108/EJMBE-01-2019-0011/FULL/PDF.
35. Kompaso, S. M., & Sridevi, M. S. (2010). Employee engagement: The key to improving performance. *International Journal of Business and Management, 5*(12), p89. https://doi.org/10.5539/IJBM.V5N12P89.
36. Saks, A. M. (2006). Antecedents and consequences of employee engagement. *Journal of Managerial Psychology, 21*(7), 600–619. https://doi.org/10.1108/02683940610690169/FULL/XML.
37. Little, B., & Little, P. (2006). Employee engagement: Conceptual issues. *Journal of Organizational Culture, Communication and Conflict, 10*(1), 111–120.
38. Sundaray, B. K. (2011). Employee engagement: A driver of organizational effectiveness. *European Journal of Business and Management, 3*(8), 53–60.

39. Young, H. R., Glerum, D. R., Wang, W., & Joseph, D. L. (2018). Who are the most engaged at work? A meta-analysis of personality and employee engagement. *Journal of Organizational Behavior, 39*(10), 1330–1346. https://doi.org/10.1002/JOB.2303.
40. Chanana, N., & Sangeeta. (2021). Employee engagement practices during COVID-19 lockdown. *Journal of Public Affairs*, *21*(4), e2508. https://doi.org/10.1002/PA.2508.
41. Li, P., Sun, J. M., Taris, T. W., Xing, L., & Peeters, M. C. W. (2021). Country differences in the relationship between leadership and employee engagement: A meta-analysis. *The Leadership Quarterly, 32*(1), 101458. https://doi.org/10.1016/J.LEAQUA.2020.101458.
42. Onağ, Z., & Tepeci, M. (2014). Team effectiveness in sport teams: The effects of team cohesion, intra team communication and team norms on team member satisfaction and intent to remain. *Procedia - Social and Behavioral Sciences, 150*, 420–428. https://doi.org/10.1016/J.SBSPRO.2014.09.042.
43. Denisov, A. F. (2021). Problems of communication culture in companies operating in the Russian market. *Vestnik of Saint Petersburg University. Management, 20(1)*, 86–107. https://doi.org/10.21638/11701/SPBU08.2021.104.
44. Górniak, A., Midor, K., & Kaźmierczak, J. (2019). Assessment of the project teams' communication skills in the automotive industry. *Multidisciplinary Aspects of Production Engineering, 2*(1), 624–632. https://doi.org/10.2478/MAPE-2019-0061.
45. Abdallah, A., & El-Tabal, A. (2020). Soft skills and its impact on an organizational creativity—A field study. *Journal of Business and Retail Management Research (JBRMR), 14*(3), 78–87.
46. Motschnig-Pitrik, R., & Figl, K. (2007). Developing team competence as part of a person centered learning course on communication and soft skills in project management. *Proceedings - Frontiers in Education Conference, FIE*. https://doi.org/10.1109/FIE.2007.4417889.
47. Lehmann-Willenbrock, N., Grohmann, A., & Kauffeld, S. (2011). Task and relationship conflict at work: Construct validation of a German version of Jehn's intragroup conflict scale. *European Journal of Psychological Assessment, 27*(3), 171–178. https://doi.org/10.1027/1015-5759/A000064.
48. Hossiep, R., & Paschen, M. (2003). *Bochumer Inventar zur berufsbezogenen Persönlichkeitsbeschreibung—BIP* (2nd ed.). Hogrefe.
49. *Gallup's Q12 Employee Engagement Survey - Gallup.* (n.d.). Retrieved September 22, 2022, from https://www.gallup.com/workplace/356063/gallup-q12-employee-engagement-survey.aspx.

Specifics of Accounting for Agent Activeness in the Digital Twin of the Social System

Mikhail Samosudov

Abstract The paper presents an approach to formalizing agent activeness in a simulation model of a social system for the purpose of creating a digital twin. It is shown that it is fundamentally important to consider the dualism of agent activeness, which has two coexisting components—resource and system activeness. These components are linked, but not linearly. Moreover, resource activeness is more important for subjective evaluations of the agent, and the system activeness, which determines an irremediable conflict in the social system that requires the system's dynamics to be considered in the calculation, is of crucial role in the development of the social system. We also examine the sequence of the agent's activeness in the socio-economic space and the influence of subjective assessments of the environment, expected incoming flows of resources and messages, as well as outgoing flows of resources on activeness. The possibility of using gradients of information and resource flows for modeling the dynamics of the social system in the socio-economic space is put up for discussion, which makes it possible to create predictive models of the dynamics of the environment and the social system.

Keywords Digital twin of the social system · Simulation model · Digital transformation · Active system

1 Introduction

A digital twin is often called a computer model that simulates the behavior of a real object [5, 6, 8, 12, 27]. But it is advisable to distinguish between the simulation model (the mechanism for calculating the dynamics of the system) and the actual digital double (information about the values of phase variables at certain points in time).

The digital twin of an object is a set of data (values of variables) that allows, using a specific simulation model, calculating the dynamics of an object and changes in

M. Samosudov (✉)
State University of Management, 99 Ryazan Avenue, Moscow 109542, Russian Federation
e-mail: samosudov@mail.ru

V. Kumar et al. (eds.), *Digital Transformation in Industry*, Lecture Notes in Information Systems and Organisation 61, https://doi.org/10.1007/978-3-031-30351-7_35

its properties. By properties it meant the nature of the object's interaction with the environment. In relation to the organization, it is an imitation of the movement of the social system in the socio-economic space (SES). In general, this implies the availability of data about the object under study and data about the environment of its functioning.

"… in the literature, simulation modeling is most often defined as a numerical method for studying complex systems whose elements are described by a heterogeneous mathematical apparatus and combined by a connecting model" [18, p. 58]. Simulation models are often implemented in the form of software and hardware complexes. Agent-based models are increasingly being used to model social systems [3, 7, 10, 11, 14, 24].

Considering the above and the trends in the society and economy digitalization, the digital twin of the social system is a computer program that provides fixation and processing of a complex of information that allows one to trace the change in the situation in the company when modeling various influences on it, such as controlling, adverse impacts of the environment, etc. Such a complex information must consider all significant cause-and-effect relationships, and also contain the necessary and sufficient data set to simulate the behavior of an enterprise in the market environment. To do this, the digital twin should allow one to perform the following actions:

- Fix the condition of the enterprise and the environment in which it operates, in the form of a set of values of phase variables (system and environment parameters).
- Fix the change in the condition of the company in the event of any phenomena, changes in circumstances or the commission of certain actions by participants (economic agents).
- Calculate the change in the condition and properties of the social system with shifts in the values of one or more parameters.
- That is, it is a complex of software modules that record and process the current values of phase variables for modeling activities, the situation of the social system, calculating its behavior and the consequences of a particular impact.

Social systems are active systems functioning in an active environment. Given that "motion" is a change in the state of an object over time, and the condition of any object is described by a set of phase variables, the functioning of the system can be represented as its movement in the SES. If, due to the movement of the system, its functional sustainability (the ability to maintain the possibility of functioning) increases, this will be the development of the system, if decreases, it will be its degradation. The source of activeness in the system and environment is a person. It cannot be a non-active element due to its dependence on the resources obtained from the SES, which makes it necessary to influence the agents of the environment.

The purpose of the article is to establish the method of accounting for agent activeness in the digital twin as the most important characteristic of a person in the SES, as well as to determine the mechanism for implementing agent activeness in the SES.

The novelty consists in considering the dualism of the agent's activeness in the SES, i.e., activeness as an action and activeness as an effect on the SES, which is fundamentally important for modeling the dynamics of the system. The mechanism of activeness realization is also formalized, assuming the interpretation of received messages and resources into information affecting the agent's behavior.

2 Literature Review

Many authors note the activeness of agents, but mostly deal with activeness as the ability to act in tune with desires. At the same time, "… activeness is a category that shows how much effort the subject has put into his activity, but not the activity" [1]. And it should be borne in mind that for the dynamics of the social system in the SES, it is not the human effort that matters, but the effect this effort creates, i.e., the resource flows entering the system.

In the literature, interaction, including unproductive interaction, is often intertwined with activeness. Thus, in [13, 26] the concept of rent-seeking is developed, where agents seek to make a profit in the form of rent by manipulating society. In [30], opportunistic behavior is considered, and in [16] the influence of institutions on the agents' choice of activity—production or redistributive—is revealed. In [15], it is shown how institutions direct agents' intellectual efforts in entrepreneurship or "rent-seeking". In [4], the authors state that entrepreneurship can be productive, unproductive, and even destructive.

But quite often the model seems to be enlarged, for example, the interaction of groups and the mutual influence of groups on each other is considered (see, e.g., [9]). At the same time, considering the group as an integrity is only possible if its unity and proven team cohesion. And even then, only in a limited range of conditions and for a limited period—if the conditions that determine the commonality of goals, interests, etc. remain. In general, it is necessary to consider each agent and its reaction to the impact, both external (management, an attempt to change behavior due to competition or other motives, etc.) and internal (body signals). As shown in [19], the behavior of social systems, such as groups of people, enterprises, and even states is determined by the behavior of individuals.

It is problematic to examine agents impersonally, as a passive part of the group. As a result, equations appear in the models that simulate, for example, the change in the number of groups when interacting with other groups (see, e.g., [9]). Along the way, we would like to note that coefficients that affect the dynamics are often used in equations, but factors that affect the value of the coefficients are not determined. Then it all comes down to solving equations and creating the illusion of solving the problem. This can also include the modeling of the system, assuming the determinism of actions, etc. And it is presumed that everyone and all know—actions, decisions, etc. "We will assume that each agent observes … the actions of all agents, the overall result and the winnings of all agents" [29]. Such presuppositions significantly limit the model and do not allow it to be used for different situations—a person does not observe the actions of all agents and often does not have information about their needs and benefits. But it predicts the incoming resource flows expected from the environment. Moreover, this is done automatically in the process of afferent synthesis based on the accumulated data [2, 23].

The natural limitations of people's abilities to receive and process information determined the evolution of the concept of limited rationality to "restricted rationality". The factors of the decision-making environment play an important role in the creation and selection of alternatives. The necessity to consider the decision-making process led to the emergence of the concept of procedural rationality, but it is not as popular as the concept of bounded rationality. The phenomenon of "procedural rationality" more fully reflects the decision-making process of an agent in a digital environment [28]. We use the concept of local rationality, which implies that an agent makes a rational decision by comparing subjective estimates of resources obtained as a result of his/her actions (stimuli) and resources lost in the process of performing actions (limitations). At the same time, the value of resources is determined by the "local coordinate system" in the subjective subspace (for more details, see [20, p. 86]). The behavior and rationality of actions depends on a range of parameters: the actions of other economic agents (they can facilitate the achievement of a goal or the implementation of a decision or make it difficult); the objective function; the information received [17, pp. 36–37].

3 Methodology

"Traditional methods of simulation modeling consider employees …, suppliers, customers, products, projects, etc. as an arithmetic mean or as passive resources. For example, … statements such as 'the company employs 100 employees, they can create … 20 new products per year', or 'the company has 100 trucks that can transport such and such a number of products per week, and 2% of them are written off every year and replaced with new ones'" [25, pp. 367–368].

To analyze the dynamics of the social system in the SES, as well as the role of agent activeness in the SES, we apply a comprehensive mathematical model of a social system functioning in an active environment [22] and the theoretical basis used to create the model. However, it should be noted that we adhere to an interdisciplinary approach, and considering the factors affecting agents' behavior is based on research in the field of neurophysiology, psychology, human ethology, behavioral economics, and other scientific disciplines that somehow deal with human behavior in the SES.

The principal features of the model are the following:

- separating entities into subspaces independent on subjective (invariant) and subspaces dependent on subjective (variable);
- embracing the whole variety of resources, including intangible ones (information, social, etc.), rather than reducing all types of resources to finance, as is often done. In a broad sense, economy is the interchange of resources in the first place.

Money is the equivalent of value and a resource for the interchange only in certain social conditions, and the real value is the resources that allow one to carry out specific activities and get the necessary benefits. Therefore, when modeling the socio-economic dynamics, it is fundamentally important to consider all types of resources. In addition, it should be borne in mind that the resource value is not an absolute value, but depends on the subjective assessments of agents formed on the basis of information received at the time of decision-making (that is, it depends on the point of the SES, the subjective subspace of the agent);

- separating the information carrier (a message as a set of signals representing combinations of primary elements of information—symbols, signs, etc.) and the actual information that arises in the subjective subspace in the process of interpreting messages based on the alphabet of the agent M_j and is important for the formation of the agent's activeness in the SES;
- considering human behavior by introducing a behavior vector, i.e., a vector value (a $1 \times n$ matrix) that determines the probability of some conditioned actions, which, in turn, are formalized by the transformation matrix of the resource base controlled by the subject of the action.

4 Results

The agent should be viewed as part of the environment and the source of activeness, which determines the features of the SES and the systems moving in the SES. It depends on the situation in which the person is. As found in the project of creating a digital twin, it is fundamentally important to regard activity not so much as an agent's ability guided by their interests to react to the impact of the environment, but as an ability to influence the SES to change the situation. It is the necessity of modeling the dynamics of an active social system in an active environment that makes it possible to identify the dualism of an economic agent's activeness.

Obviously, the ability to make decisions based on desires, needs, goals and other factors is a manifestation of activeness. But not the only one and not the main one. Firstly, needs and desires are determined not solely by body signals, but also by information received from the environment. Secondly, from the viewpoint of the situation dynamics, it is not a person's decision itself that is important, but the redistribution of resources in the SES, the change in message flows and resources due to the actions of the agent.

As a result of the impact on the SES by means of resource flows and messages emanating from the j-th point of the SES, agents change the activeness of other agents, which leads to a change in the allocation of resources in the SES. One can evaluate the agent's activeness by redistributing resources in the SES as a result of their actions.

Depending on the task, we estimate either the ratio of the number of agents who redistributed resources to the total number of SES agents or the ratio of the number of transferred resources to the total number of SES resources. But firstly, this is the resulting assessment; secondly, to determine it, it is necessary to study the influence of other agents. Therefore, in the process of managing the social system, it is necessary to consider the nature of human impact on the SES.

Let us look at the mechanism for implementing agent activeness in the SES.

Activeness depends on the agent's contentment with the situation and the benefits that it gives them. If the expected benefits $g_{\text{expect.}j}$ are more or equal to the desired benefits $g_{\text{desir.}j}$, the activeness impulse is zero; if less, then it is greater than zero:

$$a_j(t) = \varphi\left(1 - \frac{g_{\text{expect.}j}(t)}{g_{\text{desir.}j}(t)}\right). \tag{1}$$

Due to the determinacy of expected and desired benefits, activeness has a direction and determines the choice of actions that minimize the dissatisfaction of the subject of the situation. In general, the impulse of activeness leads to the choice of actions that, firstly, are more consistent with the agent's ideas about the most appropriate actions in each situation; secondly, are more consistent with the agent's current understanding of their needs.

Since actions are an act of transforming the resource base, and the impulse of activeness leads to the use of part of the resources controlled by the agent to change its situation, resource activeness occurs, implemented through actions, which results in the transformation of the resource base and the emergence of flows of message $\widehat{M}_j^k$ and resources $\widehat{R}_j^k$ emanating from the agent (from the j-th point of the SES), directed to k-th subjects from the sets of agents receiving messages $Q_{\text{rec.inf.}}$ and resources $Q_{\text{rec.res.}}$ via the transmission channels selected by the j-th agent. The set of agent actions at time t: $\exists O_j(t) : \forall t \; O_j(t) \neq \varnothing$ it is determined by the current value of the behavior vector, more precisely by the components of the behavior vector, the probability of which is 1:

$$O_j(t) = B_j(t)|_{p(o_n)=1} \tag{2}$$

In turn, the current value of the behavior vector is determined by the sum of the agent's behavior vector at the moment t_0 and changes in the behavior vector $\Delta B_j(I_j(t))$ under the influence of information received from the moment t_0 to t – a $1 \times n$ matrix, each element of which represents a divergence of human behavior (for more details, see [21]):

$$\begin{aligned} B_j(t) &= B_j(t_0) + \Delta B_k\left(\breve{I}_j(t)\right) \\ &= B_j(t_0) + \left(\int_{t_0}^{t} \operatorname{div} B_j^1\left(\breve{I}_j(t)\right)\mathrm{d}t, \; \ldots, \; \int_{t_0}^{t} \operatorname{div} B_j^n\left(\breve{I}_j(t)\right)\mathrm{d}t\right) \end{aligned} \tag{3}$$

Actions are the act of transforming the resource base $R_j(t)$ controlled by the j-th agent. As a result, it changes (resources are consumed) and flows of messages and resources are formed, directed at k-x SES agents:

$$\left\{O_j(t), R_j(t)\right\} \to \left\{\widehat{M}_j^k(t), \widehat{R}_j^k(t), R_j(t+1)\right\}, \; k \in Q = Q_{\text{rec.inf.}} \cup Q_{\text{rec.res.}} \quad (4)$$

To simplify, we assume the equality of transmitted and received messages: $\widehat{M}_j^k = \breve{M}_k^j$. But in general, this is not the case: the effect is exerted by the transmission channels chosen by the agent (noise, distortion), as well as the behavior of recipients associated with receiving information (listening/reading/watching at a certain time, etc.). Based on the ideas about the SES, a person chooses the agents to be influenced to get the resources he/she needs and determines the actions necessary for the impact. The consequence of the selected actions are outgoing flows of messages and resources toward the k-th agents. Moreover, messages are created based on the person's understanding of the alphabet of the k-th recipient:

$$\hat{I}_j^k \xrightarrow{M_j^k} \widehat{M}_j^k \quad (5)$$

Due to the receipt by the k-th agents of messages and resources from all SES agents, their activeness changes. This happens as follows. The k-th point of the SES receives flows of messages $\breve{M}_k^j$ and resources $\breve{R}_k^j$ from the j-th agents. The totality of messages is decoded based on the alphabet of the k-th agent M_k, because of which the information $\breve{I}_k(t)$ received by the agent about the stimuli, limitations and probability of aftereffects associated with specific actions arises:

$$\breve{I}_k(t) = \varphi\left(\sum_j \breve{M}_k^j(t), M_k\right) = \{s_n(o_x), l_m(o_x), p(s_n), p(l_m)\} \quad (6)$$

Decoding is carried out by means of the association of signals (combinations of primary elements of information) with actions and consequences of their commission (stimuli, limitations). Incoming resource flows are interpreted as a confirmation of the rules (a subjective assessment of the probability of effects due to the agent's actions), as well as a basis for assessing the resource base available to the agent.

This leads to a change in the behavior vector of k-th agents similarly to (Eq. 3), as well as a change in the expected and desired benefits from interaction with the SES, which leads to the emergence of an activeness impulse in accordance with (Eq. 1) and the emergence of a set of actions of the k-th agents similarly to (Eq. 2). In turn, their actions cause the transformation of their resource base, as well as the emergence of resource and messages flows originating from the k-th point of the space, i.e., there is a redistribution of resources in the SES.

In the SES, agents interact with each other and at any given time a person must decide about actions. Therefore, we are interested in decoding signals precisely from the perspective of their influence on a person's choice of certain actions. And this, as shown earlier in [20, pp. 85–93], is precisely subjective assessments of stimuli, limitations, and the likelihood of ramifications because of actions.

5 Discussion

The dualism of the agent's activeness and the relativity of the SES causes a potential conflict in the social system due to the difference in the "coordinate systems": it is natural for a person to evaluate the efforts on the cost of resources, and for the system, it is important to change the resource and information flows in the SES due to the influence of the agent (system activeness). As a result, a situation is possible where a person performs actions and gets tired, but these actions are practically irrelevant to the system since they do not properly change the flows of resources and messages in the SES. Such a conflict can be minimized by changing the qualifications of a person.

The use of the concept of space in relation to society, coupled with an understanding of the activeness of agents and the mechanisms of its implementation, makes it possible to solve the problems of calculating the dynamics of social systems in the SES in a different way. For example, to reflect motivation as a phenomenon in the model, one can use a behavior vector that determines the direction of human activity, and to consider the actions of the system for motivating a person and assessing the impact of agents (system activeness), use the gradient of information and resource flows at the SES point:

$$\text{grad}\left(\breve{I}_j(t), \breve{R}_j(t)\right) = \left(\frac{\partial B_j}{\partial s_n}, \frac{\partial B_j}{\partial l_m}, \frac{\partial B_j}{\partial p(s_n)}, \frac{\partial B_j}{\partial p(l_m)}\right) \tag{7}$$

The calculation of the gradient components of information and resource flows can be performed according to the same principles as the calculation of the divergence of agent behavior based on information about the needs of a person, the resources available to him/her and the resources they need (for more details, see [20, 21]), considering the aspects described in the article on the interpretation of messages received by the agent from the environment.

Information and resource flows contain signals directing changes in the behavior of agents due to positioned stimuli and limitations. Thus, there is an impact of the environment on a person at the SES point. We can express the direction and strength of this impact with a gradient.

At the same time, this triggers a change in resource flows and messages emanating from the SES point. The direction of these flows also varies depending on incoming flows and internal signals. The change in this direction can also be determined by a gradient.

This allows us to consider the impact of the environment more accurately on human behavior at each point of the SES and calculating the reaction of agents to this impact will help us to compute the expected flows of messages and resources. In turn, it is possible to calculate the dynamics of the space itself and predict the activeness of individual agents or groups of agents, including the forecast of social tension in some communities. The introduction of dynamic entities into the model is essential for simulating the dynamics of a social system in the SES for the purpose of creating a digital twin.

It seems promising to consider the description of the environment image that determines the activeness of the agent as a gradient of incoming and outgoing resources and information flows at the SES point. This makes it easier to organize algorithms for calculating the dynamics of the system in the SES and more explicitly introduces dynamic entities into the model.

6 Conclusion

As a result of the research, it was determined that to properly account for the activeness of the agent in the simulation model, it should be seen as two interrelated phenomena—the resource activeness of the agent manifested in its actions and the system activity of the agent manifested in the impact on the agents of the SES. In terms of calculating the dynamics of the social system, it is system activeness that matters, but it cannot be regarded in isolation from the actions of agents, since it is the actions of agents that create outgoing flows of messages and resources.

The analysis of the mechanism for implementing agent activeness and the transition from resource activeness to system activeness makes it possible to calculate marketing and control influences more accurately, determine the need to register information about active agents, flows of messages and resources created by them in the digital twin of the social system.

Acknowledgements The research was carried out at the expense of the grant of the Russian Science Foundation No. 22-28-20458, https://rscf.ru/project/22-28-20458/.

References

1. Abdrakhmanova, A. I. (2012). Psychological determinants of the manifestation of personality activity. *Psychology, Sociology and Pedagogy, 9*. https://psychology.snauka.ru/2012/09/1091
2. Anokhin, P. K. (1978). *Philosophical aspects of the functional system theory*. Nauka.
3. Bagrin, P. P. (2016). The possibility of simulation of corporate systems. *Theoretical and Applied Economics, 1*, 1–11. https://doi.org/10.7256/2409-8647.2016.1.17763
4. Baumol, W. J. (1990). Entrepreneurship: Productive, unproductive, and destructive. *Journal of Political Economy, 98*(5), 893–921.

5. Becker, M. C., & Pentland, B. T. (2022). Digital twin of an organization: Are you serious? In A. Marrella & B. Weber. (Eds.), *Business process management workshops. BPM 2021*. Lecture Notes in Business Information Processing (Vol. 436). Springer. https://doi.org/10.1007/978-3-030-94343-1_19
6. Barkalov, S., Dorofeev, D., Fedorova, I., & Polovinkina, A. (2021). Application of digital twins in the management of socio-economic systems. In *E3S web of conferences* (Vol. 244, p. 11001). https://doi.org/10.1051/e3sconf/202124411001
7. Fischbach, K., Marx, J., & Weitzel, T. (2021). Agent-based modeling in social sciences. *Journal of Business Economics, 91*, 1263–1270. https://doi.org/10.1007/s11573-021-01070-9
8. Hamzaoui, M. A., & Julien, N. (2022). Social cyber-physical systems and digital twins networks: A perspective about the future digital twin ecosystems. *IFAC-PapersOnLine, 55*(8), 31–36. https://doi.org/10.1016/j.ifacol.2022.08.006
9. Ganicheva, A. V., & Ganichev, A. V. (2018). Model of dynamic mutual influence of individuals in groups. *Bulletin of Cybernetics, 4*(32), 77–83.
10. Ghorbani, A. (2022). Institutional modelling: Adding social backbone to agent-based models. *MethodsX, 9*, 101801. https://doi.org/10.1016/j.mex.2022.101801
11. Klebanov, B. I., & Antropov, T. V. (2019). Accounting of mental properties of intelligent agents in the model of a hybrid automatic. *Modern High Technologies, 6*, 66–70.
12. Korovin, G. (2022). Digital twins in the industry: Maturity, functions, effects. In V. Kumar, J. Leng, V. Akberdina, & E. Kuzmin (Eds.), Digital transformation in industry. Lecture Notes in Information Systems and Organisation (Vol. 54). Springer. https://doi.org/10.1007/978-3-030-94617-3_1
13. Krueger, A. (1974). The political economy of the rent-seeking society. *American Economic Review, 64*(3), 291–303.
14. Macal, C. M., & North, M. J. (2005). Tutorial on agent-based modeling and simulation. In *Proceedings of the 2005 Winter Simulation Conference* (pp. 2–15).
15. Murphv, K. M., Shleifer, A., & Vishny, R. W. (1991). The allocation of talent: Implication for growth. *Quarterly Journal of Economics, 106*(2), 503–530.
16. North, D. C. (2002). *Institutions, institutional change and economic performance*. Cambridge University Press.
17. Neverov, A. N., Markelov, A. Y. (2020). To the problem of modeling the strategic behavior of states in geo-economics. *Bulletin of the Baltic Federal University named after I. Kant. Ser.: Humanities and Social Sciences, 4*, 32–41.
18. Petrov, A. V. (2018). Imitation as the basis of digital twins' technology. *Bulletin of Irkutsk State Technical University, 22*(10–141), 56–66.
19. Popper, K. (1992). *The open society and its enemies: Vol. 1: The Age of Plato*. Phoenix, International Foundation "Cultural Initiative".
20. Samosudov, M. V. (2016). *The theory of corporate interaction and the sustainability of corporate systems*. GUU, IOM. https://clck.ru/Z47H3
21. Samosudov, M. V. (2021). Formalization of impact of information on the human behaviour for automatization of calculation of the marketing influence. *International Journal of Engineering Research and Technology, 13*(12), 4849–4854.
22. Samosudov, M. V. (2022). Comprehensive mathematical agent-based model of social system for management automation purposes. In *Proceedings of the International Scientific Conference "Smart Nations: Global Trends in The Digital Economy"*. Lecture Notes in Networks and Systems (Vol. 397, pp. 346–353). https://doi.org/10.1007/978-3-030-94873-3_43
23. Sudakov, K. V. (2006). *Theory of functional systems*. Logos.
24. Terano, T. (2021). *A perspective on agent-based modeling in social system analysis*. In G. S. Metcalf, K. Kijima, & H. Deguchi (Eds.), *Handbook of systems sciences* (pp. 353–365).
25. Tsenina, E. V. (2017). Agent-based modeling as a new point of view on the company activities. *Russian entrepreneurship, 18*(3), 367–374. https://doi.org/10.18334/rp.18.3.37303
26. Tullock, G. (1967). The welfare costs of tariffs, monopolies, and theft. *Western Economic Journal, 5*(3), 224–235.

27. Uhlemann, T. H.-J., Schock, C., Lehmann, C., Freiberger, S., & Steinhilper, R. (2017). The digital twin: Demonstrating the potential of real time data acquisition in production systems. *Procedia Manufacturing, 9*, 113–120.
28. Varlamova, Y. A. (2020). Evolution of the concept of rationality: From industrial to post-industrial society. In V. S. Avtonomov & A. Y. Rubinstein (Eds.), *Proceedings of the II October International Scientific Conference on Problems of Theoretical Economics.* (pp. 32–36). IE RAS
29. Vinogradov, G. P. (2018). Modeling of decision-making based on subjective ideas about the situation of choice in conditions of incomplete and unreliable knowledge. *Information and Mathematical Technologies in Science and Management, 1*(9), 66–76.
30. Williamson, O. E. (1985). *The economic institution of capitalism: Firms, markets, relational contracting*. Macmillan.